9th Zero Energy Mass Custom Home

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Shaila BANTANUR

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Yelahanka, Bengaluru, India

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Editorial Team Members

Shreyasi PAL
Shreya SUDESH

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FOREWORD

On behalf of Zero Energy Mass Custom Homes (ZEMCH) Network and BMS School of Architecture, Yelahanka, Bangalore, the host institute, it is indeed an honor and privilege to share with you the full proceedings of the 9th ZEMCH International Conference, held from November 03- 05, 2022 at Bangalore, India.

ZEMCH is an acronym of Zero Energy Mass Custom Home aiming to tackle issues arising in the delivery of socially, economically, environmentally and humanly sustainable built environments in developed and developing countries, which accommodate people with different socio-economic backgrounds that relate to ages and abilities. ZEMCH Network was established with the aim to enhance industry-academia R&D collaborations on the delivery of zero energy mass custom homes in developed and developing countries.

Since 2012, ZEMCH has organized international conferences and events across the globe. Past conferences have taken place in Europe, the United States, South America, Asia, Australia and UAE. This was the first time that the ZEMCH conference was held in the Indian subcontinent. The primary goal of the 9th conference was to bring together academics and professionals to discuss the various issues arising in the delivery of socially, economically, environmentally and humanly sustainable built environments in developed and developing countries. I believe that our remarkable keynote sessions and technical sessions showcasing research work by eminent professionals and scholars, from across the world, provided in-depth insights, new ways of thinking and actionable tools for the same.

It was a privilege for the entire BMSSA, Yelahanka family and a personal honour for me to convene and host this prestigious event for the first time in the Indian subcontinent. I extend my gratitude to all the keynote speakers, delegates, participants and volunteers for their time and efforts for making ZEMCH 2022 at BMS School of Architecture, Yelahanka, Bangalore, a grand success!

Shaila BANTANUR
Conference Chair
(On behalf of the Local Organizing Committee)
ZEMCH 2022 International Conference

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THEME I

Sustainable Urban Development and Climate Change

EMERGING TECHNOLOGIES FOR SOLVING LOCAL URBAN ISSUES: A RESEARCH APPROACH TO DEFINE RESILIENT SMART CITIES

Pushpa Devanathan[1], Monalisa Bhardwaj[2]

[1] Professor and Head, School of Architecture, Ramaiah Institute of Technology, MSRIT Post, M S Ramaiah Nagar, MSR Nagar, Bengaluru, Karnataka 560054, email (pd.arch@msrit.edu)
[2] Associate Professor, School of Architecture, Ramaiah Institute of Technology, MSRIT Post, M S Ramaiah Nagar, MSR Nagar, Bengaluru, Karnataka 560054, email (monalisa@msrit.edu)

ABSTRACT

The Covid pandemic has forced cities to respond to dynamic factors and uncertainties from disasters in a limited time context. The recent global wide pandemic has hit every aspect of urban development and each city responded differently. This varying resilience in a city's ability to solve problems from a local perspective poses a question- how do emerging technologies equip Smart cities of the future to be resilient and sensitive to local context. This paper aims to develop a research roadmap that defines resilience in Smart Cities of the future and explores issues of capabilities adapting of new technologies like big data, AI, IOT in enhancing disaster responses during the time of distress. Cities have faced reverse migration, pattern change in work spaces, changes in transportation dynamics, character of public settings with social distancing norms, dependence on internet-based solutions causing a shift in requirement of electricity and water services across localities in urban settings. These issues that disrupt urban areas suddenly with long term bearings call for robust approaches to building urban resilience. This paper is an academic perspective based on the existing body of works and hopes to reflect on the lesser explored subject of local solutions using new technologies

INTRODUCTION

The cities across the world reeled under immense pressure when the Covid pandemic struck across populations worldwide, wave after wave from 2020. The period revealed that urban populations are susceptible to disasters of myriad nature and require the city's infrastructure to accommodate rapid change and distress from external forces of - climate change, natural disasters, accidents (e.g. nuclear reactor failure), pandemics and war-like scenarios. Physical and system ability to withstand the distress and return to balanced form, or transform to newer context without disrupting the life, flows and processes in the city are desirable goals for city performance.

More than half of the world's cities with a population of over 300,000 are at high risk of exposure to at least one natural disaster as observed by Gu et al. (Desroches and Taylor, 2018)
This study aims to understand the resilience in smart cities. Since the smart cities are dependent on data driven forecasts and analysis, it is possible to understand how local level urban issues such as- historicity, accessibility, mobilities, development, services, safety, equality and inclusion, are resolved through emerging technologies. The four dimensions of resilience namely technical, organizational, social and Economic aspects need to be handled. The purpose of the study is to explore the possibility of building robustness from local level to metropolitan scale in smart city context. The principal aspects of study therefore include-

- understanding the scope of resilience and the approaches to define resilience in urban context.
- understand the convergence of resilience and smart cities through emerging technologies

- understand the relevant emerging technologies in solving local urban issues to develop resilient local sets- that contribute to build resilience at urban scale.

Resilience may be viewed as either desirable or undesirable in a specific case; this depends on the state of concern. (Brand and Jax, 2007) In the context of urban resilience, resilience is a dynamic quality allowing for return to stability over a period of time, even in case of repeated natural or anthropogenic disasters. Since the inception of the concept of resilience is embedded in engineering studies, and later ecological studies, it is important to understand how the term resilience came to gain significance in urban context. A brief background is discussed in the following section.

BACKGROUND AND SIGNIFICANCE: RESILIENT CITIES

Diverse perspectives and derivatives can be layered, including - engineering, medicine, economics, ecology and cities to understand resilience. Understanding of resilience has been layered and derived from many diverse perspectives including - engineering, medicine, economics, ecology and cities. Manyena et al. (2011) notes that it originates from the Latin word resilio, resilire or reseller that means- to bounce back or bounce-forward. (Patel and Nosal, 2016)

The term Resilience has been used in the field of ecology since its introduction by Crawford Stanley Holling in 1973, the concept has been used in Europe and America since 1858 in the field of mechanics (Brand and Jax, 2007) Holling defines resilience as a "measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables". Alexander defined resilience as the interplay between rigidity – the ability of a structure or system to resist stress – and ductility – the ability of that same system to absorb stress through its own deformation. (Brand and Jax, 2007) White, has given the ecological concept of resilience, which epitomises the capacity of a system to adapt itself in response to the action of a force, achieving a state of equilibrium different from the original. (Colucci, 2012)

Recent studies, such as Folke 2002, Olsson et al. 2004, Janssen 2006 continue to build emphasis on social, political, and institutional dimensions to understand resilience or look at the entire social-ecological systems like in works of Adger et al. 2005, Hughes et al. 2005, Folke 2006, Walker et al. 2006; this is in contrast to the approach towards ecological studies of resilience which are becoming seldom.(Brand and Jax, 2007) A summary of the various typology of definitions on resilience has been given in table 1, based on the study of Fridolin Simon Brand and Kurt Jax.(Brand and Jax, 2007)

Table 1: Typology for Definitions of Resilience
Source: Resilience as a Descriptive Concept and a Boundary Object (Brand and Jax, 2007)

Type	Domain		Perspective	Definition
Descriptive concept	Ecological science	Ecological definition	Is based on measure of the persistence of systems.	Holling defines it as "measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Brand and Jax, 2007)

		Extended ecological definition	As per Holling, it is influenced by theory on complex adaptive systems (e.g., Levin 1998) including the cross-scale morphology of ecosystems (Brand and Jax, 2007)	Gunderson and Holling defined it as – "The magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour" (Brand and Jax, 2007)
		Systemic-heuristic definition	Cumming and Collier based it on dynamics of productive, self-organised systems, the "panarchy" and resilience as a quantitative property.(Brand and Jax, 2007)	In metamodel of Cumming and Collier of ecosystem dynamics consists of four-phase adaptive cycles, i.e., r-, K-, Ω-, and α-phases, which occur on each level of a system's hierarchy. Resilience appears at every level. (Brand and Jax, 2007)
		Operational definition	Aims to build a concept of identity and defining resilience.	
	Social sciences	Sociological definition	To apply the concept of resilience to social systems.	As per Adger it is -" the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change" (Brand and Jax, 2007)
		Ecological-economical definition	To analyse economy-environment systems	Perring defines it as "the ability of the system to withstand either market or environmental shocks without losing the capacity to allocate resources efficiently" (Brand and Jax, 2007)
Hybrid concept	Ecosystem services-related definition		Based on services in the face of human use and a fluctuating environment (Carpenter 2001, Folke et al. 2002)	
	Social-ecological system	Social-ecological definition		

		Resilience approach	
Normative concept	Metaphorical definition		Perrings defines it as “flexibility over the long term” (Brand and Jax, 2007)
	Sustainability-related definition		Ott & Döring defines it as “resilience has been suggested as to be one of the guidelines for a conception of strong sustainability. (Brand and Jax, 2007)

The latest trends advocating resilience in urban context are drawn from the normative concepts pertaining to sustainability. The National Institute of Building Sciences, defines “resilience as a strategy to enhance the ability of a building, facility, or community to both prevent damage and to recover from damage” (Sciences, 2018) Marielle Dubbeling, et.al, observes that - long-term urban sustainability depends on global scale factors such as affordability of food, fuel prices, climate change, accessibility to drinking water. and changes in macroeconomic or geo-political situations such as wars and invasions, changing patterns in occurrence of natural disasters affect sustainability (Dubbeling *et al.*, 2009)

Anumitra V.Mirti Chand observed resilience in urban context as- “a city that has developed the systems and capacities to be able to absorb future shocks and stresses over time so as to still maintain essentially the same functions, structure, systems, and identity, while at the same time working to mitigate the present causes of future shocks and stresses" (Mirti Chand, 2018) The National Research Council has defined resilience as- the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. (Desroches and Taylor, 2018)

The United Nations Agenda for Sustainable Development (SDGs) includes resilience in the following targets-

- Target 1.5 aims, by 2030, “to build the resilience of the poor and those in vulnerable situations, and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters”.
- Target 9.1 includes - building resilient infrastructure; and
- Target 11 states aim- “to make cities and human settlements inclusive, safe, resilient, and sustainable”;
- Target 13.1 aim is “to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters”.
- The Urban Crisis Charter of the Global Alliance for Urban Crisis (UN-Habitat 2016) in the World Humanitarian Summit identified resilience as a core goal for the United Nations New Urban Agenda. (Patel and Nosal, 2016)

As the concept of resilience has found significance in urban context, it is important to understand its scope in the cities- future, particularly smart city context.

SMART CITIES

Cities across the world are investing in the growth of Smart Cities. These are to be aligned with the goals of smart mobility, mainly focussing on use of non-motorised vehicles with integrated ICT and inter modal transportation, smart environment focusing on green rated buildings and green energy, smart governance using open data access with ICT, smart living that creates a safe, happy and healthy city, and smart economy, concentrating on entrepreneurship and innovation at local scale aiming to train people for smart technology in 21st century education.

Development of smart cities is a complex process, especially with diversity in occupation, population, etc with myriad aspects. As smart cities combine the advanced technologies, transparency in governance, and citizen experiences in the city. The Government of India has launched an ambitious program for building 100 smart cities. This is congruous with the goals of sustainable development by United Nations.

CONVERGENCE OF RESILIENCE AND SMART IN CITIES CONTEXT

Desouza, et.al, have conceptualised cities as 'complex adaptive systems' consisting of physical resources, processes that interact with social components i.e. humans, flows, institutions and activities. (Anthopoulos, 2017) These complexities have been studied using many approaches- patterns, systems, space syntax and so on. The rise of Internet of Things (IoT) and Information and Communication Technologies (ICT) have prompted the city to analyse its issues by data driven technologies. As per International Data Corporation (IDC), about 30% of global spending in this sector is dedicated to smart innovations. (Camryn Rabideau, 2022)

Cohen has observed four stages in the rise of smart cities (BOYD COHEN, 2015), as –

- Smart Cities 1.0 - a stage marked by the technology providers pushing for 'adoption of their solutions' to cities. Examples- Lead by private sector technology companies like Cisco.

- Smart Cities 2.0- this stage was led by city municipalities focusing development using technology solutions to improve management and quality of life.

- Smart 3.0 - this stage is marked by a new model that builds on citizen collaboration for city co-creation. This is characterised by ideas of equity and inclusion.

Cities aiming to achieve SDGs are inherently bound to build a framework that is resilient in nature. Smart cities can achieve this better as they are an integrated model of - natural and manmade systems at a large scale. Resilience as a concept can apply to systems- both natural and anthropogenic. The understanding of resilience in an urban framework can be seen evolving from the following works:
suggested by Cuny- post-crisis recovery phase in a disaster cycle or continuum. (Patel and Nosal, 2016)
Norris et.al proposed a disaster continuum approach by distinguishing between pre-event and post-event environments, thereby recognizing that a crisis leaves a community fundamentally altered. (Patel and Nosal, 2016)

Cutter et al discussed the Disaster Resilience of Place (DROP) model frames resilience as both a pre-crisis quality as well as an ongoing process. (Patel and Nosal, 2016)
Renschler et al propose- it ro be seen as a more prolonged or multidimensional crisis. (Patel and Nosal, 2016)

In this context, the scope of resilience shifts from a- a state of being to a process. This allows for further deepening of understanding resilience - not as one, but a summation of multidimensional processes in a city context- some of which include- infrastructure, information and communications, community infrastructure, economic activities. Smart cities can augment risk preparedness using this multi-dimensional and systems approach. As observed by Reza Banai - urban system connotes a holistic approach, with a synthesis of concepts of the urban system elements that are heretofore regarded individually particularly in dealing with resilience.(Banai, 2020) Scaling up from preparedness from local level to urban scale using system approach in a smart city may be a feasible model. The various issues around this are discussed in the next section.

BUILDING RESILIENCE AT LOCAL SCALE: OPPORTUNITIES

Responses to disasters, pandemics and wider risks that can disrupt the normal resources and flows in a city, are normatively human centric. Their principal approach remains- protection of human capital. As a crisis hits an urban region, approaches such as- Shuman's self-reliant local communities in a global age, and Roseland and Soots' "strengthening local economies" take precedence. Governments at local level have the opportunity to play a strong role in shaping resilience by fostering people's connectivity to their places. (Mirti Chand, 2018) As observed by Anumitra V.Mirti Chand a community's past- its traditional knowledge, past experiences, scientific knowledge, adopting innovations in design can contribute to multiple social outcomes.(Mirti Chand, 2018) Local governments have a 'critical' role to plan responses to disasters, strengthen community identity, community cohesion, and sense of belonging to their place. These outcomes factor in how effectively a community responds to the time of period of crisis and recovery.

Table 2: Characteristics of resilient responses during crisis period in urban context.
Source- Authors

Phases of resilient responses in urban context	Building Preparedness	Mitigation	Crisis Period Management	Recovery	Adaptation
Characteristics	-Passive Designs -Active Designs	-Forecasting -Monitoring -Formulating Advisories and -Assistance Framework	-Minimising loss of Human Capital	Facilitation -Assistance -Accessibility -Communication	-Alteration -Innovation

To understand better, the characteristics of responses during a crisis phase for a city were identified from literature and organised in a survey for a focus group composed of- local civic bodies, military, academicians (planners and architects), doctors and civilians. About 75 participants were identified and approached based on their experience. The following responses were obtained through the online survey from respondents. The survey questionnaire is provided in the annexure with this paper at the end. The perception of users on - the resilience in urban context can be defined in terms of one or more of the following- building preparedness, mitigation, crisis period management, recovery, adaptation, others are summarised in Figure 1.

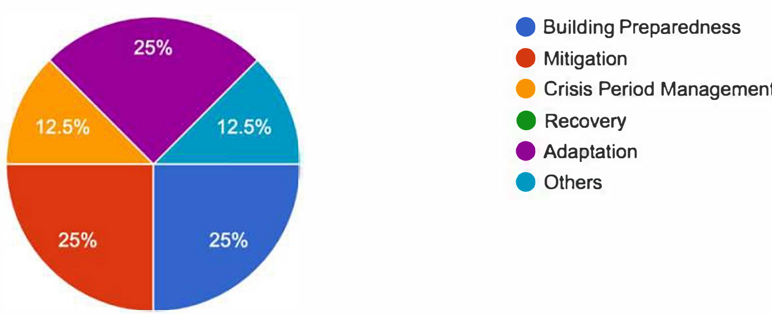

Figure 1. Understanding Perception of respondents for Urban Resilience.

The survey reveals that the understanding of resilience in urban context is very subjective among practitioners. Building Preparedness, Mitigation and Adaptation are major aspects of resilience urban context.

Table 3- Perception of Experts Focus Group towards applications of Emerging Technologies in Urban Resilience.

	Smart Technologies that can build Urban Resilience	Building Preparedness	Mitigation	Crisis Period Management	Recovery	Adaptation	Other
1	Sensors based Monitoring of Hazards	**44.4%**	22.2 %	33.3%	-	-	-
2	AI based forecasting of possible Crisis	11.1%	22.2 %	**44.4%**		22.2%	-
3	Crowd Sensing Applications	22.2%	**33.3 %**	22.2%	11.1 %	11.1%	-
4	Real time monitoring of existing and damaged infrastructure	22.2%	11.1 %	-	**55.6 %**	11.1%	-
5	Smart Grid and Micro Grids	22.2%	**33.3 %**	11.1%	-	**33.3%**	-
6	Stormwater Network System Design	**33.3%**	11.1 %	22.2%	-	**33.3%**	-
7	Safety assessment of Infrastructure	**66.7%**	-	22.2%	11.1 %	-	-
8	Enabling Payment transactions during crisis and recovery period	-	-	22.2%	**66.7 %**	11.1%	-

An important aspect of building effective response ability during a crisis- requires the local government to build robust infrastructure around communication, coordination, implementation and monitoring. In the following section- cases of emerging technologies assisting in solving local urban issues have been identified to understand their application and challenges, for the purpose of summarising best practices.

LOCAL ISSUES AND SMART SOLUTIONS USING EMERGING TECHNOLOGIES

As discussed above, during a period of crisis, the ability of local areas to solve issues can build tremendous resilience in the urban system. Emerging technologies of myriad scopes integrate in smart systems mainly based on remote sensing, cloud-based technologies, IoT driven systems, sensors-based data monitoring and so on. Some examples include- Sensors based Monitoring Hazards, AI based forecasting of possible Crisis situations, Crowd Sensing Applications, Real time monitoring of existing and damaged infrastructure, Smart Grids, Stormwater Network System Design, Safety assessment of Infrastructure, Robots and cyber physical systems, Enabling Payment transactions during crisis and recovery period, and so on. Discussion with experts on IoT, disaster mitigation planning, planners helped to organise the array of emerging technologies in the matrix given below.

Table 4: Matrix of Emerging Technology Solutions and Application in Building Resilient Smart Cities
Source: Authors.

	Building Preparedness	**Mitigation**	**Crisis Period Management**	**Recovery**	**Adaptation**
Passive Designs	Traditional Knowledge systems	Traditional Knowledge systems	Community Driven actions	Community Driven actions	Technology driven actions
Active Designs	-Technology intensive Designs -Stormwater Network System Design with sensors	-IoT based predictive maintenance			
Forecasting	-Wind Speed Monitoring -Remote Sensing for weather forecasting	-IoT based early warning systems.	-IoT based early warning systems.		
Monitoring	-Cloud based systems -Remote Sensing -Sensor based Smart infrastructure at ground.	-Rain gauge sensors -Monitoring Water levels using sensors	-Smart Grids Micro Grids -Cloud based systems -IT infrastructure monitoring (ITIM)	-Robots and cyber physical systems for safety assessment. -IoT based monitoring of strategic reserves of food, water, clothing, medical equipment	
Assistance Framework	-IoT based Emergency Planning -Disbursing smart cards to those affected.	-Remote Sensing -GIS based planning IoT based rehearsals	IoT based data network resilience. -smart traffic management systems.	-Enabling Payment transactions during crisis and recovery period -Smart identification	

				and authentication of beneficiaries	
Minimising loss of Human Capital		-Iot based Asset track and trace	-IoT based search and rescues operations	-NFC for geofencing	
Communication	Vehicles using telematics		-IoT based emergency micro-message delivery	IoT based dissemination information.	
Alteration					-Investment in Smart Technologies
Innovation	AI, robotics, computer vision, data analytics, and machine learning	AI, robotics, computer visio890890n, data analytics, and machine learning			Smart Cities 4.0

In addition to above, Radiation produced inside smart buildings and smart cities with 5G and the Internet of Things (IoT) is a newly discovered concern as WHO and scientific evidence indicate that the radiation may cause unintended health problems such as tumours and cancer. Different indoor and outdoor design features ranging from zoning in buildings, selection of building materials to landscape design are explicitly modelled to show how radiation generated in a smart building can be made zero. This idea utilises Computer Simulation technology (CST) and 3D modelling software to showcase how radiation can be reduced to zero for a smart building.

Currently, sustainability rating systems such as LEED, BREEAM, Estidama or WELL do not consider this radiation aspect though they consider several environmental and health problems. As smart buildings and smart cities are about to become a reality, innovating the design to create a zero radiation smart building helps overcome many health and environmental problems. This aspect is discussed as it is a crisis building in continuum and has characteristics distinct from the sudden and disruptive types of crisis as seen during natural disasters.

CONCLUSION

Resilient design features are an embedded aspect of sustainable cities aiming to achieve SDGs. Smart Cities are better equipped to achieve resilient and sustainability goals due to advantages of embedded technology intensive infrastructure. The array of technologies allow for robust preparedness, mitigation and crisis responses. The capabilities of new technologies like big data, AI, IOT in enhancing disaster responses during the time of distress disrupting urban areas suddenly with long term bearings, are constantly innovating and calling for cities to respond as adaptive systems. Building local response robustness is critical to achieving a uniform resilience over urban regions.

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SUSTAINABLE URBAN REGENERATION OF OLD NEIGHBORHOODS: A REVIEW TOWARDS ASSESSMENT FRAMEWORK TO ACHIEVE SOCIAL SUSTAINABILITY

Boshra Hassan[1], Baraah Hamdoon[1] , Sahera Bleibleh*, Aya Mousa[2] and Rouda Alneyadi[2]

[1] Ph.D student, Department of Architectural Engineering, United Arab Emirates University, Al Ain, Abu Dhabi, UAE, 202190191@uaeu.ac.ae, 201770200@uaeu.ac.ae
*Associate professor, Department of Architectural Engineering, United Arab Emirates University, Al Ain, Abu Dhabi, UAE, sahera.bleibleh@uaeu.ac.ae *(corresponding)*
[2] Bachelor students, Department of Architectural Engineering, United Arab Emirates University, Al Ain, Abu Dhabi, UAE, 202050909@uaeu.ac.ae, 202014017@uaeu.ac.ae

ABSTRACT

The debates are ongoing regarding the old neighborhoods and heritage environments in general, achieving comprehensive outcomes of sustainable pillars development. Social sustainability has received much attention in recent literature on urban planning and urban regeneration in old neighborhoods. The idea of "neighborhood" and "social life" has been the key focus of the investigation in this built environment. Urban regeneration, in conjunction with social sustainability, has emerged as a mainstream policy for the creation of "sustainable communities." However, in the Gulf region, specifically in UAE, the rapid growth of urban development has overlooked achieving social sustainability in old neighborhood regeneration. This study aims to: first, discuss the relationship between social sustainability, urban regeneration, and old neighborhoods. Second, explore social sustainability principles and related indicators through literature review. Third, propose a framework to evaluate the social sustainability factors of urban regeneration in the old neighborhood. The interrelationships of the social sustainability principles in old neighborhoods were discussed based on logical argument and critical review of relevant literature. The research accumulated these principles from the scholarship work of four authors due to their regional relativity. Based on the conducted review, this study proposes a theoretical framework that combines subjective and objective strategies to serve as an assessment tool of four social sustainability dimensions; social equity, social coherence, need satisfaction, and sense of identity. Due to its appropriate local condition, the proposed framework helps evaluate old neighborhoods in the Gulf region in general and the UAE in specific. It can also be examined by urban designers, planners, and policymakers for broader use of sustainable urban regeneration in future actions involving social sustainability in old neighborhoods.

Keywords; Sustainable Development, Urban Regeneration, Social Sustainability, Cultural Heritage, Old Neighborhoods, UAE.

INTRODUCTION

During the twentieth century and beyond, urban regeneration in old neighborhoods has become the core of today's world of changing environmental, socio-economic, and economic. At research regarding urban planning and urban regeneration in old sites, social sustainability has received much attention Boussaa (2017). The regeneration has a "Social" dimension throughout the sustainable approach (A. Mehan (2016), Chan and Lee (2008), Lee & Chan (2010), Landorf (2011), Doner (2019). The idea of "neighborhood" and "social life" has been the key focus of the investigation in this built environment. Urban regeneration, in conjunction with social sustainability, has emerged as a mainstream policy for the creation of "sustainable communities" Zheng et al. (2017), Chan and Lee (2008). In recent years, practices and policies aimed at improving social values and contributions to old neighborhood regeneration have received attention UNESCO (2004), UNESCO (2005), UNESCO (2008), (UN-HABITAT (2008). According to a review of relevant literature; Doner (2019), Landorf (2011), Mehan (2016) and Al Fadala & Furlan (2018), Zheng et al. (2017) & (2014), Xiuli & Maliene (2021), and Yung et al. (2014), the focus of sustainable urban regeneration strategy is not only on preserving cultural heritage but also on increasing the quality of residents' life and satisfying their satisfaction, feeling, and attitudes on the quality of life within the community. As a result, old neighborhoods have a parallel and individual contribution to urban regeneration initiatives, to which careful consideration should be given during the development of sustainable planning ideas.

Among the three pillars of sustainability (environment, economic, and social pillars), the social element of sustainability has been significantly recognized as an inherent part of sustainability from the year 2000. This paradigm change in which social sustainability is regarded equally with all other variables in the implementation process, rather than only due to regeneration activities A. Mehan (2016), Yung et al. (2014). The most important aspect of this paradigm shift is that in the procedure of physical area regeneration, not only tangible factors but also intangible factors that include a sense of belonging and identity in the place, are retained and enhanced Doner (2019).

In addition, in the field of urban planning, hundreds of different methods and tools have been developed to measure the sustainability of the built environment, each with its perspective, approach, or goal. However, the lack of literature conducting these urban planning tools is adapted to the specific characteristics of an old neighborhoods, which in turn makes them unsuitable in conservation. In the best case, cultural aspects receive limited attention as a single indicator or sub-indicator. As a result, the principles that should be applied in urban regeneration initiatives must be re-established within the context of social sustainability within the old neighborhoods. Whereas, within the Gulf Countries Council (GCC) region, a limited number of studies have been conducted for assessing and attaining social sustainability, especially on the old neighborhood sites level. In UAE, the accelerating pace of urban development has overlooked achieving social sustainability in heritage site developments to some extent. This is particularly noticed in the historic sites of the city.

In this regard, this review paper is aimed to establish an approach to the evaluation of social sustainability in old regenerated neighborhoods by drawing a conclusion on “what are the urban regeneration criteria for achieving social sustainability in old neighborhoods?”. In order to answer this question and achieve the research objective, this article studies theoretical background related to sustainable development and sustainable urban regeneration, definitions, evolution, scales, and dimensions. Additionally, investigate the relationship between cultural heritage and urban regeneration, then explore the social sustainability themes and dimensions in urban regeneration. Finally, investigate the criteria of social sustainability in old urban regeneration sites. The goal is to propose a framework that urban designers, planners, and politicians may examine for greater use of sustainable urban regeneration in future practice involving social sustainability.

METHODOLOGY

This review aims to create a holistic framework, based on a set of indicators to evaluate and assess local or global projects of urban heritage regeneration. Accordingly, an analyzing approach was followed to develop a theoretical framework in which the principles and indicators were chosen based on the findings of a theoretical and comparative study of previous tools, frameworks, and strategies. The proposed assessment tool was developed as a method that could be applied and integrated into the evaluation of old sites in the UAE and within the Gulf Countries Council (GCC) region. The suggested framework is unique in that it is based on previous studies that have been adapted to a heritage environment regionally.

The method of this review paper is a qualitative data analysis that aims to give a critical review and interpretative analysis of current literature on socially sustainable urban regeneration old sites. The following was the technique for retrieving papers:

The papers were extracted from the Scopus database.
The search rule utilized was based on the following keywords, ("sustainable development" OR "sustainability") AND ("social sustainability") AND ("urban renewal" OR "urban regeneration" OR "urban redevelopment" OR "urban rehabilitation") AND ("heritage site" OR "historical site") AND ("cultural heritage") which was entered into the SCI database's Topic searching criterion.

Topics in the SCI database were scanned using the above-mentioned search strategy, with a period of 1985-2021 and the language of English. (Including articles, book chapter, conference paper, and reviews) were retrieved.

Each paper's abstract was examined to eliminate those that were irrelevant. Finally, 32 papers were chosen for the review of the literature. (Including 23 articles, 3 book chapters, 5 conference papers, and 1 review) were retrieved. 4 papers only were chosen to develop the assessment tool for the framework based on its content and regional relativity.

Urban Regeneration and Sustainable Development

Urban environments are in a constant state of change. Different terms are used in each decade: urban reconstruction, revitalization, improvement, and renewal, and more recently in the United Kingdom, urban renaissance, and sustainable urban regeneration. In most academic literature after the 1990s, urban sustainability and sustainable urban development appeared. From this stamen, several studies stated that every attempt at "urban regeneration" and "development" should incorporate sustainability as a basic premise for future urban planning A. Mehan (2016); Lee and Chan (2010). Changes in the physical, social, environmental, and economic realms are all reflected in and amplified by urban areas. Theorizing urban issues and possibilities is integral to urban change. Roberts (2000); (Chan and Lee, 2008). Roberts (2000) identified five major factors that derived and shaped the practice of modern-day urban regeneration. The factors contain; the physical conditions and social response, housing and health, social improvement and economic progress, containment of urban growth, and changing role and nature of the urban policy. Additionally, urban regeneration is defined as "a comprehensive and integrated vision and action, which leads to the resolution of urban problems, which seeks to bring about a lasting improvement in the economic, physical, social and environmental condition of an area that has been subject to change." (Roberts et al., 2000)

Sustainable urban regeneration has become an increasingly essential worldwide strategy in urban planning and development. In addition to demolishing and rebuilding decaying and outmoded structures to provide a better living environment, urban renewal stresses conservation and regeneration (Yung and Chan, 2013). Furthermore, as Mehan (A. Mehan, 2016) stated in her paper, if people's participation, social equity, environmental quality, revitalization, and improving economic growth are followed, urban regeneration can improve sustainability and quality of life.

Moreover, as claimed by Xuili and Maliene (G. Xuili and V. Maliene, 2021) argue that the integration of heritage preservation with urban regeneration has been crucial to the area's economic and social viability after the regeneration process. There has been researching in numerous sectors, including constructed heritage, industrial heritage, tourism, and many more. Moreover, a definition argues by Zheng et al. (Zheng et al., 2014) that the term "urban regeneration" means considering the economic, physical, social, and environmental aspects of a city's problems before deciding how to approach them, all with the goal of improving residents' quality of life of low-income urban communities. Furthermore, Zheng et al.

(2017) stated in their recent study that urban revitalization can help to mitigate urban deterioration while also enhancing many socioeconomic goals.

Rehabilitation of environments and streets, restoration of homes or historical buildings, updating of infrastructure, changes in land use, urban functions, and reuse, building block and open space design, and architectural formation are all examples of physical interventions in urban regeneration. (Doner, 2019) & (Lee and Chan, 2010). The redevelopment of neighborhood infrastructure, restoration, destruction of ignored structures, provision of individual needs of the community, creation of public recreational areas and public amenities all contribute to the site's social regeneration (Doner, 2019).

Cultural Heritage in Urban Regeneration

Different authors examine the relationship between cultural heritage and urban regeneration. It allows us to identify how 'spaces' change in their historical settings utilizing numerous human activities. Spaces in historical places act as a force driving urban areas towards conserving and revitalizing through urban regeneration to make the most of their cultural heritage and tourism (Jimura & Wise, 2020).

The paradigm shifts in conserving heritage emerged in a variety of ways. It initially manifests itself in the adoption of heritage by communities worldwide. The second was an increase in the natural qualities assigned to heritage. The third and most fundamental development has been the creation of intangible conceptions as reservoirs or containers of the qualities that define a location as a legacy.

The idea of restoration is employed to oppose the concept of preservation, with restoration serving as the protector and reconstruction serving as the destroyer of heritage. Restoration and reconstruction are concerned with the treatment of the fabric and involve the addition and subtraction of materials and the use of advanced techniques (Assi, 2015).

The twentieth century's dramatic environmental, social, and political transformations were built on the urbanization of historic towns. Many academics discussed the relevance of cultural heritage as the main force behind both cultural and economic development. Tweed and Southerland (Tweed & Sutherland, 2007) examined how cultural heritage may improve people's lives while satisfying their needs for identity and affiliation. Evans also emphasized the benefits of attempts to revitalize old urban neighborhoods while urging several governments to pursue culturally urban policies (Boussaa, 2017). Regeneration is essentially a design approach for revitalizing, improving, and integrating an old historic area into a new, modern, economically viable context. Urban regeneration promotes economic and social regeneration as well as, most importantly, opportunities for the creation of jobs and income in order to enhance the physical, social, environmental, and economic conditions in order to achieve a greater quality of life. It represents a change toward a more comprehensive strategy and method that puts integrated urban development first (Dogruyol et al., 2018).

While the built heritage is essential, further values should not be neglected related to memory and identity, as they form the essence of a city's urban identity. In the following statement, UN-Habitat stressed the importance of cultural heritage in present cities; "As a result, planning is being required to preserve and promote cultural heritage, tangible and intangible, of the communities living in cities, since heritage has been recognized to have a role in shaping the city's identity." This claim highlights the need to revitalize cultural heritage to enhance a city's distinction and individuality (UN-Habitat, 2008).

Cultural Heritage in Gulf and UAE

Cities in the Gulf have seen major social, cultural, and economic forces since the oil discovery in the 1950s and 1960s. These changes have directly influenced their historical contexts, putting the identity of their cities and their uniqueness at risk. The quick flow of information and globalization trends have played a key influence in modifying the built environment; as a result, their cities' distinct identities based on their histories have been radically affected. The unprecedented development boom in the Gulf left no place or time for stakeholders to appreciate their city's cultural legacy (Boussaa, 2017).

Heritage conservation in the Gulf is a relatively new field that has grown in prominence only since the mid-1990s. Apart from important ancient sites, Gulf (and UAE) legacy is generally new, dating mainly from the late nineteenth and early half of the twentieth centuries. During the 1990s, cities such as Dubai, Jeddah, and Sharjah participated in urban regeneration and revitalization plans based on their heritage. As a result, residents of these towns and their rivals are becoming more conscious of the need to preserve and enhance a city's urban character. Therefore, urban regeneration can help rejuvenate the economy of the neighborhood while also contributing to enhancing the urban character of cities (Boussaa, 2017). The temporal proximity and the disappearance of traditions clearly describe architectural conservation approaches commonly used in the region. Reconstruction as a strategy may create a profoundly inspiring feeling of connection to the community and landscape, as well as its past and lived experience (Boussaa, 2017).

Social Sustainability Evaluation Criteria for Heritage Urban Regeneration Neighborhood
In this part, we present a framework for measuring the long-term viability of urban neighborhoods in cultural history. Several criteria must be met before a suitable and effective theoretical framework can be constructed, allowing for the development of meaningful indicators. Urban revitalization and social equality are two areas that should get special attention from the indicators used.

First, a study on the Assessment of Urban Regeneration Project in the Gaziantep Historical Quarter done by Doner (2019) provides a specific strategy for assuring social sustainability with a precise assessment criterion in place. Hence, the purpose of this research is to build a comprehensive framework with objectives, processes, and strategies for adaptive reuse, as a development tool for social sustainability in urban regeneration development. Therefore, this study concentrated on the adaptive reuse techniques and implementations used in urban regeneration of the old neighborhood to achieve social sustainability. Doner defined adaptive reuse as the process of utilizing an existing site or structure for use other than the one for which it was created or planned and its approach to conservation practice of urban heritage sites (Doner, 2019). Adaptive reuse incorporates the significance and authenticity of old sites with new functions that enable modern activities. Thus, perception of area in social terms is developed by the collective value of new and old (Yung and Chan, 2013), and it considers the needs of the community and ensures that these needs are met in the most proper context, location, and architecture (Doner, 2019).

These results and techniques for ensuring social sustainability using adaptive reuse from the literature have been compiled into a comprehensive evaluation tool. This evaluation tool is being used to evaluate adaptive reuse activities in the Gaziantep Historical Quarter. In building scale Gaziantep Castle, street scale Culture Route, and neighborhood-scale Bey and Kepenek Neighborhoods. Doner chose two neighborhood studies, Anlurfa Historical Quarter, Anlurfa, Turkey and Al - Abhar Historical Neighborhood, Sana'a,Yemen, in comparable contexts to Gaziantep. It is crucial to examine adaptive reuse at the neighborhood scale for two reasons: first, the neighborhood is an essential unit in urban planning; and second, evaluating the social sustainability aspect is more informative, relevant, and worthwhile to evaluate at the neighborhood scale. The study provides a sort of assessment criteria to achieve social sustainability in neighborhood scale:

- Conservation of urban image, identity, and architecture heritage value through the street within its historical character.
- Keeping the traditional activities local society has.
- Protecting and improvement of gathering places for socializing.
- Community center development for the neighborhood.
- Informing the community on interventions and their essentials.
- Strategies on not destroying local community privacy and their common rituals.

- Unity and integrity of developers, so they cannot emerge – preventing individual practices.

Second, AL Fadala & Furlan (2018) (AL Fadala & Furlan, 2018) investigate the neighborhood of Msheireb Downtown Doha and the factors that caused its renewal. Also, the study compares the image of old Msheireb with the current regenerated one. It starts with the background about urbanism and the Msheireb neighborhood Later, the authors assessed the downtown incompatible intervention on four principles: connectivity (Pedestrian paths/walkability), mixed-use, smart transportation and parking strategy, and signage and wayfinding. The new, revitalized Msheireb is more walkable and mixed-use than the previous one, which in turn stimulates and supports more social involvement and adds to the neighborhood's urban livability. Finally, the study provides a sort of guidelines to achieve social sustainability in any area:

- Focus on connectivity between pedestrian and bicycle paths in the neighborhood to enhance walkability on the buildings' ground levels.
- Provide smart public transportation options connected with the surrounding context.
- Respect the local traditional form and integrate it with modern architecture with respect to neighboring buildings.
- Create mixed-use facilities.
- Apply environmental systems criteria to manage and control the area, for instance, LEED criteria.
- Establish social spaces that reflect a sense of belonging and engagement.

Third, research is done by A. Mehan (2016); it focuses on social sustainability strategies in historic public squares as one of the fundamental aspects of urban social well-being. In addition, as argued by the author, the focus of sustainable urban regeneration practice is not only on preserving cultural assets but also on increasing the quality of residents' lives and satisfying their happiness (A. Mehan, 2016). Accordingly, the purpose of this research is to introduce holistic strategies for future cities by extrapolating the main strategies of urban regeneration for developing social sustainability in historical public squares of sites based on relevant literature. In this context (A. Mehan, 2016), according to the findings of the study, to achieve social sustainability in historical public squares of cities, the author indicates six approaches considered as the critical contributing approaches in urban regeneration strategies, including meeting citizens' needs, providing social infrastructures, increasing public participation, accelerating economic growth, preserving historical identity, and managing green space. Regarding this, the objective of this framework is to propose a guideline that urban designers, planners, and policymakers may examine for greater use of sustainable urban regeneration in future action involving social sustainability in historical squares (A. Mehan, 2016).

Finally, Landorf (2011) proposed a paradigm for assessing social sustainability in historic urban areas. The framework defines three dimensions of social sustainability, evaluation criteria and a methodological approach. The process begins with discussing a shared definition of sustainable development within a collectively agreed federal structure. Previously, efforts to assess sustainable development have tended to be technologically developed and centrally administered. The emergence of participatory governance implies that future practice will require a balancing approach based on socially created and politically active approaches that address local issues and concerns. The author built a set of comprehensive criteria for evaluation as shown in table (1); also, two main elements must be addressed before implementing the assessment. First, the local definition of sustainable development should be identified, and second, the significant vision of heritage needs to be agreed on. Finally, the author represents an application of the framework on the case of Broken Hill based on the council's draft community strategic plan.

Table 1: Evaluation criteria for social sustainability of the historic urban environment.
Source: Landorf (2011)

Dimension	Characteristics	Criteria
Social equity	Access to services, facilities, and opportunities	Housing infrastructure Community infrastructure Social infrastructure
	Level of institutional stability and flexibility	Stability Flexibility
Social coherence	Strength of networks, participation, identification, and tolerance	Networks Participation Identification
	Level of empowerment and accountability	Empowerment Accountability
Basic needs	Objective satisfaction of basic needs	Nutrition Housing Education Health Employment Security Built Environment
	Subjective satisfaction of basic needs	Perception of basic needs objectives

Conclusion and Discussion

Heritage neighborhoods are the essence of cities, and the depletion of concrete structures harms intangible values and the disintegration of continuity with the past. As a result, urban regeneration has become a critical way to preserve heritage locations by preserving good characteristics of cultural heritage and limiting gentrification (Doner, 2019). Historic sites are values that must be passed down to future generations and integrated into the city as a whole to ensure long-term urban development. The findings of this paper showed that the concept of urban regeneration and social sustainability had been significantly taken into consideration in urban heritage redevelopment. Moreover, it identified a possible assessment tool to evaluate existing regenerated historic sites in the Gulf region in general and UAE in specific shown in table (2).

Table 2: Assessment tools and strategies of urban regeneration social sustainability for heritage sites
Source: Authors (Hassan, Hamdoon, & Galal Ahmed, 2022)

Dimension	**Subjective Indicators**	**Objective Indicators**
Social equity	Strategies for preserving local community privacy and shared tradition practices.	Accessible community facilities and services for all ages and users.
		Provision of a wide range of housing choices in sort and design.
Social coherence	Increasing public awareness of the old site's regeneration projects. Encouraging the community to involve in the renewal process.	Provision of social gathering spaces. (e.g., public open spaces, plazas, community parks)
		Encouraging the community to involve in the renewal process.
Basic needs	Providing tourist destinations to boost the local economy.	A hierarchy of services and facilities of different capacities and
		Provision of children and youth physical activities and sporting activities.

		Provision of shaded, well-lit, pleasant, and comfortable pedestrian routes leading to all services and community facilities.
		Provision of pleasant public transportation stop
		Provision of tourist destinations
		Provision of a wider range of job opportunities and facilities including a diverse shopping center, banks, several pubs and cafes, health center, schools, and mosque.
Safety	Emphasizing the socio-cultural interrelationship among residents. Prevent informal activities within the neighborhood.	Good visibility at night, street lighting and accessibility of spaces.
		Safe and clear pedestrian and cycling lanes
		Safe streetscape and open spaces.
		Safe public transportation stops
		Set speed limits linked to livability for higher density urban areas (e.g., 50km/h) and for inner streets (e.g., 15km/h)
Accessibility	Enhancing the connectivity of the urban environment and the accessibility to nearby amenities.	Services and facilities are located within walkable and bikeable distances through well-defined pathways/ cycling lanes for all ages and residences.
		Connection with the surrounded neighborhood through pedestrian and cycling.
		Accessible and connected transport corridors and nodes by pedestrian and cycling from all facilities and activities. (Accessible to people of all ages and abilities)
Sense of identity	Creating a sense of social responsibility within residents through public accountability for the future possible urban identity of public spaces.	Good physical quality and maintenance of the built environment
		Preservation of urban image, identity, and heritage building value within its historical character
		Preserving the traditional practices of the local society

Limitations

The main limitation in this paper review is the limited studies conducted in old regenerated neighborhoods in Gulf specifically. Qatar has the most active publication in the Gulf due to renovation projects. Studies conducted for the UAE are from different countries. The available studies in the UAE are outdated and conducted before the current changes. Moreover, there are no clear and direct policies for the assessment tools that address urban heritage. The overall strategies focus on buildings scale. Also, due to the culturally diverse and differences between countries, some strategies could not be applied to other areas. To strengthen the outcomes of the study, further studies will be conducted to use the framework on case studies in the UAE, which would enrich the outcomes and prove the applicability of the proposed framework.

Notes
This research was followed by an application of case study as part of coursework of Advanced qualitative research method (ARCH710 – Spring 2022) taught by Dr. Khaled Galal at the UAEU. Although this main framework study was initiated first, the case study was published prior to this produced main framework, therefore, has been cited in this paper as (Hassan, Hamdoon, & Galal Ahmed, 2022)

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REVIVAL OF THE INDIGENOUS TOY MAKING PRACTICE AND TO STRENGTHEN THEIR ECOSYSTEM THROUGH URBAN INTERVENTIONS - CASE OF CHANNAPATNA

Vidhyashree H

Assistant Professor at Nitte School of Architecture Planning and Design, Bengaluru, ar.vidhyah@gmail.com

ABSTRACT

Throughout centuries, crafts have been embedded as a culture and tradition within rural communities. One such skilled community is present in Channapatna who are involved in toy making. From last 5 years toymakers of Channapatna have migrated to Bengaluru by giving up the profession and migrating to cities in search of a better livelihood, making it a waning town. The town is drastically losing its identity and essence with decline in trade and economy. Hence there is a need to revive the socio-economic factors of the town and also to strengthen their environment structure of the city.

The research aims at strengthening the socio-economic conditions of the community and to uphold the identity of the town. To preserve and promote the community skills and to strengthen their local economy, give them better opportunities to improve their standard of living in the present urban life, which in turn would make Channapatna a sustainable town. The study is carried out by analysing the threats of the place, by understanding the land use and ecology pattern, socio-economic conditions and also by comparing the existing relationship between city and community. Both qualitative and quantitative methods are used to carry out the research. The qualitative methods are driven by conducting interviews with the localities and government bodies. The quantitative study is carried out by analysing the existing statistical data available. The research demonstrates to come up with a strategy to improvise their socio-economic conditions and also to strengthen their ecosystem structures with the connection with their settlement patterns. Furthermore, it would also lead to bring out their fading talents with urbanity and to create awareness by educating them through offering design platforms for cultural exchange and to give them an active public life.

Keywords: Identity; Local Economy; Ecology Structure; Trade Networks; Socio Economic Factors; Urbanity; Active Public Life.

INTRODUCTION

The crafts of India are diverse, rich in history and religion. The craft of each state in India reflect the influence of historical significance. Throughout centuries, crafts have been embedded as a culture and tradition within rural communities. In present scenario the roots of these traditional crafts, which are the rural craftsmen, are in decline. On the other hand, statistics from the All-India Handicrafts Board show that craft export has risen from 23 crores to over 9000 crores since the past 50 years. With rising socio economic and political issues in India, the craft sector is struggling to uphold especially in the present urban trends.

One such city which had rich cultural heritage is Channapatna. It is a city located 60 km south-west of Bangalore, India on Bangalore-Mysore state highway known for its wooden toys and lacquer ware. Channapatna is also called as "gombegala ooru" meaning town of toys. It has three hobli's namely 1) Kasaba 2) Malur 3) Virupakshapura. Primary occupation of the town is manufacturing wooden toys and lacquerware These toys are manufactured in traditional and advanced small-scale industries, small components are done in hand without usage of machines. Secondary occupation of the town is manufacturing and twisting of raw silk. Rice, ragi and coconut is a major product of Channapatna taluk.

The origin of these toys can be traced to the reign of Tipu Sultan, 200 years ago, who invited artisans from Persia to train the local artisans in the making of wooden toys. Bavas Miyan is the father of Channapatna Toy. He is the one to sacrifice his life for Channapatna toys. He adopted Japanese technology for toys making and help the local artisans improve their art. Channapatna craftsmen are referred to as acharya and belong to the community of Chitragars. Traditionally, they made wooden masks, human and animal figures, and painted the temples around Channapatna. The craft flourished in the region due to royal patronage. The decline in toy making industries from 1800 to 500 show a significant downfall of the craft economy. Though government has initiated certain schemes like crafts park, the revival is not successful. The town is drastically losing its identity and essence with also decline in trade and economy. The purpose of the research is to bring back the glory of toy land and to make it an economic hub by strategizing tourism as new economy. The total geographical area of the taluk is 53,587 hectares (12.87 km^2).

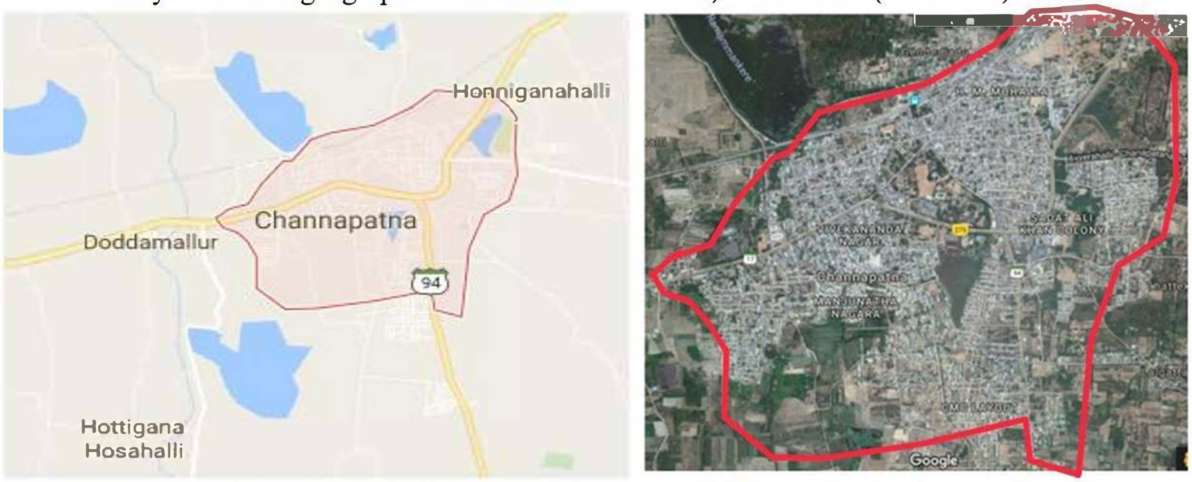

Figure 1. (a & b) Geographical maps of Channapatna to show the location.

BACKDROP TO STUDY

The arts and crafts of the nation reveal its culture and heritage of India. Throughout centuries, crafts have been embedded as a culture and tradition within rural communities. One such skilled community is present in Channapatna, Ramanagar district who are involved in toy making. Channapatna is called as "gombegala ooru" meaning town of toys. Channapatna has a strong historical background that the city evolved when Tipu Sultan brought Persians and made to settle them. As time went these people became well versed, with the art of toy making they made it as their source of income. The geographical location of the place gives them an added advantage. The placement of craftsmen settlement, natural bodies in connection to the spread of industries brings in a special character of the city. It is estimated that approximately 62 million and 7 million domestic and foreign tourists respectively visit Karnataka in a year.

Ten years down the line there was decline in toy manufacturing. The major reason was the introduction of Chinese toys at low quality but at cheaper rates. This made people to change their occupation and migrate to different cities in search of new jobs. This led to a big void in the city. The city has an existing rich relation with ecology, settlements, community, skills, industries and trade. All these layers faded slowly and now the city is left with 6000 artisans struggling hard to make their livelihood. Though we see support from the government of Karnataka who has helped by constructing a Lacquer ware craft complex, which includes manufacturing centre with 32 turning lathe machines, but it lacks in successful execution of it. Financial assistance to the artisans, with help from the Dutch Government and the Karnataka Government's Vishwa scheme has also been provided. The major intention is to bring back this vanishing skill and make them recognisable worldwide with socio-spacial implifications by introducing a strong layer of economy with new developments and guidelines.

The purpose of the research is to bring back the lost identity of Channapatna crafts and to improve the craftsman's socio-economic conditions. To identify space for resource generation and active public spaces, to create a platform for them to showcase their skills by redesigning their urban grains, by engaging them directly with the tourist or buyers by creating a trail in urban context which runs through their settlement patterns along with natural features.

URBAN ENQUIRY

How special Zoning can be achieved to connect ecology, community skills, settlements, industries and natural features which in turn will help to improve the growth of the city catering to the new developments with new economy layers and guidelines.

SOCIO ECONOMIC CONTEXT

Socio economical study is necessary to know the economic activity affects and is shaped by social processes. In generally analyses how societies progress, stagnate, or regress because of their local or regional economy. A mere change in attitude and determination to modernize with respect to the current trend will not only give a new lease of life to the entire handicraft industry, but this will help to economically uplift the entire craftsmen community engaged in handicrafts. To improve their living conditions by providing them training, employment opportunities and infrastructure facilities. Till today napkin holders and other utilitarian items are being exported from Channapatna to Europe and other parts of the world. Due to lack of interest among community workers, though there is a demand, the town is not successfully earning profits. There is a need to establish relationship between trade, community and city. The trade networks have to be strengthened for the economic growth of the city.

Table 1. Channapatna census data-2011

Town	Population	Hindu	Muslim	Christian	Sikh	Buddhist	Jain	Others	Not Stated
Channapatna	**71,942**	**55.66%**	**42.96%**	**1.00%**	**0.04%**	**0.01%**	**0.20%**	**0.01%**	**0.12%**

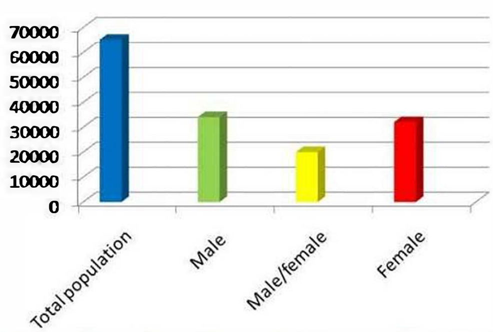

Figure 2. Graph to show the existing population of Channapatna.
Source: As per physical survey conducted on site.

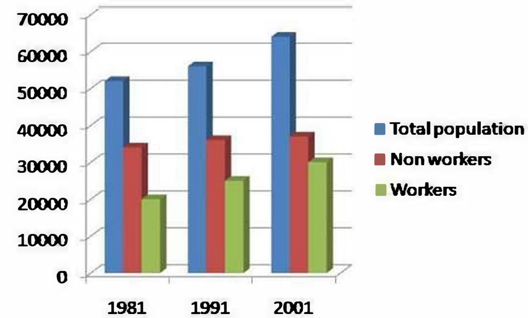

Figure 3. Graph to show the statistical data of workers and non-workers of Channapatna over the period of time.

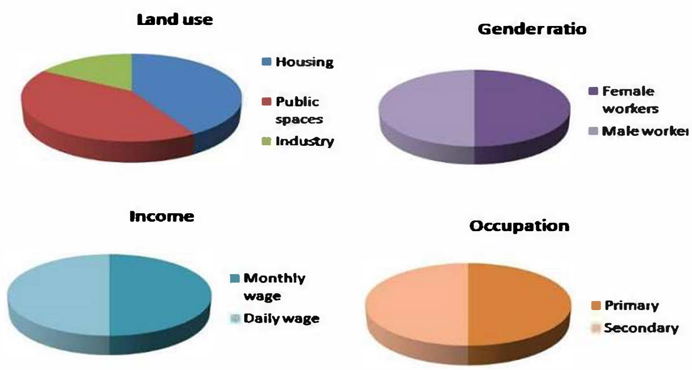

Figure 4. Chart to show the existing socio-economic patterns in the town.

THE ART OF TOY MAKING- INDIGENOUS PRACTICE

Table 2. Manufacturing process of toys.

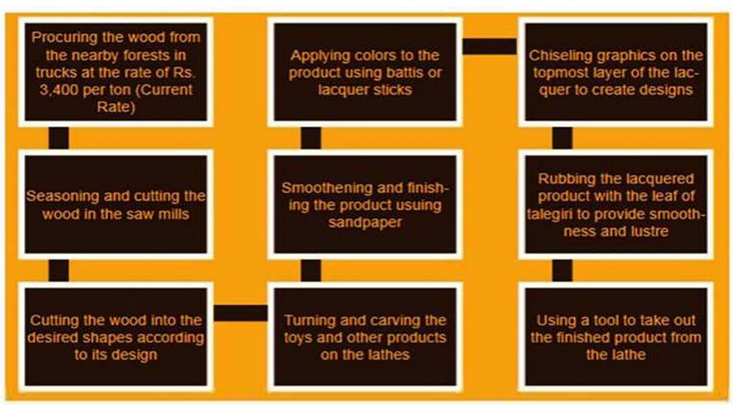

Table 3. Variety of Products manufactured in Channapatna

Decorative & Utility Items	Toys	Sports, Games & Educational Aids	Jewelry
- Flower Vases - Bowls - Salt & Pepper Shakers - Napkin Rings - Wall-panels - Pin Cushions - Pen Holders - Paper Weights - Rubber Stamp Holders	- Spinning Tops - Dolls depicting characters from Hindu mythology - Dolls in costumes of various countries around the world	- Skipping rope handles - Chess Sets - Disc Sets - Counting frames with beads	- Bangles - Necklaces - Beads - Earrings - Frames

Figure 5. Photograph showing the toy manufacturing process.

TOY MAKING PRACTICE THEN AND NOW

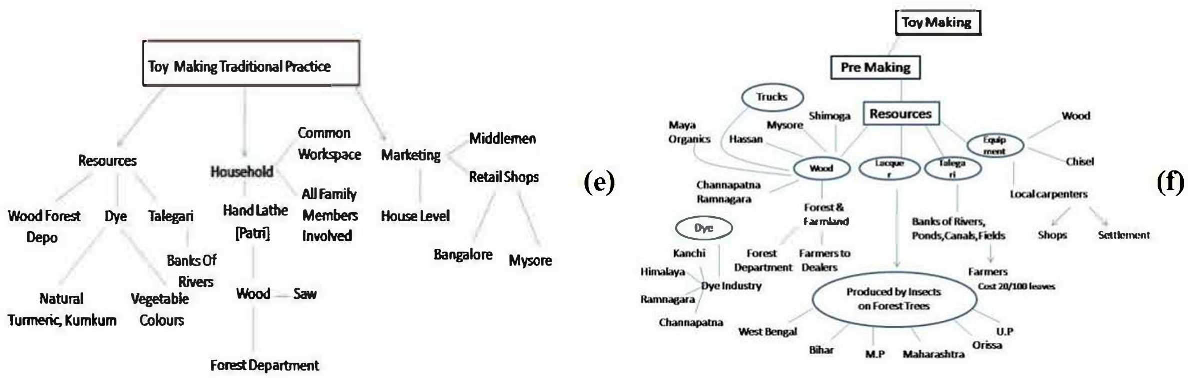

Figure 6. Structure of traditional Toy making practice **(e),** Present day toy making practice **(f)**.

Typology Study of Artisans Settlements

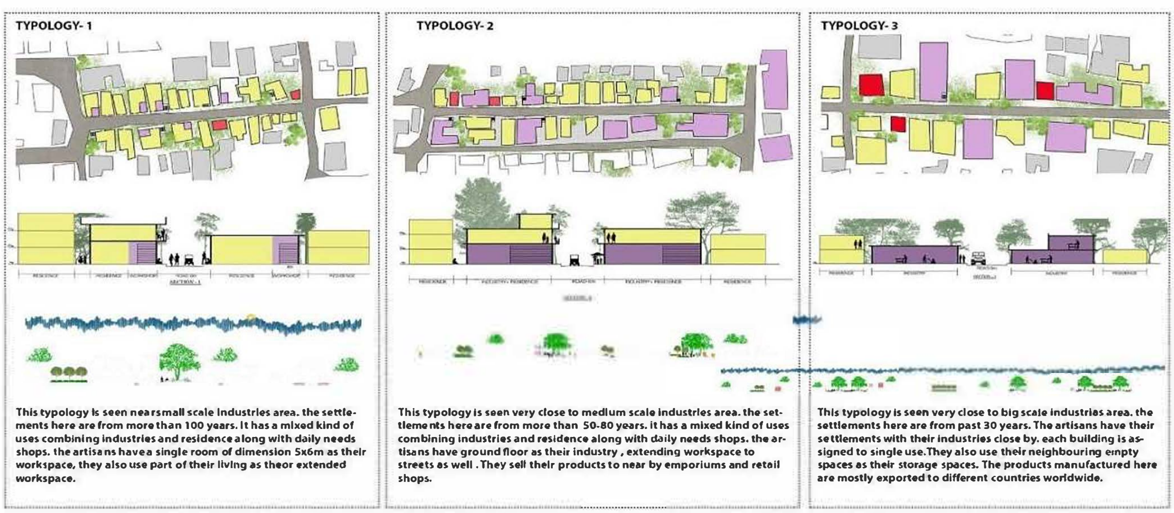

Figure 7. Graphical representation/mapping to understand the existing typology pattern.

Figure 8. Photographs of artisan's settlements.

EXISTING ECOLOGY STRUCTURE

Figure 9. Mapping of existing Ecology structures.

UNDERSTANDING THE TOY INDUSTRY PATTERN

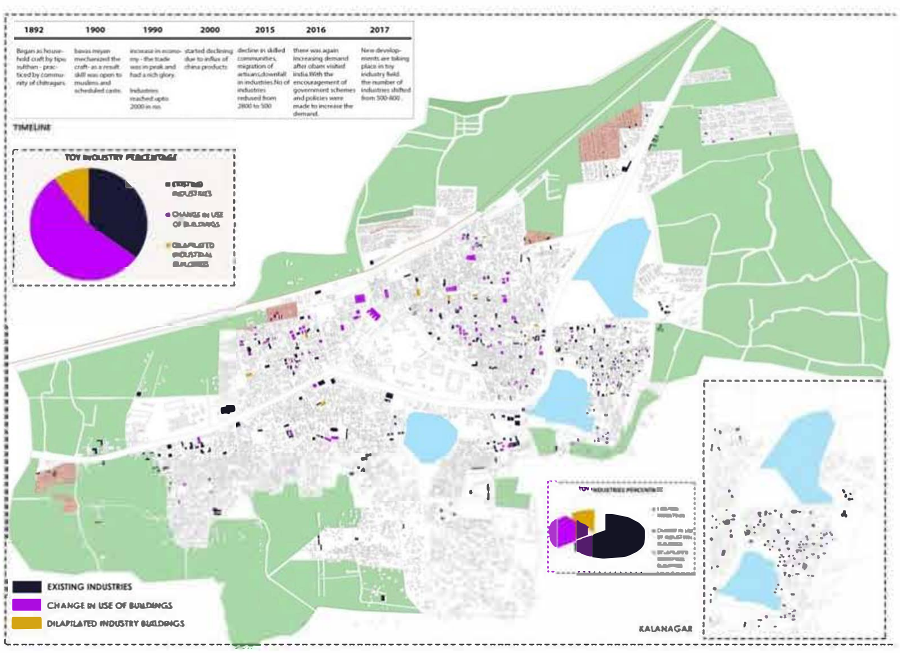

Figure 10. Mapping of industrial pattern.

The city has an existing rich relation with ecology, settlements, community, skills, industries and trade. All these layers faded slowly and now the city is left only with 6000 artisans struggling hard to make their livelihood. From the above studies we can understand its importance and the major role it is playing in upholding the heritage of Karnataka and it will still continue its glory in the future also.

ANALYSIS PATTERN

SWOT Analysis:

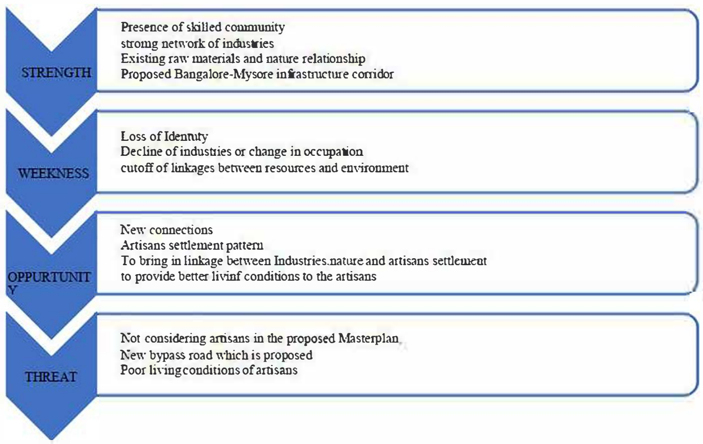

Figure 11. SWOT Analysis

Problem Statement
Channapatna has a rich traditional background for toy manufacturing but due to lack of services and amenities the artisan's settlement is suffering from poor quality of life. Though there is a demand from international market and higher opportunities they are unable to meet the demand. Transformation of their cluster settlement is a negative growth being one of the reasons for their decline.

Research Question
Can the local economy and living conditions of toy based communities improve through design strategies and urban interventions with the revival of ecology pattern of the city?

Issues and concerns

Figure 12. Showing the major issues and concerns of the place.

- City losing its identity associated with particular skill set communities.
- Identity of specific craft/skill with settlement and city.

- Issue of particular group of craftsmen/their workspace identity with settlement.
- Linkages of various related/support trades, network within the settlement.
- Related source material and its relation to craftsmen settlement.
- Change of occupation of skilled community.
- Decline of industries.
- Bad living conditions of artisans.
- Unutilized open spaces.

There is also a treat from the proposed master plan of Channapatna, by not considering the artisans settlement and negligence to their basic facilities and related infrastructure needs.

METHODOLOGY

Figure 13. Study Methodology followed to understand the Research gap.

Research Design Model

This research consists of communication and collaboration between research, design, and the implementation of policies and objectives involved for the city development. This research consist of both qualitative & quantitative research methods along with on-site observations, semi-structured interviews and focus group discussions.

Initially on site present condition was documented with maps, drawings, tables, charts etc. Through interviews, observations, photographs, understanding of the historical layer present, skillset of the community, community study was done from socio-economical and historical aspects. After the collection of the necessary data through on-site observations, the study focuses on a case study approach to carry out analysis on similar skill based communities decline.

The interviews were conducted with the skill based communities, tourists, visitors, toy based organizations, with group of people supporting this skill. Focus groups were also involved during the finalization of design &ecological strategies along with implementation stage.

During the research process, the researcher has contacted 35 artisans, 10 toy industries, 2 NGO's, 6 emporiums and 50 tourists at different intervals.(all age group of people were involved in this process).This research also includes some case studies to understand the cause, issues and solutions for the same cases with different skillsets. Hence approach was much clear by studying these cases.

The qualitative studies were made based on the activity pattern, ecology & economy cycle, natural resources network & availability, land use and the surrounding upcoming projects study.

List of Stake holders involved in the project implementation process are:

1. Karnataka Tourism department
2. Non government organization
3. Local communities.(artisans)
4. Craftsmen Co-operative society
5. Lake development authority
6. PWD
7. Forest department
8. Land owners
9. Ward committee
10. Urban development authority
11. National highway authority
12. Karnataka handicrafts Development Corporation

Collaboration with stakeholders

- Questionnaire was created and made to answer by choosing few samples.
- Identifying the issues and concerns of the local community through interacting with all especially elderly people.
- An attempt was made to understand the needs of all age people especially children because we don't see a city level functional open space in the place.
- Understood the working culture as it helps to rejuvenate the front yards & backyards based on their work culture.
- During the study strategy & design was presented to the people & inputs were taken accordingly.
- Hope in them was rejuvenated among the community as a result they all responded confidently and hence positive results were expected.

Figure 14. Stakeholders & collaborations

LITERATURE REVIEW

Urban design and local economic development: A case study in Birmingham -
Phil Hubbard - Geography Division, School of Natural and Environmental Science, Coventry University, UK

Birmingham is a case study of a local authority that has explicitly recognized. It accepts the fact that the improved urban design can contribute to local economic regeneration. Birmingham's urban landscape has been 'revived' as an attempt to attract investment and act as a catalyst for economic rejuvenation. It demonstrates how the city council have been careful to cultivate a new image for the city through policy initiatives, with the new urban landscape playing a crucial role in the transformation of the city. Hence concludes by reassessing the role of urban design in economic regeneration and suggests that urban design policies can potentially make a positive contribution to the rejuvenation of a local economy.

CASE STUDIES

Case of Kanchipuram:

Kanchipuram town, apart from its temples, is also known as the silk city as the main profession of the people living here is weaving silk saree, settled more than 400 years ago. Many families are engaged in the industry and the saree are famous all over the world. Its economy is entirely dependent on tourism and handloom industry. Kancheepuram silk saree is known more as a hand-woven saree. It is woven with dyed silk yarn with interleaved designs made with 'zari' – a silk thread twisted with thin silver wire and then gilded with pure gold. In fact, the silk thread used for weaving Kancheepuram sarees is made up of three single threads twisted together. This gives more strength to the Kancheepuram saree than other sarees like Dharmavaram and Arni. It is the designs in the Kancheepuram saree that bring whole fame to the saree and is considered to be one of the finest pieces of art. The decline of silk industry was tackled appropriately and was revived using the following strategies mentioned below.

Inference of Kanchipuram case study:
Kanchipuram silk sarees have become an integral part of occasions like wedding and celebrations. Main part of the city is entirely flourished with shops and commercial centres segregating the weavers from the consumers.

The sarees are hand weaven in villages like Sevilimedu, Pillaiyar Palayam etc. Though several weaving traditions have been lost, with the setting up of weaving centres by the government, the traditions are being carefully studied, researched and revived. Especially with technological development, computer-aided designs that are easily replicated. Each village consist of co-operative societies which provide the weavers micro-credit, training and market services. Thus, by engaging the visitors directly with the weavers and making the place more visible the revival would automatically happen flourishing weaving industries.

RESULTS AND RECOMMENDATIONS

Design Strategies to Make Channapatna a Self-Sustainable Town

- It is essential to analyse the issues and come up with a plan, helpful for the communities as well as to increase the economy of the town.
- To reinforce the traditional link of environment and toy industry through urban specialized zoning mechanisms.
- This will help retain their network hence triggering economic cycle.
- Relation to the environment will be retained.
- Knowledge propagation layer added to it along with market facilities
- To regulate the special zones with restrictions to new developments.
- To reinforce the relation between dependent environment and work zone.
- Can be done by special zoning mechanism/guideline within city.
- To provide platform for artisans to exhibit their skills and to engage them in public spaces through direct interactions with the community and visitors.

Ecology strategies

- Green zone protection.
- To strengthen Water network linkages.
- Creating Special zone to protect & continue agriculture fields.
- To revive the lakes with activities and interlinkages.

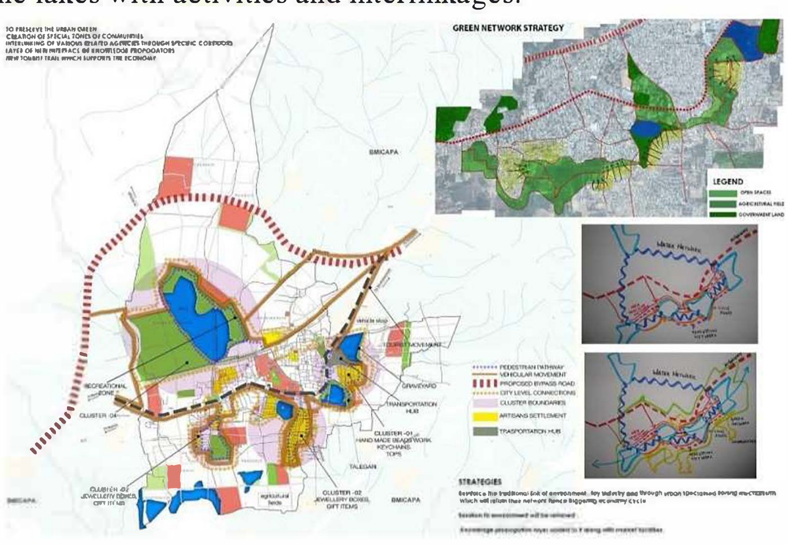

Figure 15. Strategy map

DESIGN IMPLEMENTATION PROCESS

Table 4. Methods & ways of design implementation

LOCATION	ACTIVITY PROPOSED	ACTORS	OWNER
Artisan cluster	To experience work process, and lifestyle	Craftsman,locals,tourists ,craftsmen co-operative society,KSTDC	Privately owned
lake	Landscape around with seating, pedestrian path provided all around	Tourists,,locals	Lake development authority
Open spaces	Production of raw materials, recreational activities	Locals, artisans,forest department, urban development authority	Government
Industries	Spatial planning, relation with natural features,upgradation of products.	Artisans,dealers,distributers,buyer s.	KIADB
Markets	Buying and selling of toys, raw materials and other supporting commodities, emporiums.	Locals,visitors,craftsman	Private lands,lake development authority
Vacant lands	Toy emporiums, landscape features, tourist hub,plaza,gathering spaces.	Various institutions,community people,localites,urban development authority.	Government
Finance institutions	Provides financial assistance, training, marketing.	Ngo,banks,artisans.	Banks,NGO's

Roles and duties of stakeholders

- To help us during the strategy derivations.
- To contribute their experience and perspective to a project
- They were involved in the decision making process to share the responsibilities equally.
- To analyse,understand and visualize the master plan designed by various experiments and interactions with the community.
- Commitment towards the proposal was guaranteed by providing the complete information required.
- The design was approved by community people based On Various trial and error methods. Every decision was openly taken to have the clarity in the proposal.
- Everyone started visualizing the dead spaces transformation into their active spaces as it would be part of their daily routine.

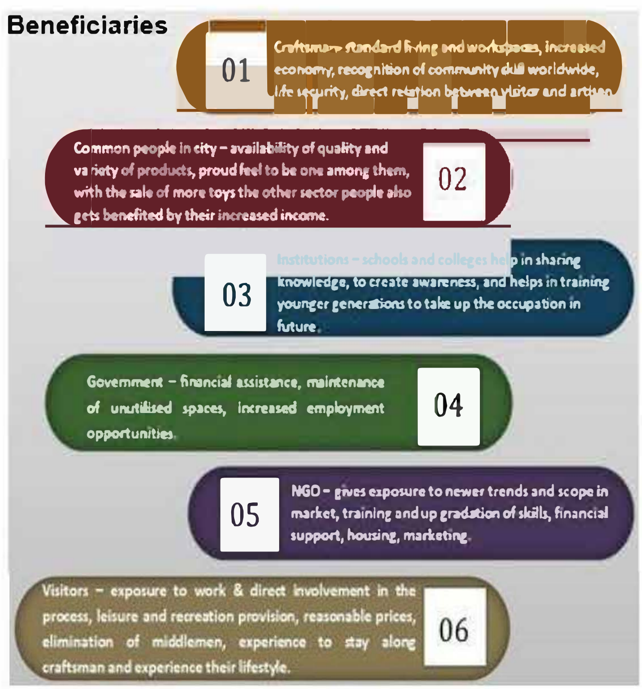

Figure 16. Beneficiaries details

CONCLUSIONS

From the findings of the study, it can be concluded that here is a need to revive the whole toy makers community and their skills to bring back their identity. It is also necessary to help preserve, nurture and grow their skills by providing them with employment opportunities, to strengthen the identity of craft culture. Enhance their skills, knowledge and professionalism to provide visitors a pleasant experience and promote local employment opportunities. The responsible Stakeholders who can be involved in the implementation process are Karnataka tourism department, NGO's, Local communities including artisans, Craftsmen Co-Operative society, Lake development authority, PWD, Forest department, Land owners, Ward committee, Urban development authority, National highway authority, Karnataka handicrafts Development co-operation. In summary, this study and methodology process analyses the pattern of Channapatna city in relation to artisans' settlement, workspace and nature. Hence different strategies have been proposed to cover the research gap and to make Channapatna a self-sustainable town by bringing back its glory and identity. In this context, no existing research was identified with design implifications through urban design strategies. The results of the research tell us that there is a need for urban intervention to enhance the skills, knowledge and employment opportunities to the local craft communities by bringing their talent foreground through urbanity, where the buyers of crafts can engage themselves in product making and experience their culture by staying with them through organising workshops etc by adopting piece by piece urban design methodology.

RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the findings and analysis it is necessary to extend and complete the research by providing a detail urban intervention through most effective approach. It is required to come up with an artisan's village with different parameters catering to the needs of the local communities. Creating awareness programs and interactions are very important to extend its essence to future generations. Detail design proposals can be advised to strengthen the traditional skill, workplace, settlement patters with ecology structures to make the place identifiable and evident. Hence promoting generation of sufficient local economy. Further research has to be conducted in detail to explain interventions and implementation in detail which leads to improve the socio-economic and living conditions of the communities.

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VISIBILITY AND IDENTITY OF HERITAGE PRECINCTS FOR TRAVELLERS: CASE OF RANJANKUDI FORT

Ophelia Vinodhini G[1], Godwin Emmanuel J[2], Monisha Nageswaran[3], Henya Stephi S[4], Sarayu Priya P[5]

[1] Associate Professor, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. ophylia.vinodhini@care.ac.in
[2] Professor, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. godwin.emmanuel@care.ac.in
[3] Assistant Professor, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. nmonisha@care.ac.in
[4] Associate Professor, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. shenyastephi@care.ac.in
[5] Undergraduate student, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. sarayupriya.p@care.ac.in

ABSTRACT

The rapid transformation of historic areas reduces the experience of the built environment with significant historical background. Traces of yesteryear settlements are identified with the visibility of historic buildings in ruins and are significant to protect these areas. Forts are one the historic structures along old travel routes that have strong cultural values. This research paper intends to understand the visibility of Ranjankudi fort located 22km north of the town of Perambalur connected to NH45, built by the feudatory Nawab of Carnatic, maintained and administered by the Archaeological Survey of India. The fort has reduced visibility linkage from the Highways which has led to a reduction in tourist flow and less awareness about the place. The proximity to the highway provides scope to increase the visibility for travellers thereby enhancing their experience, focusing on conserving the structure and its surrounding vicinity. The results of the visibility analysis can significantly aid in locating a pause point in connection to the travellers' field of view, from the highway. This research paper intends to emphasise the cultural values and understand the possible zone of Intervention for planning pause points that can direct a traveller toward the historical monument. The logical positioning of the pause point as an identity element attracts clear visibility for travellers. The present condition is identified through archival records, interviews and focus group discussions.112 maps are generated with 7 design proposals for nodal options along the highway to identify the ideal node as a pause point with Isovist analysis in UCL DepthmapX 0.70. The research concludes with a suitable method to identify the locations of pause points near similar historic precincts for travellers along the highway. The recommendations are provided to design the pause points with a higher degree of visibility thereby creating sustainable heritage zones to understand the importance of heritage protection.

INTRODUCTION

Heritage and tourism

The challenge of preserving and conserving cultural heritage, as well as other related concerns, is addressed by the cultural effect of tourism. (PS, P., 2017.) GJ Ashworth 2000. stated that heritage tourism may be managed to achieve local goals, most commonly local economic development, which necessitates research on the relationship between heritage and places, as well as heritage tourism and local economies. According to the author (N Rezaei, et al., 2022) of research done in Qazvin, the lack of a complete and multifaceted approach in the process of tourist place development might exacerbate the situation for residents and diminish the residential function of key neighbourhoods. The Daming Palace Heritage Site in Xi'an was investigated to see how archaeological and cultural features impacted tourists' impressions. (H Li, Z Qian. ,2017) In research done in Gyeongju, South Korea, the author looked at the relationship between heritage and tourism via the views of visitors. The ethnographic methods used in this study range from in-depth interviews to casual talks with domestic visitors. Based on human perceptions and narratives that express and affirm tourism experiences, three types of tourism-heritage relationships are proposed: synergistic, complementary, and hostile (Cho, H.D., 2022.).In the context of UNESCO World Heritage, the recent upsurge in the conflict between urban development policies and heritage conservation has drawn more attention to Heritage Impact Assessment (HIA) as a tool for identifying and analysing human-induced impacts on cultural heritage property to achieve a sustainable balance between cultural heritage protection and urban development needs(Ashrafi, B et .al., 2021)

Heritage and identity

The geography of a place comprises history, local customs and cultures, religion, industry, the natural environment, food and arts, as well as attractions and events in the case of place-based cultural tourism development and promotion. (Smith, S., 2015.) Ripp, M. and Rodwell, D., 2015. Argues that Particularly in cases when demands for big change or redevelopment are focused on culturally sensitive historic centres of towns and cities, and counterbalancing regulations are not in place to handle those pressures proactively. While comparable macro-scale forces prompted both cities to adopt historic tourism as an urban regeneration strategy, the outcomes reflect substantial local impacts, according to the case studies of Montreal and Singapore. Chang, T.C., et al., 1996.

A visual connection to the heritage site

Roads do have personality, and users may recognize and rate traits unique to each road stretch. Many road characteristics that contribute to the preservation of scenic and environmental aspects were highly regarded (Gartner & Erkkila, 2004), By studying destination image components and tourist experience, for travellers departing from Lisbon International Airport towards Spain in July 2017 adds to a deeper understanding of the influence of a tourist's consciousness on the perceived value of a travel experience. (Loureiro,et.al., 2020).

Why to Use Isovists for Analysis

Isovists today work in a larger area of study called visibility analysis. (Ostwald, M.J. and Dawes, M.J., 2013). Franz, G. and Wiener, J.M., 2005, documented that analytical step is the generation of certain characteristic values, which may be done using Isovists and visibility graphs to translate a variety of spatial settings into a standard and generic data format. (Benedikt, M.L., 1979) used Important and different size and form which are quantified using numerical metrics and these actions produce a group of scalar Isovist fields in turn. Isovists and Isovist fields also give insight on the significance of common architectural concepts regarding space.nThe socio-spatial organisation of architecture is examined by the author (Ostwald, M.J. and Dawes, M.J., 2018). In This investigation of the social, cognitive, and experiential aspects of Modern domestic architecture are explored using computational and mathematical methodologies and these methods help to identify different aspects, such as the sensory and emotional appeal of space and shape, using space syntax, Isovist geometry, and graph theory.

Ranjankudi fort as heritage precincts

Art, architecture, and sculpture were given far higher emphasis by the Tamil kings. A country's art and architecture are always a reflection of its people's lifestyles and attire. The Kings took great care in constructing the fort for their defence. that provides protection and security to the upper class and, on occasion, the lower class.

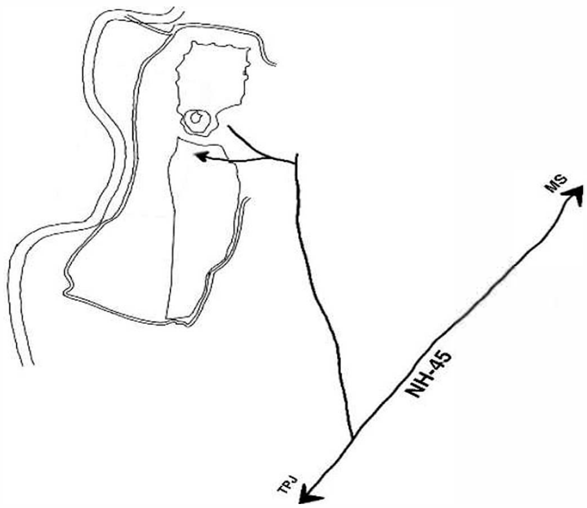


Figure 1. An observation sketch of the location of Ranjankudi fort the Highway NH 45.

Ranjankudi Fort also known as Nanjankudikottai and Nanam kudikottai is built by feudatory Carnatic Nawab at a 17th-century castle in Tamil Nadu, India. The fort lies 22 kilometres north of Perambalur NH 45 in Tamil Nadu, India, as shown in figure 1. and 1 kilometre off the Chennai-Trichy National Highway. It is 253 kilometres (157 miles) from the state capital of Chennai and 70 kilometres (43 miles) from Trichy. The old premises were said to house Shiva and Hanuman shrines. The fort was the site of the Battle of Valikondah in 1751 when British troops led by Mohammed Ali defeated French troops led by Chanda Sahib. Figure 2 and 3 depicts the section of the fort along the waterbody and the three tiers of the fort.

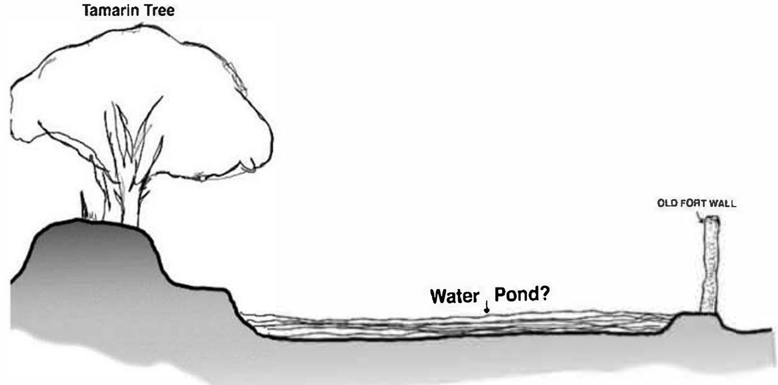


Figure 2. Sketch of the water body surrounding the fort wall.

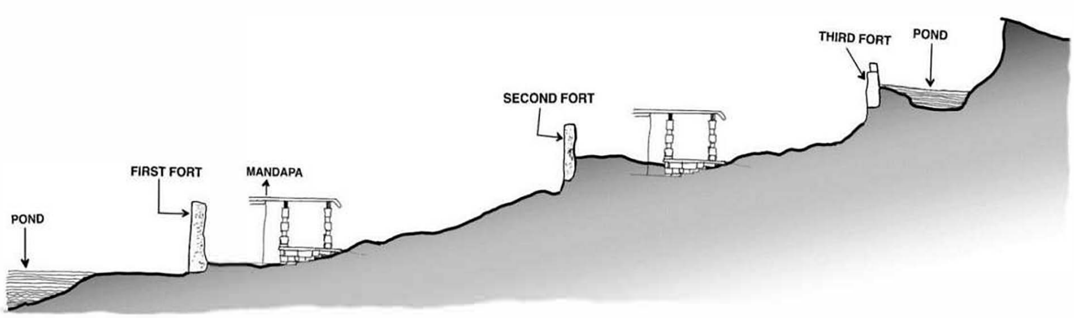


Figure 3. Section of the 3 fort walls of Ranjankudi fort.

The oblong-shaped fort with semi-circular bastions is surrounded by a moat. There are three levels of fortifications made of cut stone blocks. The main rampart is the lower bastion, which is surrounded by a mud wall. Pettai, the open ground, is approached via a flight of steps that was once a battlefield. The top tier is known as Kottai Medu, and it houses cannons and serves as a guarding tower for soldiers. The small body of water in the fort is thought to have been used as a swimming pool by the Nawab. The fort houses residence buildings, a palace, an underground chamber and an underground connecting passage between Pettai and Kottai Medu. The pit in the centre of the fort was used as a male prison.

NEED FOR IDENTITY AND VISIBILITY

Recent rains severely destroyed the top portion of the old fort. The destruction detracts from the fort's beauty and endangers tourists. Locals have requested quick action to renovate and revitalise Ranjankudi Fort, which has tremendous tourism potential and historical value. Locals have requested the government to develop a high visibility linkage from the highway since many people are unaware of this fort and the Perambalur district lacks tourist attractions. This can help to raise awareness about the existence of the place for people travelling along the Corridor of the Chennai-Trichy National Highway, thereby indirectly aiding in the preservation of local culture and heritage; strengthening communities; providing social services; commercialization of culture and art; revitalisation of customs and art forms; and the preservation of the environment.

NEED FOR THE STUDY: SUSTAINABILITY IN HERITAGE PRECINCTS

This research intends to bring to the limelight hidden historical monuments. Enhancing the character of certain nodes near a historical precinct can improve the place identification thereby contributing to the development of the region. This would help to increase the social and economical sustainability of the place. This adds to the mental map of the traveller, thereby persuading them to visit the place again and also suggesting to the other travellers. The loss of identity weakens the depth of meaning, attachment and diversity of place experience in heritage precincts. The lack of connectivity of the physical landscapes with place meanings is held within a broader physical, cultural and emotional context. Sustaining the meanings and identity of such elements of strong historical values are important because they contribute to self-identity, sense of community and sense of place. There is an urgent need to reconsider the depriving heritage precincts and the imperativeness to coordinate in the present and future. Sustainability is one of the Framework for Action on Cultural Heritage's five pillars, which establishes increasing the potential of social capital, supports economic growth and enhances environmental sustainability. Culture and cultural legacy can contribute to inclusive and long-term development.

This includes revitalisation of cities and regions through cultural heritage and access to balance in cultural heritage with sustainable cultural tourism and natural heritage. Increased resilience and sustainable reconstruction of historic areas to cope with climate change and hazard events as recent catastrophic damage to cultural heritage sites has placed fair stronger stress on the necessity to safeguard sites from natural and non-natural hazards. It also aims to offer initial and permanent education to professionals and craftspeople providing traditional competencies and skills for built heritage.

RESEARCH METHODOLOGY

Ranjankudi fort is chosen as the heritage monument, for which the accessibility is to be analysed. A reconnaissance visit and a detailed study visit were undertaken to understand the existing approach routes to the fort. Four entry nodes from the highway to the fort were identified. One of the nodes was a mud path and was traversing within the settlement with lesser road width. Hence it was not taken for the study. The other three routes were observed and studied with sketches and photo documentation.

Identification of Nodes & Isovist Analysis

The node in the south had a clear approach leading to the fort. There is a school and fewer street to the settlement on this route. The node in the centre is a junction with 4 roads, this route completely passes through the settlement. There are many traditional and vernacular house forms, intact with the village life. Widening the road will involve the land acquisition and also affect the character of the settlement, which can otherwise be enhanced as an added tourism attraction. The node in the north, though a wider road passes through the settlement and passes across open spaces used for domestic purposes. The three nodes are further simulated for viewshed area analysis using the ISOVIST tool from Depthmap.The location of Ranjankudi fort and the nodes from the highest is represented below in Figure 4.

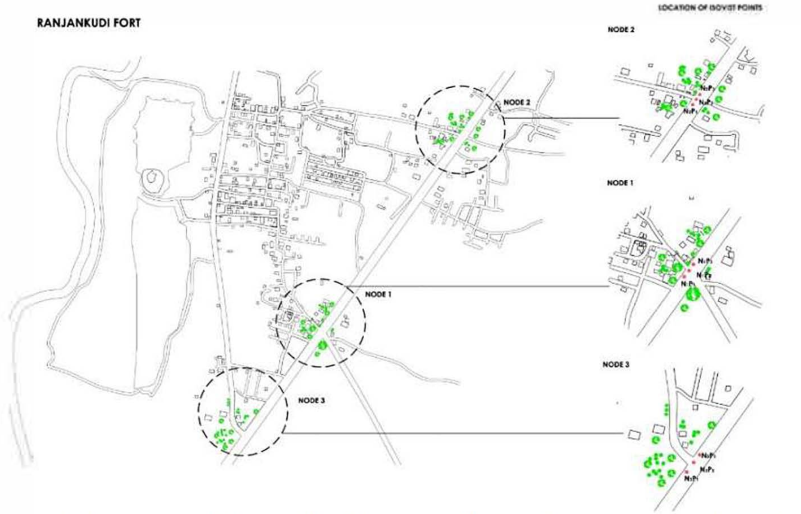


Figure 4. Location map of Ranjankudi fort and the nodes for approach routes

VISIBILITY OF NODES USING ISOVIST ANALYSIS

Three points of observation are taken at on 50m distance from the node on the onward side, the centre of the road and the opposite side of the road. Isovist maps are generated shown in figure 5.

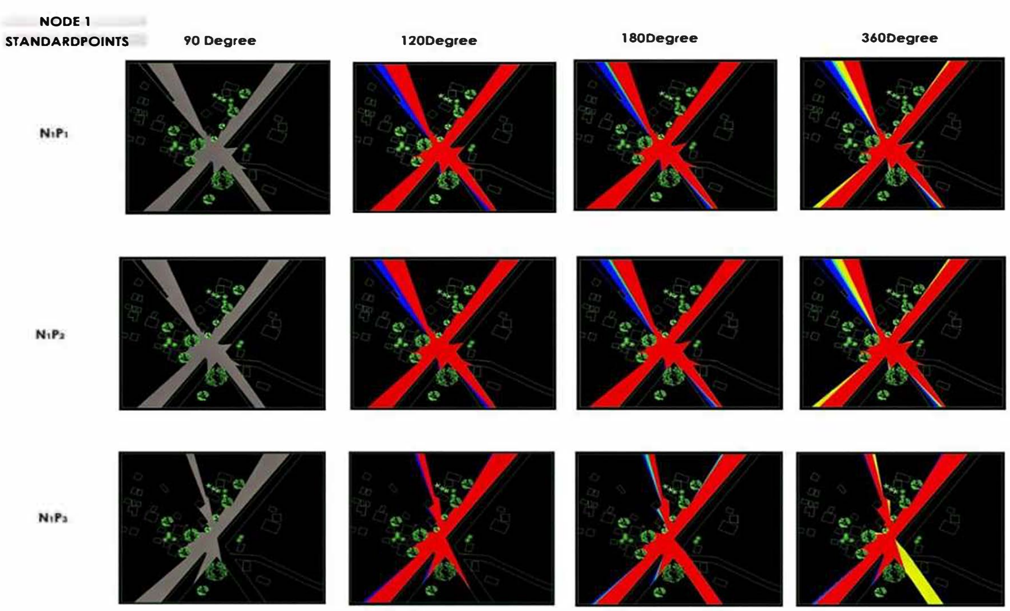


Figure 5. Isovist maps generated for Node 1.

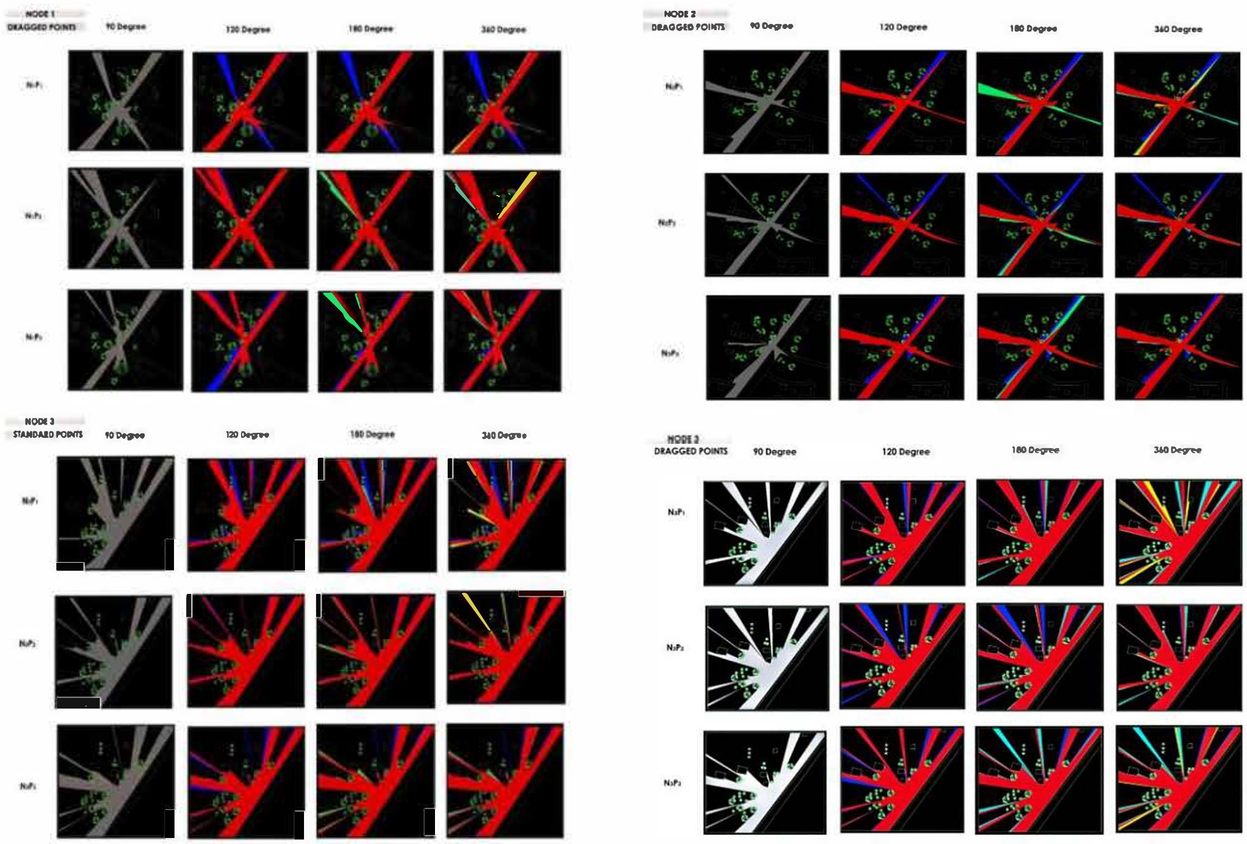


Figure 6. Isovist maps generated for Nodes 2 and 3

Validation with Photographs

Table 1: Photograph Validation of three different nodes at four different Angles (90°120°,180°and 360°).

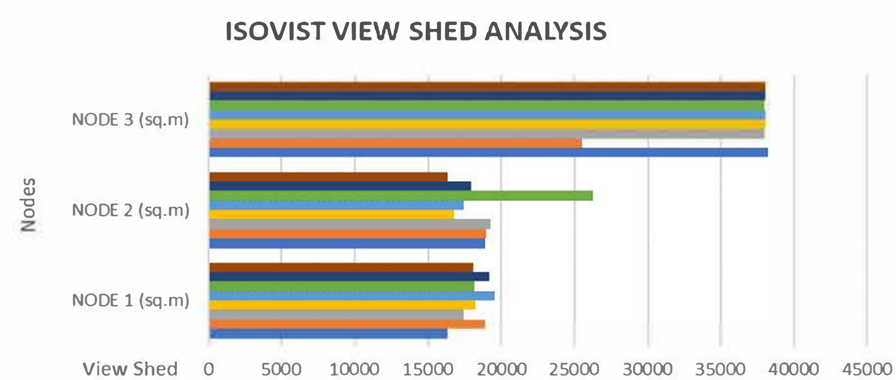
Isovist Angles	Node1	Node 2	Node 3
90°			
120°			
180°			

360°			

RESULTS AND DISCUSSIONS

Table 2: Viewshed areas of the three different nodes

NODES			DEGREES OF ISOVIST							
			90 Degree (standard)	90 Degree (dragged)	120 Degree (standard)	120 Degree (dragged)	180 Degree (standard)	180 Degree (dragged)	360Degree (standard)	360 Degree (dragged)
NODE 1	N1P1	MIN	0.676865	0.644662	0.676865	0.676725	0.676865	0.676725	0.676865	0.559291
		MAX	0.676865	0.686289	0.698785	0.686289	0.698785	0.686289	0.698785	0.686289
	N1P2	MIN	0.599729	0.619971	0.599729	0.56411	0.599729	0.383522	0.599729	0.383522
		MAX	0.599729	0.619971	0.683197	0.619971	0.625816	0.619971	0.683197	0.619971
	N1P3	MIN	0.467181	0.539481	0.467181	0.567088	0.467181	0.567088	0.467181	0.574102
		MAX	0.467181	0.539481	0.482897	0.539481	0.482897	0.539481	0.482897	0.539481
NODE 2	N2P1	MIN	0.51854	0.551164	0.51854	0.481663	0.51854	0.481663	0.51854	0.481663
		MAX	0.51854	0.551164	0.562688	0.551164	0.562688	0.551164	0.542973	0.551164
	N2P2	MIN	0.568125	0.579387	0.568125	0.549048	0.568125	0.457011	0.568125	0.457011
		MAX	0.568125	0.579387	0.696638	0.579387	0.770131	0.579387	0.770131	0.579387
	N2P3	MIN	0.694655	0.658804	0.694655	0.608281	0.694655	0.608281	0.694655	0.608281
		MAX	0.694655	0.658804	0.699073	0.658804	0.791677	0.658804	0.791677	0.658804
NODE 3	N3P1	MIN	1.28716	1.28933	1.28716	1.26633	1.28716	1.25663	1.28716	1.25763
		MAX	1.28716	1.28933	1.27716	1.28933	1.30396	1.28933	1.30396	1.28933
	N3P2	MIN	1.22231	1.29381	1.22231	1.23531	1.22231	1.23228	1.22231	1.24531
		MAX	1.22231	1.29381	1.23031	1.29381	1.24546	1.29381	1.24546	1.29381
	N3P3	MIN	1.25085	1.28585	1.25085	1.26634	1.25085	1.25634	1.25085	1.23058
		MAX	1.25085	1.28585	1.29169	1.28585	1.27167	1.28585	1.27167	1.28585



	NODE 1 (sq.m)	NODE 2 (sq.m)	NODE 3 (sq.m)
360 Degree (Dragged Point)	18078.56	16338.14	38021.5
360 Degree (Standard Point)	19172.22	17925.31	38029.2
180 Degree (Dragged Point)	18169.43	26251.62	37953
180 Degree (Standard Point)	19549.32	17442.44	38047.3
120 Degree (Dragged Point)	18266.75	16748.58	38024.9
120 Degree (Standard Point)	17456.5	19252.61	37954.7
90 Degree (Dragged Point)	18876.3	18928.58	25549.81
90 Degree (Standard Point)	16350.35	18899.69	38183.6

Figure 7. Comparative graph of viewshed areas of three different nodes

Table 3: Isovist areas: Comparison of three different nodes

S.NO	DEGREES OF ISOVISIT	NODE DEGREES	NODE 1 sq.m	NODE 2 sq.m	NODE 3 sq.m	TOTAL (VIEWSHED BASED) sq.m
1	90 Degree (standard point)	NSP1	16350.35	18899.69	38183.6	73433.33
2	90 Degree (dragged point)	NDP1	18876.3	18928.58	25549.81	63354.69
3	120 Degree (standard point)	NSP2	17456.5	19252.61	37954.7	74663.81
4	120 Degree (dragged point)	NDP2	18266.75	16748.58	38024.9	73040.23
5	180 Degree (standard point)	NSP3	19549.32	17442.44	38047.3	75039.06
6	180 Degree (dragged point)	NDP3	18169.43	26251.62	37953	82,373.62
7	360 Degree (standard point)	NSP4	19172.22	17925.31	38029.2	75126.73
8	360 Degree (dragged point)	NDP4	18078.56	16338.14	38021.5	72438.4
	TOTAL (NODEBASED)(sq.m)		149990.77	147715.54	253739.31	

Node 01 has a minimum viewshed of 16,350 sq.m and a maximum value of 19,549 sq.m.
Node 02 has a minimum viewshed of 37,953 sq. m and a maximum value of 2,53,739 sq.m.
Node 03 has a minimum viewshed of 16,338 sq. m and a maximum value of 26,252 sq.m.
And total viewshed area at 180 degrees is maximum with the value of 82,374 sq. m.

CONCLUSION

Node 03 has maximum visual linkage to Ranjankudi fort from Chennai – Trichy highway as per ISOVIST Analysis (with a total viewshed of 2,53,739 sq.m) and through physical onsite observation and interaction with local people of Ranjankudi. While Node 01 and 03 have closer viewshed areas of 1,49,991 sq.m from Node 01 and 1,47,716 sq.m from Node 02, however onsite physical observation and interaction with people found that the routes cut across the settlement, so people do not prefer routes directed from Node 01 & 02. Whereas Node 03 has a direct, uninterrupted and clear route. Hence for route choice, the route directed from Node 03 is better. There are similar precincts away from the highways, with a similar study using ISOVIST Visibility Analysis we can identify which node is better to be served as an entry to the precinct. At the macro level for any precinct planning proper nodes and routes to the precinct using ISOVIST, gives way for more economic and social development for that region as it aids spread awareness among travellers and tourists on a regular basis, thereby creating job opportunities for locals, and improving microlevel growth of that region. Therefore, ISOVIST Analysis will help the tourism department, landscape architects, architects, urban designers, geographers, and historians to properly locate nodes for heritage precincts which will help travellers to identify the structure.

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SUSTAINABLE URBAN MANAGEMENT THROUGH PARTICIPATORY APPROACH

Seema Anil[1], Dr. Shaila Bantanur[2]

[1] Associate Professor, BMS School of Architecture, Bangalore - 64, India, seemaanil@bmssa.ac.in
[2] Director, BMS School of Architecture, Bangalore -64, India, director@bmssa.ac.in

ABSTRACT

Cities are meant for the people to live in. People have aspirations from the city. These are taken care by the Governance. Hence Cities, people and governance are all interdependent. Wards: being the smallest entity of city considered for the provision of basic amenities and infrastructure by the Authorities. At this level the immediate necessities of people can be addressed and this can be the bottom-up approach. This in turn would lead to the structured Master Plan and the overall planned growth of the city.

Mangalore is a culturally rich and diverse coastal city; it is also a well-documented city. Due to the rapid transformations, it is facing newer challenges and lacks the physical infrastructure due to the topographical challenges, which has resulted in pockets of development. There is a mismatch between the expectations of the people and the efforts of the governance in meeting the same. The policies are not able to address the on-ground issues. The Intent of the study was to find out is there any relation between Urban governance and Urban Fabric. Identify how to involve people from the lowest level for better planned cities. Some of the parameters were measured at the ward level to study the disparity like master plan proposals, Contour/landform, Green/blue network, administrative boundaries etc.
The overlay of Maps gave inferences about what is ignored and what is more relevant to the Mangalore's context that needs to be addressed in the Master Plan proposals.
The study suggested lacuna in different authorities providing services to the cities and the disparity in their boundaries. People's perception and socio-cultural beliefs are entirely ignored in the Master Plans.The paper intends to propose new perspective to the bottom-up approach. Looking at it from the perspective of micro-level planning and involving the end user – a participatory approach.

Keywords: masterplan, people's aspirations, wards, cities.

INTRODUCTION – MASTER PLANNING

Master Plan being a key tool in the urban planning practices in Indian cities. Resource allocation especially land and finance are done through the master plan proposals for the overall comprehensive development of a city. Master planning in India has remained largely top-down approach. The 73rd and 74th Constitutional Amendment Act of the Indian Constitution entitled the local self-governing bodies (Ward sabhas) with the task to prepare Master plan. But even post this amendment on-ground there are very few cities where Ward sabhas exist and have been able to exert their power and be involved in the process of Master plan preparation and implementation. Since India is a developing country, the primary focus of Master planning process is towards achieving socio-economic and infrastructural development primarily.

STUDY AREA – LOCATION: MANGALORE

Mangalore city, a prominent coastal town in Karnataka region, has gone way beyond the town once called Mangalapuram to the second fastest growing city (tier II) in Karnataka next to Bangalore. It is one of the prominent destinations for education, health not only within the coast but also at state level. Mangalore's economy is dominated by the agricultural processing and port-related activities. Mangalore has a population of 484,785 per the 2011 census of India (MCC limit). The urban area has a population of 619,664 (L P A limits) while the Mangalore city metropolitan area has a population of 484,785 (2011).

Mangalore city shows a north – south direction growth, parallel to the sea coast. Ribbon type developments are common all along the transport corridors with narrow approaches from the main road to interior development. The old part of the town is grown quiet dense. The growth of the city, has a special character, guided by the topography. The topography is undulating with hillocks with steep terrain and natural drain pattern towards the two main rivers, namely Gurupura and Netravathi.

Figure 1: Mangalore city map

The circulation has followed the ridges and developments have occurred all along, ribbon type, with isolated thick developments depending upon availability of land for development. The areas of study included, the economic hub-Hampankatta, the coastal areas of Bengre, Bunderport, Boloor and sultan Battery, The colonial planned layout of MG road, the developments along the coastal town of Thaneerbavi etc.

Mangalore is a culturally rich and sensitive city. It has strong Tangible and Intangible culture integrated into the lifestyle and emotions of the people. People have socio-cultural beliefs and their sentiments are associated to these spaces. Kambala, puli vesha, Janmashtami procession and games, Dusshera, Bhootha kola, Nagaradhana, Nagabana etc. these are few cultural activities and spaces where they conduct them.

INTENT OF THE STUDY

The intent of the study is to bridge the gap between the process of preparation of Master Plan and its implementation, to bridge the gap between the top down and bottom-up approach in the preparation and implementation of Master Plan. As well as to Identify the tools to study the lacuna in the present system of Master Plan with participatory approach.

The scope of the study involves proposing strategies to include public participation in the process of preparation and implementation of Master plan and suggest suitable strategies to address the socio-cultural aspects missing in the Master plan preparation as of now.

ESTABLISH THE GROUND FOR THE STUDY

RESEARCH OBJECTIVES

i. To bridge the gap between the Master Plan and its implementation.
ii. To bridge the gap between the top down and bottom up approach in the preparation and implementation of Master Plan.
iii. Identify the tools to study the lacuna in the present system of implementation of Master Plan.

RESEARCH QUESTIONS

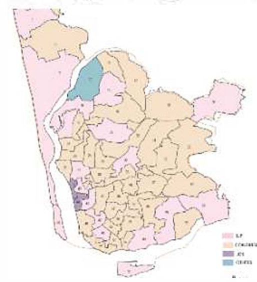
i. Is there any relation between Urban governance and Urban Fabric?
ii. Where does Master plan in its present status lack?
iii. How to bridge the gap between the Master plan and governance?

iv. The process of implementation of Master Plan needs any changes?
v. Incorporating Urban Design tools in the Master plan preparation.
vi. Is identification of the Urban resources the key elements in the preparation of Master plan?

METHODOLOGY OF STUDY

A detailed investigation trying to understand the relationship between the urban governance and urban fabric. The lacuna in the present master plan proposals and in relationship with different layers were carried out across the city in different wards as per the classification done under the study. Understanding the need to identify the significant urban resources forming key element in the Master plan process.

Conflict in the physical boundaries

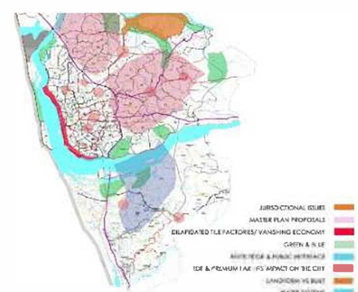


Enlisting the list of authorities having jurisdiction on the city with similar interests but different/ conflicting physical boundaries. MUDA, MCC, CRZ, PORT and other service-related ones falling under MCC like Health, revenue, power, fire, election, surveillance etc. MUDA and MCC jurisdictions were mapped, the overlapping showed the controversies in their physical boundaries. Area part of Local Planning Area is not part of MCC. Pilikula comes under this area which is a regional level tourism attraction.

Political parties of elected ward representatives

Once mapped shows the agglomeration of parties in groups. It could probably help in working together with a comprehensive approach for the issues. It might reflect the common interests of elected representatives of same party.

Multiple common issues mapped at the city level

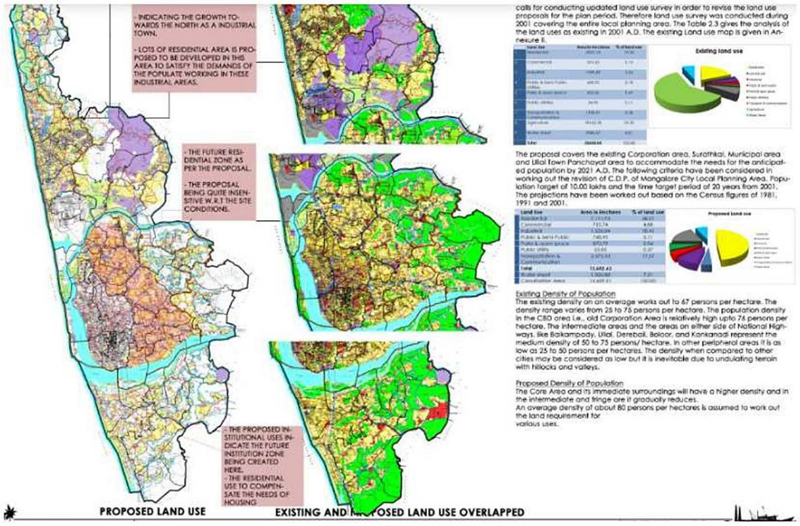


Based on the previous Urban design studies mapped the issues like jurisdictional issues, master plan proposals, dilapidated tile factories/ vanishing economy, green and blue, river edge and public interface, TDR & premium FAR – its impact on the city, Landform v/s built and water systems. A pattern merged out on the city map showing the wards/ areas which are most representative of the city issues.

Master plan proposals

Suggested the future proposals hint at new industrial area emerging on the north as a Industrial city. New residential areas proposed to be developed in the peri urban area to satisfy the demands of the populate working in these industrial areas. The proposals emerged into being quite insensitive with respect to the site conditions especially the landform.

The proposed institutional uses indicate the future institutional zone being created towards the university area. The residential use was proposed to compensate the needs of housing. The master plan proposals suggest the area for roads almost doubled in some of the planning districts. At regional level the road widening proposals indicate the growth towards Surathkal, Bajpe, Deralkatte -university. At the study area level there is concentration towards the centre of the city. The spread is towards east where we can notice new townships coming up.



Ward density and Zones of the city

The mapping showed hardly few projects coming up in the Zone A. Most of the projects are concentrated in the Zone B. There is a gradual spread of these projects in the Zone C. The area with maximum density is as well the low-lying area. No further potential for growth in the core area. The areas with moderated density is now getting loaded with new projects in the master plan proposals.

Upcoming high-rises and the land value mapped

Most of the upcoming projects are along the transit routes. Gradually there is a spread in growth towards the outskirts. Comparing with respect to the price can notice wherever there is steep contours the land price is comparatively low. So, its along these corridors that the new projects are concentrated. Can notice a trend of group of apartments coming up in one area.

Typology of wards

A portion of the city which are most representative of all the issues of the city were categorised into Coastal core, Core, Transition, Peri urban 1 and peri urban 2 wards.

Overlay of different layers of map across the different wards

Different layers built-open, contour/landform, green and blue, existing landuse, proposed land use, proposed road network, wards boundary, planning district boundary all these layers were overlapped as per the categorisation of wards.

In coastal core wards

The landform and the proposed landuse doesn't have any co relation. The proposed landuse and the road network also lack co relation with the landform. Landform and existing landuse doesn't have any co relation. Ward boundary lacks co relation with the master plan proposals.

Core wards

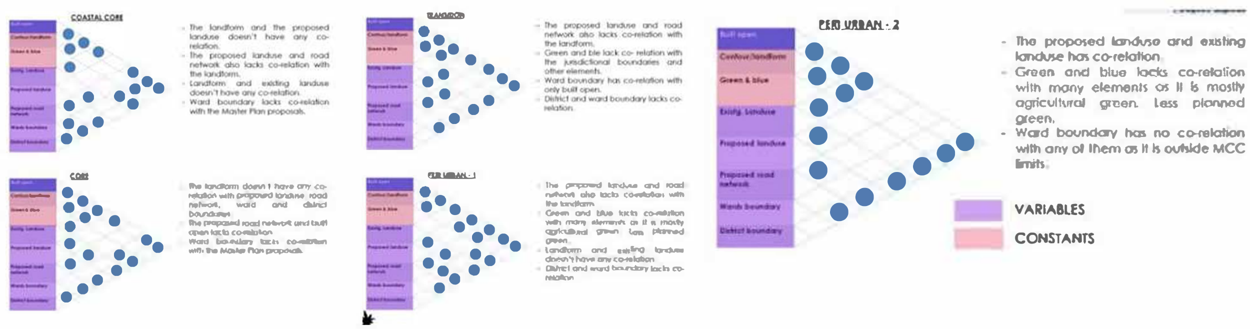
The landform doesn't have any co relation with proposed landuse, road network, ward and district boundaries. The proposed road network and built open lacks co-relation. Ward boundary lacks co-relation with the Master plan proposals.

Transtition wards

The proposed landuse and road network also lacks co relation with the landform. Green and blue lacks co relation with the jurisdictional boundaries and other elements. Ward boundary has co relation with only built open. District and ward boundary lacks co relation.

Peri urban 1 wards
The proposed landuse and road network also lacks co relation with the landform. Green and blue lacks co relation with many elements as it is mostly agricultural green less planned green. Landform and existing landuse doesn't have any co relation. District and ward boundaries lacks co relation.

Peri urban 2 wards
The proposed landuse and existing landuse has co relation. Green and blue lacks co relation with many elements as it is mostly agricultural green. Less planned green. Ward boundary has no co relation with any of them as it is outside MCC limits.



Landform analysis

In coastal core wards
The lowest contour lies at these wards. Within the ward not much variation is there, only 12m to 1.5m difference can be noticed. Dense – compact fabric, hardly few open spaces can be found here. Co-relation between the landform and built in the existing fabric can be seen. Storm water drain joins the river in this zone.

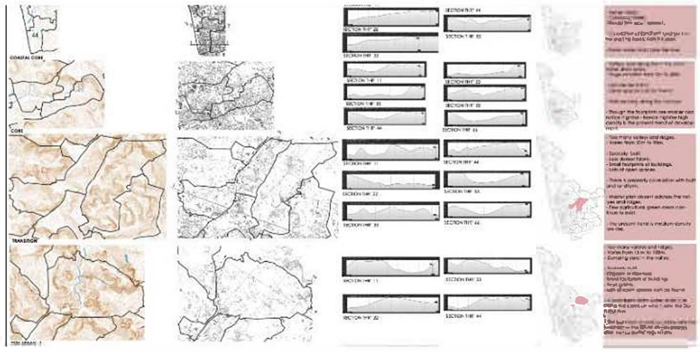
Core wards
Valleys and along them the storm water drain exists. There huge variation in the contour from 5m to 60m, quite steep. Nala running along the contour can as well be witnessed here. Though the footprints are smaller can notice lot of high-rise buildings. Hence high-rise high density is the present trend of development of the city.

Transtition wards
Too many valleys and ridges, the contour varies from 30m to 90m. There urban fabric is sparsely built. The urban built ffabric is less dense in this region. Small footprint of buildings can be noticed. Lots of open spaces since its built sparsely, not part of designated open spaces. There is presently co-relation with built and landform. Master plan doesn't address the valley and ridges. Few agricultural green spaces continue to exist. The present trend is medium density low rise.

Peri urban 1 wards
The contour is very undulating varying from 15m to 100m. The city's dumping yard is in the valley region here. The urban fabric is sparsely built, organic in structure. Small footprint of buildings, finer grains. Lots of open spaces can be found. A prominent strom water drain runs along the contours which joins the Gurupura river. The built form should co-relate with the landform in the future developments also. Hence the regulations need to be reframed to guide this.

Peri urban 2 wards
The contour is very undulating with the lowest and highest contour of the city passing through this zone. Varies from 5m to 105m. The urban fabric is sparsely built, built in pockets, suggesting settlemtns/villages.

Organic in structure, few planned settlements can be noticed. Small footprints of buildings and finer grains can be seen as pattern.



ISSUES AND PROPOSED STRATEGIES

Master plan ignores the topographical aspects into consideration while making any proposals. The culturally and environmentally sensitive areas like nagabanas and kambalas are not earmarked in the master planning zones. one of the kambala space was converted into residential plot in the last master plan proposal. Nagabanas will also start vanishing unless demarcated as cultural spaces meant for conservation. Nagabanas are such culturally sensitive area, since its not well designated and its even being vandalised.

CONCLUSION

The Master plan process needs to be sensitive to the landform of the city, since its proposal has direct implications on the implementation of the same. Cultural spaces are not demarcated in the master plan and hence makes people feel ignored and affects their socio-cultural beliefs attached to these cultural spaces. Elected representatives can act like a liaison and meet the peoples' expectations from them.

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AFFORDABLE HOUSING- A SUSTAINABLE PERSPECTIVE

Deepshikha Sarkar[1], Manjari Kapoor[2]

[1] Research Scholar, School of Architecture & Planning, GD Goenka University, Sohna Road, Gurugram, India, ar.deepshikha@gmail.com
[2] HOD & Professor, School of Architecture & Planning, GD Goenka University, Sohna Road, Gurugram, India

ABSTRACT

Due to rapid urbanization, most cities in India are experiencing an increase in population with people migrating from villages/ smaller towns to the city for employment. This is increasing the demand for shelter in inner city areas. The cost of housing in cities is unaffordable due to high land cost, which is disproportionate to the income levels of urban migrants. Therefore, affordable housing becomes the feasible solution and the Government steps in to address the gap in supply of this housing typology. Historically in India the preservation, improvement, and creation of the required quality of habitable space is integrated with the design process for public dwelling. Policies are being formulated by Central & State Governments to assist in the allocation and delivery of affordable housing for urban migrants, which mostly ignore inputs from architecture & sustainability perspective as well as integrating the requirements of the current situation of the Pandemic. We need to understand the status of affordable housing policy in India to integrate sustainability as a parameter.

Keywords: affordable housing, sustainable communities, architectural environment, government policies.

INTRODUCTION

Humans have three primary requirements: food, clothing, and a safe place to live. The term "house" is used to refer to the essential shelter that all humans need. A person's home is a safe place, a place where they may focus on themselves and their loved ones, grow, and be ready to face the challenges of the outside world and daily life. Due to rapid urbanization in our country, most of the cities of India is experiencing an increase se in population (people migrating from villages/ smaller towns & cities for employment). This is further increasing the demand of shelter for these people. Due to Population increase in Urban Areas, housing demands have increased eventually. Further, the cost of housing is increasing in these areas, but the income of the people might not be increasing in the same proportion. It is taking the center stage as it is being recognized as the basic need and hence the government has also initiated many rules for the same. The term "affordable housing" is used to describe homes that are within the financial reach of people whose annual incomes are much lower than the overall median [9]. What constitutes "affordable housing" varies by country, but often refers to a person's ability to pay for a mortgage. In the United States and Canada, it is generally agreed that a household's yearly income must not exceed 30 percent after paying for housing expenses such as taxes, insurance, and utilities. It is crucial to work on concerns of both affordability and sustainability at the same time. But economic viability alone is often used to define and evaluate housing affordability. Sustainability, home location, as well as housing quality are three additional concerns that are commonly ignored. [16].

BACKGROUND

Making affordable housing a reality is still difficult. The rising societal need for the inclusion of sustainability principles into these housing types for promoting resident health as well as well-being while avouching the necessary affordability levels adds an additional layer of difficulty to the situation. The implementation of sustainable affordable housing was defined as benefiting from innovative technology and methods. Sustainable, innovative, affordable housing (SIAH) is a growing field, but there is still a lack of information on how to implement new technology and techniques into the construction of such housing.[1]

In view of the country's lenient housing policy and its stringent protection of the rights of private property owners, the removal of irregular settlements has proven to be far more difficult than originally envisaged. Despite the many opportunities that exist in slums, it is not always the case that low-income housing unit ownership serves the interests of low-income families.[2]

Housing serves several purposes and has many ramifications for a community's well-being, including but not limited to: poverty, education, infrastructure, health, household wealth, employment, maternal and child mortality, women's labour force participation, and many more. It is becoming more difficult for Indian individuals to have access to housing that is within their price range as the country works to enhance its living circumstances on a massive scale.[3]

It is now the biggest issue in urban India to develop AH on a wide scale; doing so promises a solution to the expansion of slums, uncontrolled growth, and transport congestion. For AH to become a reality, many urgent concerns must be resolved quickly. Concerns on the demand side include making sure you're reaching the right people, increasing accessibility via means like micro mortgage financing and self-help groups, and being able to accommodate erratic cash flow with flexible payment plans. Incentives through policy (free sale areas, extra floor space index, etc.), rehabilitation schemes, slum redevelopment, streamlined land records, adequate land availability, inclusion of mass housing zones in comprehensive development plans (CDPs), partnership, encouragement of private participation, and single window clearance for smaller projects along the lines of large township projects are all needed on the supply side..[3] Also, it is clear that there are three phases involved in the construction of low-cost housing: policy formulation, design, and post-occupancy assessment. Policymakers, researchers, and designers are all essential participants in this process.[4]

Sustainable affordable housing has been regarded as a goal, and innovative technology and practices have been described as helpful in achieving that goal. Sustainable, innovative, affordable housing (SIAH) is a growing field, but there is still a lack of information on how to implement new technology and techniques into the development of these housing. As a result, stakeholders have not settled on a shared understanding of how to bring SIAH into being. This study aims to add to this growing body of knowledge by determining the necessary CSFs for the effective implementation of SIAH.[5]

It is believed that more than a billion people in developing countries now live in shanty towns, slums, and other types of inadequate housing.[6]. Most industrialized nations reportedly have problems providing low-income residents with affordable housing [7,8]. As a result, With the global urban population expected to grow exponentially from 4.3 billion in 2020 to 6.7 billion in 2050, there is strong support for building more homes to meet this rising need (2052).[9].

The difference between an individual's reality and anticipation is reflected in residential satisfaction, which views happiness as a function of how much an individual may obtain and how near his or her perceived position is to the level that is desired. [10] It's envisioned as a multidimensional entity, with several dimensions corresponding to different qualities by which inhabitants' satisfaction answers might be categorized. Some examples of these attributes include the housing unit, the environment of the neighborhood, the management of the estate, and the services provided to the social environment. [11]

METHODOLOGY

Based on the above Literature review, works done in these areas were reviewed and analyzed to understand the parameters/ cost effectiveness for affordable and sustainable housing. While defining the perception of affordability, the important factors to be considered which are related to the requirements of the households are the quality, location and access to services and facilities.

CASE STUDIES [17], [18], [19], [20], [21]

INTERNATIONAL CASE STUDIES ON AFFORDABLE HOUSING

PROJECT DETAILS	OVERVIEW	ANALYSIS	
		AFFORDABILITY ASPECTS	SUSTAINABILITY ASPECTS
Amstrong Place, San Francisco, Affordable Family Townhouse		This affordable family townhouse community is part of a trend of transit-oriented development along Third Street and lies just ablock from a stop of the new Muni Third Street Light Rail. The townhomes have a unique configuration, stacking an "upside down" townhouse on top of one with a more conventional plan. The lower-level homes are entered directly from the podium level and in many units, via stoops from the sidewalk, into the main living level, with the bedrooms upstairs. The uppertownhouses are entered from elevated fourth floor catwalks into the living level and descend to the bedroom area downstairs. This arrangement keeps the private quarters above street level, manages internal noise by not having active spaces above neighbors' bedrooms and avoids public walkways along bedroom levels.	Additionally, ten three-story townhomes with private garages line Mendel Street, which is designed with pedestrian-friendly features such as pavers and extensive plantings. Surrounding the development, the street edge is lined with curbside bioswales-landscaped swaths thatadd green and collect and manage stormwater runoff. The central courtfeatures allotment gardens for resident families, as well as a rain garden and bioswale plantings to manage and clean stormwater runoff biodynamically
Paseo Center, Coyote Creek, San Rose, California, Affordable Multifamily Housing		One of the primary goals of this project was to bring the community together. This was done by implementing the paseo or large street that bridges the block between 2 large residential areas. Withtrying to bring about this sense of community and gathering, The project purposely adds retail space below the units not only to house businesses and bringing income into the area, but they purposely tried to preserve the nonprofitand community organizations that were already there before	Paseo Center focuses on two major areas ofsustainability, environmental and cultural. Cultural: With cultural sustainability, Paseo Center focuses on both maintaining the current retail and community experience that was already there and adding a level to the design that enhances the community and group experience. Along the main paseo (street) the architects preserved the already powerful storefrontorganizations by giving them a permanent home in the design Environmental: This Project being the winner of the AIA/HUD design for excellence, David Baker architects sought toreally make this building environmentally friendly and sustainable. Although much of the faces of some units are exposed to eastern and western sunlight, David Baker Architects quite successfully introduce louvers to help shade the main spaces of the units
98 Archer Street Project, San Jose, California, Single Room Occupancy Affordable housing		Mid-Rise, Single Room Occupancy, these compact units provide a private dwelling space, as well as access to a variety of amenitiesand outdoor living space. The units feature a 9' ceiling height for a more open feeling and additional vertical storage space. The large rasied outdoor patio area, a few units have semi-private outdoor space, and amenities within the base of the building. The buiding footprint and amenity space assisting in defining a boundary for the development and minimizing the parking lots size as perceived from the units due to the overlap of spaces and use of plantings centrally located	California Green Build Guidelines have been accomplished in a variety ways by exceeding the California Code Title 24 by at least 15% and utilizing energy modeling. Specifically, meeting these guidelines by having 80% of the units ranges vent to the exterior to assist in improving indoor air quality. The project also used at least four recycled products listed in the Construction, Flooring, or Recreation section of the California Integrated Waste Management Board's Recycled Content Products Database Environmental Mitigation. The poured in place concrete was also a sustainable choice for the construction since the site is located in a known flood zone. Additionally, the context around this project has many characteristics that will allow this site to helpsustain and build the community.
Homes for all- Dortheavej Residence, Denmark, Affordable Housing		The housing modules repeat along the curve and are stacked to the height of the surrounding buildings. The stacking creates additional space for each apartment to have a small terrace, providing a setting for healthy, sustainable living. It provides affordable housing and public space in an urban environment while simultaneously keeping pedestrian passageways open and the adjacent courtyard untouched. The housing modules repeat along the curve and are stacked to the height of the surrounding buildings giving the structure both vertically and horizontally achieving the living spaces.	The structure is created from modular construction with modest materials allowing the formation of generous living spaces at both the urban and the residential scale. Interior and exterior spaces feature wood and unfinished concrete in light colours, eliciting a sense of lightness and openness. Natural Lighting and Ventilation: Expansive floor to ceiling windows in each unit allows daylight, and view to the courtyard and surrounding neighbourhood. The offset stacked modular system creates spaces between the modules, allowing each apartmentto have its own terrace and access to fresh air and sunlight.
Urban Rigger, Copenhagen, Denmark, Affordable Housing (Hostel)		The Urban Rigger project shows how thinking smart can lead to creative ways of solving housing challenges. Made from upcycled shipping containers, construction ofthe prototype was finished in the summer of 2016 and the Rigger is now located in the city's harbor. Along with its modern style, the green benefits can also make people feel proud about living there. The Urban Rigger housing unit is a unique, design protected, floating, flexible, energy efficient and mobile property, totaling 745 m2 spread over 300 m2 of housing (9 + 3 individual student residences of respectively 23m2 – 30m2), a 160 m2 shared green courtyard, kayak dock, bathing platform and BBQ area, aswell as 65 m2 communal roofterrace. Downstairs, below sea level, the 220 m2 pontoon (basement) is comprising of 12 storage rooms, a big lounge area plus kitchen, a technical room and a shared fully automated laundry.	The containers are arranged into a triangular composition to create a central courtyard. This allowed to minimize the footprint of the pontoon, while opening views to the water- optimizing the housing units. The hexagon combine in a variety of ways to form different communities, focusing views in all directions and creating clear and unique views directed towards the sea. The energy for heating and hot water is extracted from the sea. Today buildings account for 40% of the world's energy consumption and 1/3 of the CO2 emissions. Energy consumption is saved with light floor heating.

INDIAN CASE STUDIES ON AFFORDABLE HOUSING			
PROJECT DETAILS	OVERVIEW	ANALYSIS	
		AFFORDABILITY ASPECTS	SUSTAINABILITY ASPECTS
Aranya Housing, Indore by BV Doshi, Affordable Housing		Aranya Housing was designed as a site and services project spread laid out in six sectors that converge on a central spine i.e., the Central Business District. It's a Low-Cost Housing built in the Year 1989 in Indore. Mixed and multiple land use. Formation of small neighbourhoods and houses extending to the outdoors. Small shops operating within congested areas. Streets accommodating social, economic and domestic activities.	Most of the plots are small in size and clustered in low rise blocks. Longer side façade oriented in the north-south axis to reduce the solar radiation on the building. Each house has minimum exposure to wall surface and a common wall. Trees planted in public places. The building height to street width ratio is such that streets are shaded except when the sun is overhead. The clusters are designed in the north south orientation.
The Hamlet, Thiruvananthapuram by Laurie Baker, Low-Cost Housing		This was Baker's home in Thiruvananthapuram. This is remarkable and unique house built on a plot of land along the slope of a rocky hill, with limited access to water. Use of corbelled arches for openings avoids the usage of R.C.C lintels, thus reducing building cost. The integrated furniture further adds to the cost-effectiveness. This is remarkable and unique house built on a plot of land along the slope of a rocky hill, with limited access to water.	The natural landscape around the built environment was left unaltered, with construction done around the existing landscape. The greenery and the natural materials gave a blend that made any human entering the space to experience a recognizable shift in temperature between the outdoors and the indoors. The planning of the residence mainly involved usage of materials that would usually be neglected as construction waste. The entire volume is a balanced juxtaposition of materials from various sources.
Belapur Housing, Navi Mumbai by Charles Correa, Affordable Housing		Belapur incremental housing project - a proposal for mass affordable housing in New Bombay (Navi Mumbai), which demonstrated how high densities could be achieved with low-rise courtyard homes, built with simple materials at a human scale. This Housing was built in the 1960s' 550 families were planned for in a 6-acre area limitation. Based on clusters of between seven and 12 pairs of houses arranged around communal courtyards, the buildings did not share party walls – allowing ach family to extend and adapt their own house independently.	Sustainable technology used: external walls of brick; roof structure covered with wooden shingles. Local materials like brick, plaster of white color, colorful wooden fixtures, outdoor paving stone blocks. Individual houses rely on simple floor plans and building methods, enabling local masons and craftspeople to construct them making them sustainable.
Signature Global- Prime, Sector- 63A, Gurugram, Haryana, India, Affordable Housing		Signature Global Prime Affordable housing in Gurgaon Sector 63A being developed by Signature Global under Haryana Affordable Policy 2013. The Project is Strategically located in Sector 63A Gurgaon on Golf Course Extension Road Area. Signature Global The Prime though affordable but boasts of facilities like Central Greens, Club, Kids Play Zone, Sport Facilities, Convenience Shopping Center which no other Huda Affordable Projects are providing.	Spread Over 5 acres of land with minimum 65% of Open Space Comprising High rise story of 714 Apartments of 2 BHK .These homes are true green in nature as the project overlooks the proposed Huda green belt earmarked in the Master Plan of 2031.
Signature Global- The Millennia 3, Sector 37 D, Gurugram, Haryana, India, Affordable Housing		Signature Global the Millennia 3, is the most popular Affordable Housing in Dwarka Expressway which is located in sector 37 D Gurgaon. It offers 2 BHK affordable flats outfitted with world class amenities including club house, swimming pool, round the clock security, ample parking space, kids play area, jogging track, dedicated sports area, CCTV surveillance, multipurpose hall, gymnasium, etc.	Signature Global the Millennia 3 Sector 37D Gurgaon are ideal for the individuals who are seeking serene, peaceful and healthy environment. You would find plentiful greenery here as well as alleviating hints of nature. Today, it has become extremely difficult to find a pollution free dwelling especially in NCR where the air quality index is worsening with each passing day. Buying home at Signature Global the Millennia 3 Gurgaon will not only ensure improved lifestyle but also fresh breeze of air.
Signature Global- Proxima, Sector 89, Gurugram, Haryana, India, Affordable Housing		Signature Global Proxima is smartly developed by the well-known builder Signature Global Group. The Signature Global Proxima is equipped with all the modern facilities and amenities though it is an affrdable housing, such as Lift, Power Back Up, Club House, Gymnasium, Security, Jogging and Strolling Track, CCTV Camera, Kids Play Area, Fire Fighting Equipment.	It falls under the IGBC Gold rated affordable housing, this residential complex is an epitome of green building; constructed with eco-friendly processes and practices this is augmented with energy saving measures that include rain water harvrainq, solid waste management, solar panels and use of fly ash; to name a low. Signature Global Proxima brings the best in tile Spread across 5 acres land Sector 89 Gurgaon.
Signature Global- Aspire, Sector 95, Gurugram, Haryana, India, Affordable Housing		With its 2 BHK Apartments, Signature Global Aspire Affordable Housing Project offers a dream home with its ultramodern apartments aesthetically designed keeping in mind your contemporary lifestyle, maximum comfort and minimum budget.	It falls under the IGBC Gold rated affordable housing, this residential complex is an epitome of green building; this project brings world class amenities such as toddler's play area, half basket ball court, jogging track, senior sang, water features. amphitheatre and many more.

DISCUSSIONS

Government policies

Policies are being formulated by Central & State Governments to assist in the allocation and delivery of affordable housing for urban migrants, which mostly ignore inputs from architecture & sustainability perspective as well as integrating the requirements of the current situation of the Pandemic. We need to understand the status of affordable housing policy in India to integrate sustainability as a parameter.

One of the policies issued by Government is Deen Dayal Jan Awas Yojna- Affordable Plotted Housing Policy 2016 for Low & Medium Potential Towns. In this Policy, the Real Estate companies shall come forward and develop affordable projects for the Indian citizens on their own lands [12].

The purpose of this policy is for promoting the growth of high-density planned colonies in Medium and Low Potential towns throughout the state, where a liberal policy framework will make it possible for small plots to be made accessible to residents [12].
The Second being Pradhan Mantri Awas Yojna [13]:
It is divided into 3 phases

- PMAY Phase 1: As this phase from April 2015 to March 2017, a total of 100 cities will be established. PMAY
- Phase 2: From April 2017 to March 2019, Following the completion of Phase 1, an additional 200 cities will be included in the development plan.
- PMAY Phase 3: From April 2019 to March 2022, Housing construction under India's PMAY program will be finished in all remaining cities.[13].

The Government of India has also established the Affordable Housing Policy. A policy whose stated goal is "to support the design and construction of group housing projects" in which flats of a "pre-defined size" are made available at "pre-defined prices" within a "specified time-frame" as established in the policy.[14].

ANALYSIS OF GOVERNMENT POLICIES

1. However, the high cost of land is a key barrier to building affordable housing. Increases in FAR are necessary for affordable housing plots, and state governments should make such increases. If the developer can increase the FAR, the cost of FSI will drop significantly. The more floor area ratio (FAR), the more money a developer may make. If this approach is implemented successfully, the developer may reap the benefits of increased turnover and profit sharing despite lower margins per unit.
2. The density set by the local authorities determines how many housing units may be developed for a given development. This is something that needs to be investigated and included into the policies.
3. The cost of affordable housing may be kept in check if the government provides single-window approval for development projects. Delays in project completion, caused by the several state governments' approval agencies, may increase the project's total cost by as much as 3% every year. The government should assume control of the clearances and work toward creating a single window clearing authority if it wants to guarantee the timely completion of projects at minimal expenses that can be passed on to the buyer.
4. A key flaw in the affordable housing strategy is that limitations are established in terms of unit size rather than a maximum price. If the unit is less than sixty square metres in size, the developer may set the price at whatever they choose. Because of this, the goal of providing inexpensive housing is undermined, as developers may profit from the term "affordable housing" while still charging prices that are out of reach for most potential buyers.

INDIAN GREEN BUILDING COUNCIL NORMS [15]:

IGBC Green New Buildings Certification Levels	
Certification Level	**Points**
Certified	**40-49**
Platinum	**75-100**
Gold	**60-74**
Silver	**50-59**

CREDIT FOR IGBC RATING SYSTEM

1. Innovation & Development- 07 Points
2. Indoor Environmental Quality- 12 Points
3. Building Materials & Resources- 16 Points
4. Energy Efficiency- 28 Points
5. Water Conservation- 18 Points
6. Site Selection & Planning- 14 Points
7. Sustainable Architecture & Design- 05 Points [15].

S.NO.	DESCRIPTION	POINTS
A.	**SUSTAINABLE DESIGN**	
1	Local Building Regulation	MR1
2	Soil Erosion Control	MR2
3	Natural Topology or Landscape	4
4	Heat Island Effect-Non-Roof 50%, 75% & Roof 75%, 95%	4
5	Passive Architecture	2
6	Universal Design	2
7	Green Parking Facility	4
8	“Access to Amenities	2
9	Basic Facilities for Construction Workforce	1
10	Green Education & Awareness”	1
B.	**WATER CONVERSATION**	
11	Water “Efficient Plumbing Fixtures	MR1
12	Rainwater Harvesting	MR2
13	Water Efficient Plumbing” Fixtures-10%, 15%, 20%, 25%, 30%, 35%	6
14	Landscape Design	3
15	IRRIGATION Management System	2
16	Reuse and Recycle Waste Water	4
17	Water Quality	1
18	Enhanced Rainwater Harvesting	4
19	Water Metering	3
C.	**ENERGY EFFICIENCY**	
20	HCFC-free requirement “(Hydro-chlorofluorocarbon (HCFC) refrigerants in Heating, Ventilation & Air-conditioning (HVAC) equipment)”	MR1
21	Minimum Energy Performance	MR2
22	Improved Energy Performance	10
23	“Alternate Water Heating Systems (50%, 75%, 95%)	3
24	On-site Renewable Energy - Common area Lighting” (25%, 50%, 75%, 95%)	4
25	Energy Saving Measures in Other Appliances & Equipment	1
26	Integrated Energy Monitoring System	2
S.NO.	**DESCRIPTION**	**POINTS**
D.	**MATERIALS & RESOURCES**	
27	“Separation of house hold waste	MR1

28	Green Procurement Policy	1
29	Optimisation on Structural Design	1
30	Certified Green Products" (5%, 10%, 15%, 20%, 25%)	5
31	Local Materials (50%, 75%)	2
32	Eco friendly wood based materials (50%, 75%)	2
33	Alternative Construction Material 5%, 10% (Civil & Interior Cost)	2
34	Handling of Construction & Demolition Waste (50%, 95%)	2
35	Organic Waste treatment Post Occupancy (50%, 75%, 95%)	3
E.	**RESIDENTS HEALTH & WELL-BEING**	
36	Minimum Daylighting, 50%	MR1
37	Ventilation Design	MR2
38	No Smoking Policy	MR3
39	Enhanced Daylighting- 75%, 95%	2
40	Enhanced Ventilation Design	2
41	Cross Ventilation (25%, 50%,75%,95%)	4
42	Connectivity to Exteriors- 50%, 75%	2
43	Low VOC Materials, Paints & Adhesives	2
44	Facility for Physical Wellbeing	2
F.	**INNOVATION & DESIGN PROCESS**	
45	Innovation in design	2
46	Exemplary Performance	2
47	IGBC accredited professionals	1

When we talk about affordable housing with sustainable design, it is taking green building from niche to mainstream, where work done is scant as there are relatively many challenges like competitive products, improved technology, need for lower costs, skilled professionals with expertise in green development and design. Although such challenges must be overcome, affordable green housing has a bright future. Green affordable housing has many individual and environmental advantages, and as consumers become more aware of these benefits, the market demand for green initiatives will only rise. As a result of this need, both for-profit and non-profit builders will have access to innovation in green building techniques and technologies.

CONCLUSION

Based on the case studies done and the policies reviewed, it was found that there are still inadequacies in the regulatory frameworks. When a developer plans to build affordable housing, generally the Land cost inside a city is quite high and the location becomes premium for an affordable development. Hence, the developer prefers a cheaper land in the outskirts of the city to get the best Return of Investment (ROI). As the Affordable residential colony is built at the countryside, the amenities might be a concern around the development (starting from the infrastructure, approach to the project, the Electricity, Sewer, Water Supply, etc. to the Amenities like, Schools, hospital, etc.). Secondly, the people living in these societies must commute a long way to the existing cities for work, education, health which could be challenge for them if proper transportation is not provided in that area. Sustainability aspects still come at a higher price in cities and hence higher project cost are impediment for implementation of sustainability aspects in affordable housing schemes. Government policies shall be re-framed in such a way that sustainable practices are part of affordable housing. Construction practices in India shall be reviewed and modified to ensure focus on sustainability in affordable housing projects to minimize the project budgets and cost of homes. Demonstration of the above study shows that there are not enough inputs from sustainability integrated in the current affordable housing policies formulated by the government. Based on the Case studies done it is found that today affordable housing is a way of living and is for all people living in urban cities (besides their income) to make the communities more sustainable.

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THE NEED OF HEALTHY PUBLIC SPACES FOR THE WELLBEING OF URBAN COMMUNITY

N. Sunil Kumar [1], Jahnavi Janardhan [2]

[1] Associate Professor, BMS School of Architecture, Bengaluru, sunilkumarn@bmssa.ac.in
[2] Director, LKSJR Developer pvt ltd, Bengaluru, janhaviblr@gmail.com

ABSTRACT

This paper investigates the need of healthy public spaces for the wellbeing of urban community. The ever shrinking living scale of modern day habitat further pushes stress which is eventually affecting the health of urban community. This study is a direct comparison of living conditions of new-age housing projects to age-old communities, an understanding of urban population moving into large housing projects from independent houses, the co-existence of lateral living conditions shows the emergence of different perspectives from an urban, cultural, social and economic viewpoint. The study further pushes the need to visualize traditional neighborhoods for a thorough understanding of well curated public spaces. The urban public spaces have a role to play in the present unscientific migration and rapid loading of urban density. This study formulates the nature and design of the public space, the findings of this study help to reconstitute the existing urban grey spaces in cities and design future public spaces to promote health and wellbeing.

Keywords: modern day habitat; Public spaces; traditional neighborhoods; well curated public spaces; urban grey spaces; urban density.

INTRODUCTION

Bengaluru, (formerly known as Bangalore) capital (since 1830) of Karnataka state in southern India is also known as 'Garden city of India' the city owes this name to Krishna Raja Wodeyar, the 24th maharaja of Mysore developed Bengaluru with lavish parks, gardens and lakes. The transition of the city growth identity from Garden city of India to Silicon Valley of India due to which the city which was once a retirement paradise is now a city that doesn't sleep, the huge administrative growth vision change witnessed a huge influx of urbanization, rapid development and unscientific zoning.

The need to accommodate all along with increased cost of development as led to ever shrinking living scale of modern day habitat further pushes stress which is eventually affecting the health of urban community. The built heritage is a blessing for us to look back in the mirror of history which always helps us to find answers to solve developmental problems pertaining to urban, cultural, social and economic viewpoint. In a journey to find the true essence of well curated public spaces to promote health and wellbeing of dense urban neighborhood.

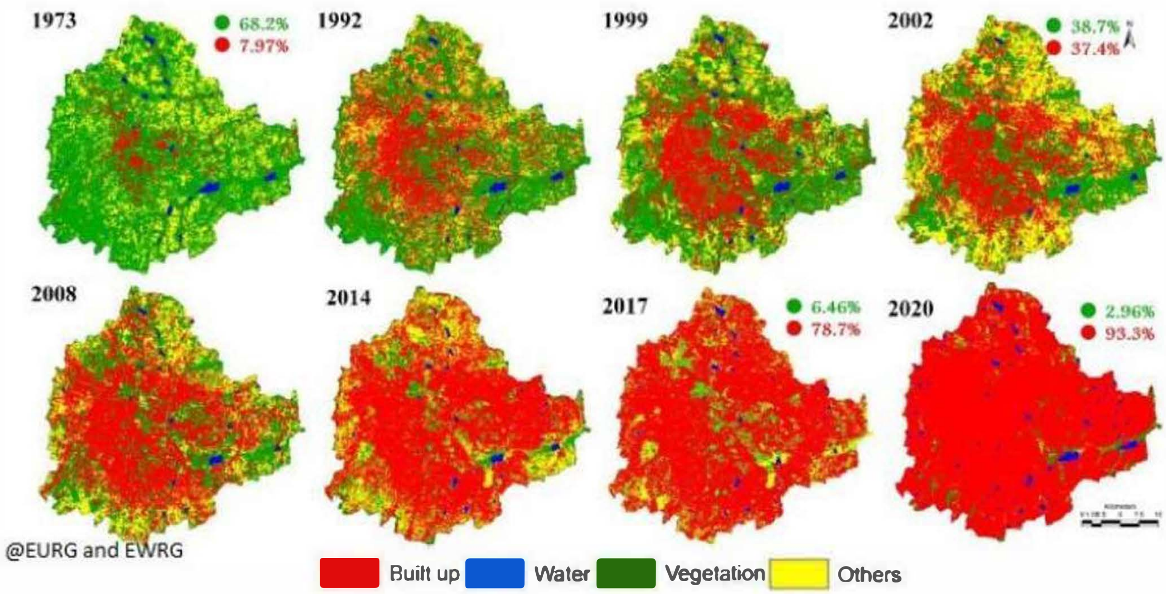

Figure 1: **Land use dynamics in Bengaluru**
Source: [1] Dr. H A Bharath (2017)

The City Improvement Trust Board (CITB) was formed in **1945** which later evolved into Bangalore Development Authority (BDA) in 1976 Under CITB The now well—known extensions of Bangalore, the Jayanagar, Rajajinagar, Indira Nagar, Palace Upper Orchard, Koramangala were developed by the City Improvement Trust Board. From creating plotted Development in the heart of the city The BDA now as changed the housing typology to apartments in the outskirts of the city which is now adding fuel to the uncontrolled radial growth of the city.

Today Bangalore is spread to an extent of **2190 km²** to accommodate a huge migration population from all over the country it's time we shift the capital or think about second capital. To hold such high influx of people new developments are going for high density low carpet area development leading to massive space crunch at homes along with this the already developed area which are over saturated gets to the need of healthy public spaces for the wellbeing of urban community.

When we try to establish answer to the modern day disarray created the answers usually prevails in the traditional systems one such age old housing typology of the Mysore region comes forth are the Agraharas. Traditionally the agrahara is a Brahmin residential quarters built and donated by the Kings to meet accommodation constraints of different communities the houses are built in a U shaped cluster and with a temple at the open end to name a few Krishnarajendrapura, Laxmivilas and Ramavilas and so on.
A typical agrahara house is typically narrow and long, a small frontage jagali to the street starts with the veranda as a transitional space from outdoor to indoor, the jagali will open into courtyard which is partially open to sky, surrounded by hall behind with kitchen and a back door which leads to cowshed and a garden a separate granary and shrine room and big houses have a upper story as well with few extra rooms [2] Biradar, Anjana Vasant; Papu, Sapna (2019). "The Agraharas of Mysuru".

Inscriptions dating from 1821 found within the premises of Prasanna Nanjundeshwara Swamy Temple in Santhepete says that three of the houses were established by the queens of Mummadi Krishnaraja Wadiyar, Devajammanni, Lingajammmani and Cheluvujammani, respectively. They are now called the Lakshmi Vilasa Agrahara, Krishna Vilasa Agrahara and Rama Vilasa Agrahara.

Figure 2: **Lakshmi Vilasa Agrahara** – Street with few original houses.

Figure 3: **Rama Vilasa Agrahara** – interaction of neighbors.

Social get-together

The central green space in Agrahara is a very safe space for children to play under the vision of parents these central space have been created with lot of Indigenous trees and flowering plants where in many instance gives a character and name to the Agrahara in old times when the agrahara was designed when no TV was available a radio room was built in the courtyard as a common facility where in evening people can sit in the Jagali and listen to the radio off late when TV came to individual house the community radio room was converted to community temple.

The planned transitional entry to the house Jagali

In traditional architecture the entry to the house from outside is always a well-guarded activity it is at this point Jagali features in Agrahara it's a low height verandah which acts as a transition from outside to inside the house jagali is the one space of the house which is shared with the neighbors in continues corridor but a clear demarcation can be established by the way every house decorate the jagali space of their individual house the jagali is a small 4' wide most utilized space of the house diverse uses by different age groups different time frame of the day different seasons.

The Jagali features cultural lifestyle of an individual residence in a community, depending on utility purpose an auspicious Tulsi plant will be usually placed along with an area for Rangoli pattern made of rice flour which is left for ants to feed on. On the other hand Jagali accommodates lot of utility features like space to store footwear, space to dry clothes and in certain cases a drying area for grains and space to park cycles. The uniqueness of using the Jagali space identifies distinctive individualistic character of a house.
Transition spaces that interlinks (street and house) every space has its own relevance in architecture as it as direct influence on behavior of end users. A classical architectural element Jagali, when a person comes home from outside, One shall take a small break at the Jagali area where one can park his cycle, remove footwear and wash once legs before entering the house. The shaded Jagali helps as as a transition space to adjust a person's vision to light while moving in and out of the house.

A classical Architectural element the jagali is a pivotal space of the house were neighbors meet for quick conversation. Where children play during summer, women use this space to tie flowers in the evenings and at night this space transforms as sleeping area for men and children during summers.

DESIGN INTERVENTIONS FOR DENSE URBAN FABRIC

Identification of possible development spaces within the neighbourhood

Spaces below flyovers, secondary streets, sidewalks of main streets, school grounds, water front edges or even drains and so on can be identified and the need of social interactive spaces to encourage harmonious neighbours.

Figure 4: A interactive social space below flyover

Spaces below flyovers can have perforated fence and can be utilized as play lots for different age group children depending on the size of the space available. Secondary streets alternative streets can be closed for vehicles and be converted as pedestrianized stretches for a limited time during day to boost the interactions between neighbours. Sidewalks of main streets can be created as linear parks with rich collection of foliage which intern shades the walkway as well the road with a few benches could create an ideal morning walks.. School grounds the most underutilized spaces after schools can be converted as community play grounds or the corridors could be created as common TV points, interactive neighbourhood library.

Figure 5: A play area for different age groups

Water front edges or even drains can be identified and in case of drains can be covered and the reclaimed spaces can be used as cycling tracks or skating tracks.

Figure 6: skating tracks below metro lines
Source: [3] (Pic: Prashant Jadhav)

The Compound walls of some important building can be painted with creations depicting the past to visually educate across age groups.

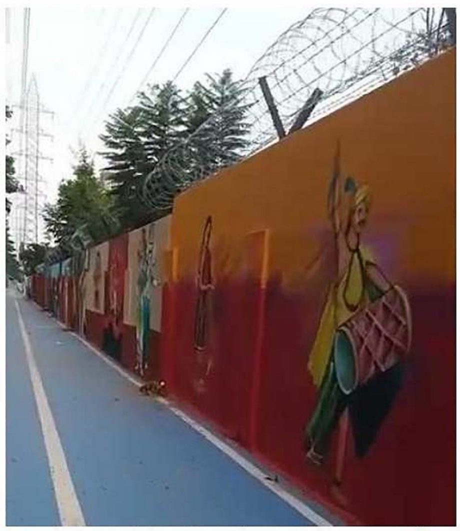

Figure 7: Reclaimed land and prominent wall are painted

CONCLUSION

The community thrives on the social interactions. The agrahara connects the idea of a community that is enrich in culture, a age-old concept of co-living with neighbours – Privacy was always a question between neighbours – and spaces between houses like courtyards and backyards have a enriching culture experience the way these spaces are used. Agraharas are a time tested module for an urban sustainable cities.

On the other hand, the public space is a crucial tool to recalibrate urban health and wellbeing because of the numerous advantages and opportunities it can offer. This study critically looks at the possibilities of improving urban living conditions in Indian cities through spatial transformations in the existing public spaces and explores the required design interventions for the rejuvinated public spaces in cities. From the analysis, a theoretical framework is proposed that helps in understanding the wellbeing of people in the urban areas from the lenses of the built environment.

ACKNOWLEDGEMENT

My heartfelt and sincere thanks to BMSSA organization, Prof. Harinadha Reddy and my Family for their continued help and support in conducting this study. Photos are by author.

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ATTITUDES OF PEOPLE TOWARDS CAR: EXPLORING HABIT FORMATION PROCESS

Pramod Rajendran[1]

[1] Transport & Infrastructure Advisor, GIZ, New Delhi, India, r.pramod5@gmail.com

ABSTRACT

Private car usage is an ever-growing problem globally, but the factors associated with choosing a car as travel mode are varied in nature and at present are not restricted to functional value only. It thus becomes important to understand these multiple aspects from the viewpoint of a commuter and their attitudes towards the kind of mode they prefer based on habit formation which in itself is a process encompassing various stages. The complex nature of a habit and to change the same involves intervention at all levels based upon the criticality of the condition being viewed. The study is further verified by conducting a revealed preference survey which will be used to analyse further the measures which could be taken to induce shift among commuters to shift from usage of private cars to other efficient modes of transport. Initial stages of habit formation shall be dis-cussed to suggest need for exploring interventions at such crucial junctions which would ensure future choices among commuters to be more sustainable. In the process, the attitude towards car will reveal the factors as to what are the general perceptions amongst commuters with the usage of private car over public transit.

Keywords: Habit, travel behaviour, pre-contemplation, private car, attitude, symbolic-status

INTRODUCTION

In a developing nation like India growing population and ever-growing economic activities lead to a multi-fold increase in travel demand of mega cities and, eventually growth of vehicle stocks. A 2004 research suggested despite implementation of MRTS,8.85 million vehicles are expected to be moving on Delhi roads in 2020 (Das & Parikh, 2004), contrary to that we have 10.98 million vehicles on march 31 2018 (Delhi economic survey) with less than a month to reach 2020. Cars are having an adverse effect on the local air in the city as these have been often making headlines in the recent years with air quality index fluctuating between a moderate (101-200) to hazardous (500+) (Centre-run System of Air Quality Forecasting and Research-SAFAR). Not to skip out on traffic congestion and lethargic lifestyle this choice of private car travel is causing, If the ultimate aim is to improve the quality of life for everyone and everything in the long term then the current trend of growth in private car use is clearly not sustainable. Thus, it becomes very important to understand why people are choosing car over various other modes of public transport for daily travel, and what method could be implemented to make them use their cars less and eventually shift them to greener public modes of travel. Private car use is one of the significant causes of environmental problems worldwide, local and individual level. Approximately 21 percent of energy consumption in India is for transportation of total final energy use (Pinna, Dalla Chiara, & Pant, 2014) What is the cause of impending love for private car travel and how can psychology contribute to the mode choice stigma?

It is known that travel is a derived demand and the choices a person makes are dependent upon multiple variables. Taking an example that if given an option an individual to participate in any activity would be expected to undertake very little or no travel at all. thus, stating that if an individual can avail certain facilities at 1 kilometre and equivalent facilities about 10 kilometres, he or she is bound to give in to the first option, thus, indicating that conventional and predominant perspectives on transport should be thought over again to achieve sustainability (Schwanen, Banister, & Anable, 2012). The basic assumptions of conventional transport research and planning were in denial of travel not only being a derived demand but also that it has certain essential values showcased in its symbolic and affective factors in line with emotions and feelings related to travelling (Gatersleben & Appleton, 2007).

To understand travel behaviour, dependent activities in which one wishes to indulge at the destination or during the course of travel also have to be considered as options available to an individual for consideration. Taking into consideration the NOA model (Needs, Opportunities and Abilities) from psychology three general parameters that influence behaviour for discussing the behavioural choices. The behaviour rises from needs(N) and availability of opportunities (O) in an individual's scenario to fulfil his needs and the individual abilities (A) refer to aspect of time, money, skill etc. available for certain travel choices. These factors determine the viability of the individual's behaviour and also put forward that solution to behavioural changes can be found in these three factors namely needs, opportunities and individual abilities (Schwanen, Banister, & Anable, 2012).

At an initial stage, rational considerations play a vital role in choice of transport mode which are based on influential or active factors of transport modes, for example, choice of transport mode based on duration of travel, cost of travel and comfort. Under further consideration, social factors also are important for people as they tend to choose what other people in the society would view as 'desirable' hence elevating the status of the individual in the society. Thus, in a similar state the individual is bound to prefer private car as it provides more status over bus or any other public transport (Steg, Vlek, & Slotegraaf). Emotional factors also tend to play a vital role as some people associate driving with recreation as it provides them with a kick and supposedly contributes to de-stressing while for some it can be a very stressful activity overall. Furthermore, people often overestimate advantages of their own behaviour (private vehicle use), while underestimating the disadvantages of this behaviour such as pollution etc. on the opposite end people are bound to overestimate the negative aspects of public transport (congestion, duration of travel, connectivity) and other alternative behavioural options. There are various reasons as to why people would be willing to reduce their car use when environmental cons are highlighted, most are also well aware about the rising harm being caused due to such travel choice but still do not act upon their attitudes. Behavioural change is considered to be a process rather an event, cause changing behaviour even in most ideal conditions needs humongous efforts than is often estimated. Behaviour change has one important factor which contributes significantly against the change namely habit.

Habit is something which will render providing information to people towards making better choices meaningless, if an individual is not bound to make a conscious choice at first. This particular habit will tend to change an individual's attitude in a negative direction (of one being aware of the environmental cons of car usage to being a low or leas contributor to pollution) rather than reduce the usage of car. Thus, it seems to be an easier option to change the attitude or even have inconsistent thoughts regarding certain actions than bringing about change in behaviour. The re-search on attitudes and sustainable transport has long been exploring or measuring interpretations of effort involved or comfort, money or active costs, benefits of driving in terms of travel duration and speed. But still much of these decisions are based upon the societal status pressure one wants to keep up with and showcase himself to the assumed judgement, trying to make one feel and seem good in front of everyone. This puts light on the aspect that symbolic and affective aspects are pertinent for private car use and provide a new dimension to explore the behaviour or habit shaping process in individuals to address the behavioural change towards sustainable transport choice in a more informed manner (Prochaska & Diclemente).

BEHAVIOUR CHANGE - A PROCESS

While Stages of change model in modification of problem behaviours generally utilised in health psychology which may render helpful to resolve unsustainable transport choices (Prochaska & Diclemente). The understanding of the model is such that the stages of change represent an array of attitudes, the need or behaviour of an individual in certain circumstances during the process of change. The stages further are very specific to the kind of certain problem behaviour and the level of change status achieved by an individual by one's own intentions which means that an individual has to participate by self, contrary to imposing the change which leaves no option to adopt any alternative behaviour than what is being imposed. Thus, the stages of change model clearly put emphasis on the aspect that change is not an event but a process where in individuals pass through five stages namely pre-contemplation, contemplation, preparation, action and maintenance. It is established through the model that each stage can be seen as a period of time and set of tasks or regime one has to follow for upgrading to the consecutive stage. The time consideration during each stage could vary between each individual but the tasks carried out are considered unvarying (Prochaska & Diclemente). Understanding more closely all the stages will help us understand the basis of classification of each stage and the analysis decision as to intervention at which stage helps alter an individual's attitude towards private car. Pre-contemplation is the earliest stage where in the individuals for example are into the habit of using a car daily for commute unaware, unwilling to change when their problem behaviour of using car is being provided with alternative mode. These individuals in this pre-contemplation stage can be highly defensive about their existing behaviour as these individuals are not convinced that the negative aspects of their problem behaviour that is private car usage outweighs the positive aspects by a great factor. Thus, believing that the behaviour pursued is carefully controlled.

This stage provides set of individuals who are ideally not considering change anytime in the future and would be the least responsive participants to any interventions focusing on behaviour change programs. It is very important for pre-contemplators to take onus of their issues while also understanding the negative aspects of their problem behaviour and accurately evaluate to move further from this pre-contemplation stage (Prochaska & Diclemente). Contemplation is the following stage where individuals are considering actively about the prospects of behaviour change inclusive of individual dimensions of the issue and the outcome of any change if followed. Contemplators tend to seek knowledge and evaluate self in view of the specific target behaviour and also evaluating the losses or rewards which may be incurred due to successful behaviour change in future. Though these contemplators are not ready yet for action and just weighing options at present with a firm decision still pending whether to go ahead with the behavioural change and involve in activities to move into the next level. For example, a group of people may be willing to reduce their car usage when they are provided with environmental costs of driving the private vehicles to a point their weighing of positive aspects subsides the negative aspects and helps an individual move from pre-contemplation to contemplation.

The technology at present has not stayed behind with applications in phone tracking health aspects of individual and suggesting the consumption of water, adequate sleep etc. to set in habits for those in the contemplation stage with the intention of the individual as discussed earlier rather than compulsion (claiming that 21 days are required for habit setting of contemplators and then further progression into preparation and action stage). The further stages of preparation are classified by individuals who are willing to change in near future and have learnt some valuable lessons from their previous attempts at behaviour change. Whereas action tends to encompass the group which has initiated the modification of their behaviour and need much active skills like countering their urge to fall back into their problem behaviour and pursue more productive pattern. Being aware of the loopholes is a must at this stage to avoid any interference from factors such as cognitive, behavioural or environmental (societal pressure) to prevent lapse of their behaviour change and reverting back to their problem behaviour. The final stage in the process of change is maintenance and requires behavioural change activity for longer periods to ensure the individual does not fall back to his problem behaviour and is kept constantly under check. For our study on people's attitude towards car we will be predominantly looking at two initial stages of pre-contemplation and contemplation to understand why how and when are the perceptions about the private car travel embedded in an individual and how do they form a certain habit (Prochaska & Diclemente).

Habit

Most of the things which we perform on a regular basis, we are likely to perform them without thinking, or giving it a second thought if it is really necessary or can there be a more sustainable way of doing the same. For example, we hardly ever would think about picking up the key and drive away in the car to work unless we are not able to find our keys or the car develops some snag, that is when we think about alternatives to mode of transport. With consistent availability and stable conditions habits can easily develop. Habitual behaviour is bound to happen effortlessly without much thought or conscious planning, hence making any suggested alternatives to mode of travel would be of no use as the pre-set in mind is already established and any interference to the habit would be easily ignored. A habit discontinuity may often only happen through a major lifestyle change, for example if we consider moving to a new place or job, it would make one reconsider his or her options of travel choice basis the availability and convenience. Thus, people in such conditions people are more often to act in line with important values be it considering environment friendly activities over others available.

Justifying attitudes and behaviour

If we ask any particular individual as to why they drive a car, one is more likely to get a response that highlights the advantage of personal car in terms of safety, comfort, status, speed, freedom or independence and brings forward the disadvantages associated with any other mode of travel. But on the contrary, it is not necessary that building state of the art or adequate infrastructure will ensure increased utilisation of the same, for example, building wider footpaths or bicycle lanes will not ensure increase in the number of non-motorised transport users. In certain cases, it is also a possibility that the improving such infrastructure may even backfire (Ajzen & Fishbein, 1977).

Attitudes towards driving

In this new generation of technology, it is evident that the people's preference is shifting from driving. Still there are people who are driving not by choice rather out of necessity. Reason being non availability of alternate mode of transport and larger distance to central business district area (Shaheen & Cohen, 2018).

Attitudes towards the environment and climate change

The concern of global warming is increased day by day and its threat awareness amongst the population is also increasing but still there are limited research to comprehend people's attitude towards it. A study conducted in the United States of America and other country on people's opinion about global warming states that the public are aware about this issue related to environment and also worried about the global warming. Still people think the threat level is less as compared to other societal issues. Multiple studies conducted in European and Western country has the same findings the attitude of people has not changed till early 2000s. millennials is the generation which remarkably noted for their concern about environment and climate change for which they are willing to change their travel behaviour. A study by the American Public Transportation Association (APTA) (2013) stated that almost one third of the population who changed their travel behaviour is due to environmental concern (Shaheen & Cohen, 2018). Anyhow, travel behaviour research (2016) and Transit Centre report (2014) states that other concern including cost and convenient can have higher rank than environment and climate change. Other studies and reports culminated that the environment concern is secondary and it helps in supporting role rather than prime role in influencing transportation habits.

Attitudes towards information and communication technology

Millennials have always held on the emerging information and communication technology (ICT) due to ease of access to internet through smart phones and broadband. This helps technology users to replace physical trip by "virtual trip". Teleshopping are examples, why physical shopping which is been avoided due to emergence of technology. ICT can also help in rise of demand of transport services for example, app-based ride sharing services like Ola and Uber in which riders and drivers are connected through real time data using mobile device. ICT helps users to locate public transport and also it helps in access car sharing locations. ICT can also provide drivers with navigation service, rerouting and real time traffic congestion alert. Not many research have been done to identify the impact on travel. Also, no study finds a relation between reduction of driving among millennial and the usage of ICT (Shaheen & Cohen, 2018).

Attitudes towards sharing

The sharing economy has grown alongside emerging ICT systems, which facilitate the sharing of assets that would have otherwise been used by one individual or household. Within the personal transport realm, shared mobility is an innovative transportation solution that enables users to have short-term access to a vehicle, bicycle, or another mode on an as-needed basis. Shared mobility is burgeoning and evolving to meet the needs of cities and travellers whose attitudes have begun to shift towards sharing. The most direct evidence of shifting attitudes towards sharing is the increased use of shared mobility systems and their direct impact on decreasing driving alone (Shaheen & Cohen, 2018).

Symbolic aspects of car use

People own a car not just for the ease and convenience of movement between two points but also multiple other characteristics. As high as the instrumental value of cars, there also exist symbolic and affective values. While the instrumental value helps one get from either home to work or vice versa much quicker as compared to the public or mass transit which may also be considered as a functional aspect. But the cars also provide us an opportunity as to showcase our choice eventually an indicator of who we are or how one would like to be viewed by public, while cruising at higher speeds would provide thrill (Schwanen, Banister, & Anable, 2012) (Gatersleben & Appleton, 2007).

Cars can be considered as visual associative objects which provide us a perspective to judge others with their choice or ownership of car helping form an impression and also in case of an individual help form his impression in the society thus making car a social-symbol indicator. In a small example if we try to co-relate images of various cars such as a Maruti 800, a swanky red Volvo or a Tata sumo with pictures of various individuals of varied personality one would be able to find it rather interesting and a relatable exercise where an individual forms a perception very easily basis the various social-symbolic aspects of car. In a similar observation, it is also seen that women tend to find men with a high-status car more attractive than with a lower segment car (Dunn & Searle, 2010). Most television commercials are put forward in such scenario as discussed, where in the manufacturer often try to market and eventually sell of their vehicles by putting emphasis on the symbolic as well as affective advantages of their vehicles. Cars eventually become an important part of identity formation for some individuals who associate cars as their chief or primary possession, something which they associate and relate to, which they can modify as per their personal choice and also as a place where they feel comfortable, something which they can have in their control and feel safe within. Thus, for such connection and attachment, invading the car space stands equivalent to invading the personal space of an individual. Individuals with a very strong attachment and are likely to put forward a thought that the car is the reflection of him or her are most preferably to be highly annoyed if their car is tampered with, scratched upon, or the dashboard settings compared to the preferred settings and even if someone parks too close to them.

The above aspects can really form hindering opinions about the reduce in car usage of a person. The higher the association of an individual's formed identity with the car, more likely are the chances that they will express their desire to drive car more and will be not willing to reduce their car use. It is also studied that scenario of car usage is dependent upon the level of threat to an individual's identity (Murtagh, Gatersleben, & Uzzell, 2012) But there are always some individualistic differences where in there is emphasis placed on the functional features of the car based upon the age of the person who is making a purchase or on the utility factor. People bound to have a higher materialistic and status inclination are likely to buy cars or maybe even an out of the budget car to be identified in the society with higher status and make an impression. People tend to associate various words to describe their attachment and their self-expression for example driving a high-end sports car would bring the expression of power, while a luxurious

Mercedes Benz may bring the idea of class to associate with and these are the cases where the willingness to shift to better modes of fuel efficient car for utility purpose etc. will be very low even with environmental conditions are placed before their eyes (Schwanen, Banister, & Anable, 2012).

Affect

Car driving is an experience perceived by individuals very differently as per the survey conducted where in about 23 percent commuters experienced higher stress when driving by self and 44 percent of the same exercise mentioned that the ride was pleasant (Gatersleben & Uzzell, 2007). This observation leads to the aspect that personal choices or freedom in a car are luring aspects for any commuter, with options such as privacy, pleasant view of nature during the course of journey, choice of music and comfort one prefers using a car over public transit. But reading is another factor for public transit users and no stress to be actively involved in the entire process also provides them with ease of mind hence leading to better productivity. Freedom or flexibility of option to manage travel time or just to put it as ease of mobility one would prefer car but whereas the pleasant experience of a public transit can be found in the company of people, striking conversation, communicating and viewing activities and people. Thus, an idea to float such positive aspects in a sustainable transit choice campaign should be put forth in way similar to automobile manufacturers to initiate a thought and lure by giving out a positive vibe about the entire experience (Steg, Vlek, & Slotegraaf).

Private usage of car adds to the wide range of issues environmental and social in the current scenario and exploring the provisions on how we can reduce the dependence or usage of cars which never has been a simple exercise as there are multiple parameters contributing to decision making. One can start with analysing the choice of vehicle which should be used for the journey, or even further if the journey is really necessary to be made at all. With current advances in technology and services of being able to access the best routes or time of departure to synchronise further travel by minimising the travel time, there is a good probability of shift from use of private car to public transit. When we are discussing about the role of the car in the present context it extends way beyond the functional aspect, thus it is very important to keep this in mind when discussing the possibilities of making the car as a choice of mode as there are multiple barriers to overcome before one in convinced and gets out of the habit which has been formed, the severity may depend from case to case. Thus, transport policies when addressing issues shall consider the point at which people make their transport decisions and inculcate the analysis to provide a better opportunity for people to utilise public transit rather than the preferred private car.

SURVEY AND ANALYSIS

A primary survey was conducted amongst a group of respondents (mostly students- an early stage of habit formation based upon the concept of brick by brick building of habits) to understand basis the above discussed aspects to find out if the justifications of attitudes or behaviour is a major factor as stepping stone towards the habit formation. A total response in the following percentage as shown in the illustration was recorded which states the fact that when these young minds have been asked about a single word to describe their association with car but they tend to point out the advantages of the same in terms of safety (28 percent), need (22 percent), class (21 percent), comfort (13 percent) which comprise for 84 percent of total responses followed by other words which also indicate only positive aspects of car. This is a clear indicator as to the impact of justifying behaviour towards car.

This is in spite the fact that of the total respondent's 65 percent acknowledge and accept that they are aware about the issues associated with the extensive usage of car while 34 percent are not sure fully about these issues or are not aware at all as assessed from survey. In numerous responses instrumental, symbolic and affective motives came forward as participants mentioned about the freedom they feel in their car, the thrill they get out of driving the car at faster or simply owning a luxury car helps them maintain their class. A sense of privacy has also been represented in the responses of the participants where there is a mention of space, customisation of interiors and the choice of colour for their private car.

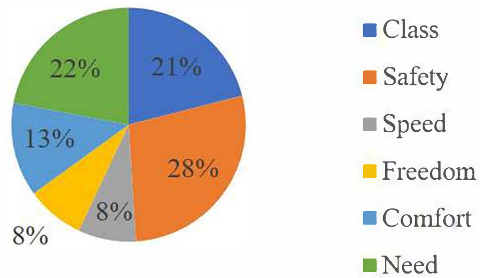

Figure 1 Single word description response found in survey
Source: Generated by author, 2020

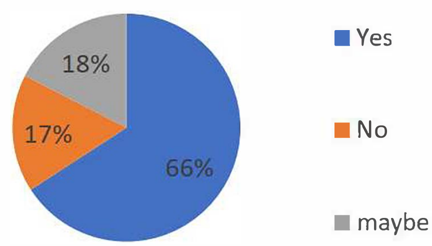

Figure 2 Acknowledging issue of car usage response through survey
Source: Generated by author, 2020

The survey indicates 60 percent of the participants pursuing their bachelors and 20 percent pursuing master and about 9 percent pursuing school, thus an indicator that most of the participants have not had an experience of job savings and other financial complications related to be dealt with but the aspiration to own a certain type of car is established which eventually has been set high by their existing knowledge and impression of the car through advertisements and portrayal of aspects through the choice of car.

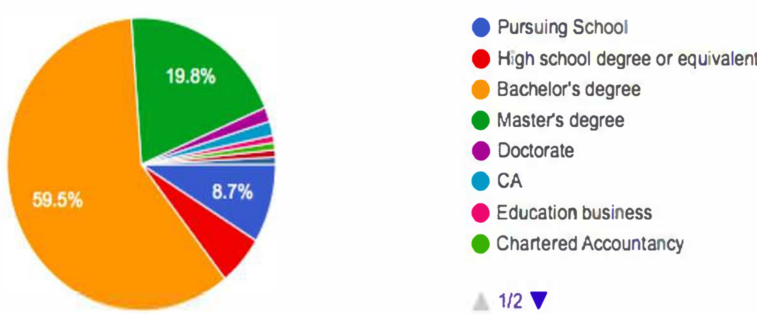

Figure 3 Education level of participants through survey
Source: Generated by authors, 2020

These responses indicate the pre-contemplation stage where in the mind-set has already been framed of the young individual when he or she sees herself with a certain type of car as it reinforces the belief of the way they wish to represent themselves in the society when they are viewed by others. This also helps us come to an inference that it is very crucial to what is being fed to the individuals in terms of the portrayal of private car usage, with multiple factors and desires which start forming at a very early stage it becomes important to mould the attitude by providing them with the right information and enlightening them with the adverse effects of the choices they might make in future and help them reconsider their choice for a greater good. The survey resulted with 31 percent showing interest in purchase of a mid-segment car while 19 percent respond with luxury segment as their choice followed by SUV and premium at 15 percent and 12 percent respectively. The rest of the participants responded for economy or a compact car which had participants from the part-time or full time employed category.

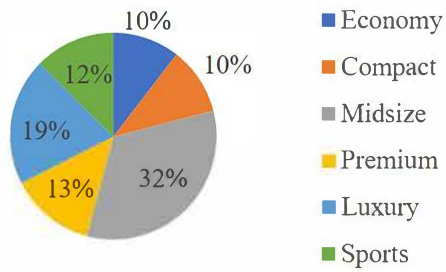

Figure 4 Choice of car if budget provided response through survey
Source: Generated by author, 2020

64 percent of the participants already owned a car within the family but when they were posed with questions of harmful environmental implications of using a private car they switched to a defensive or a more contemplative zone where they show willingness to shift to public transport.

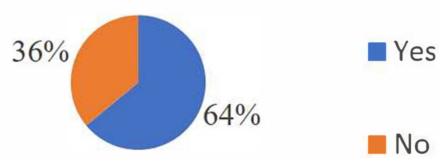

Figure 5 Vehicle ownership within family response through survey
Source: Generated by author, 2020

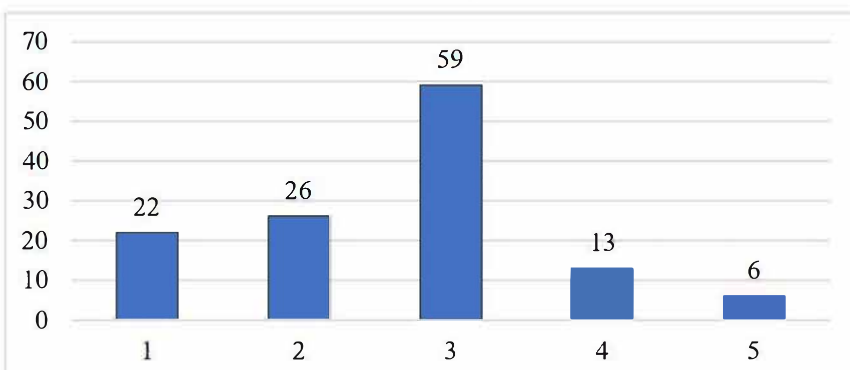

Figure 6 Likert scale for willingness to shift response through survey
Source: Generated by author, 2020

This indicates that cognitive dissonance further when asked to represent the earliest when they would like to shift to the public transport on a Likert scale which indicated 47 percent of responses as neutral and 37 percent at more or less with immediate and 19 percent not likely to shift at all to public transport, this strengthens that once triggered with the question of environmental harm caused due to their previous decisions one tends to just say that they are willing to shift but it is just to protect themselves from being judged further for giving a response which would not be appreciated in the public domain though contrary to this they would not adhere to their words.

CONCLUSION

This survey has been conducted across 4 institutes in Chennai, Hyderabad, Mumbai and Bhopal primarily with students as target community to understand their built perceptions to put forward the thought that the pre-contemplation and contemplation stages of younger generations need to be addressed with right interventions by making them aware and conducting sustainable transit campaigns with the same aspects of symbolic status, affective and impression forming strategy as showcased by manufacturers of automobiles in their media promotion and advertising which formulate the mind-set of the young as known as brick by brick habit formation.

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EFFECT OF LAND USE LAND COVER CHANGE ON THE ARCHITECTURAL STYLE AND COMMUNITY AT DEHRADUN, UTTARAKHAND

Bindu Agarwal [1], Aanchal Sharma [2], Simran Agarwal[3]

[1]Professor, SPA, Graphic Era Hill University, Dehradun, email- agarwal@gehu.ac.in
[2]Associate Professor of DITU, Dehradun, Architect, s.aanchal@gmail.com
[3]Energy Analyst, Architect, Chaman Vihar –II, Dehradun, e mail-agarwalsimran244@gmail.com

ABSTRACT

Dehradun is a medium size tier 3 city located in the fertile region near the Himalayan foothills in Garhwal region, the North-West part of Uttarakhand. It is Capital of Uttarakhand since Nov 9, 2000 and is a well-known tourist destination owing to its natural beauty. There was a surge in population between 1991-2001. Decadal population increased by 39.73% and was 574840 as per the Government of India 2011 Census. Many agricultural and forestry areas which were full of Litchi gardens and Basmati Rice fields around Dehradun region have changed into buildings comprising of apartments, universities, schools and colleges, shopping complexes, hotels, restaurants, and factories. All this proliferation happened without keeping in mind harmony and ecological balance with the neighboring environment and historical importance. It is also observed that green banks now gradually converted into gray area with sprawling slums. The objective of writing this paper is to study the effect of change of land use in last 25 years on the architectural style and community of Dehradun. The satellite geographical information system (GIS) and ERDAS software's are used to achieve the objective. The scope of community is limited to people living in Dehradun from last 25 years and seen the urban growth and changes in the city. The effect is profoundly visible in terms of various kinds of infrastructural development and varied changes in residential areas especially in ground coverage and total built up areas, even in architectural built forms, on FAR. Open spaces and green areas, and traffic transportation main roads and link roads etc. City required more and more houses which lead to increase encroachment of agricultural and forest land for infrastructure development.

OBJECTIVES

1. To Study an evolution of Dehradun city with respect to city growth. Architectural study & Compression of Dehradun lost And latest Dehradun
2. Analysis of built up area 1998-2017 through GIS
3. To establish through the socio-economic assessment of plot areas and comparison of circle rates.
4. Prepare a theoretical model and give suggestions for the development of residential areas

INTRODUCTION TO STUDY AREA: DEHRADUN CITY

Dehradun History: The journey of city from 1676, the seventh Sikh's guru Shri Guru Ram Rai's came here and the town established as Gurudwara / Dera (Camp) . During Mahabharata time Dehradun was known as Dronagiri as Pandavas and Kauravas Guru Rishi Drone lived here around 1100-800 BC. In Mauryan reign during Asoka Empire it was known as Sudhanagar 273-232 BC. Today's time it's known as Dehradun. Dehradun is known for the aural environment of the Himalayas. The Mughal Emperor Aurangzeb was very impressed with Fetah Singh, Maharaj of Garhwal. Aurangzeb extends all possible help to build Shri Guru Ram Rai Darbar Sahib- Jhandeji , Gurudwara is completed in 1707. Anglo – Nepalese war (1 November 1814 – 4 March 1816) is continuous war between two armies i.e. Gurkhas and Britishers, also known as the Gorkha War .That war Gurkhas lost Deradun to British which later came to be known as Dehradun. In

1867 Dehradun Municipality Council was established and in early 20th century railways station was built. MDDA was established in 1984 with objective of planning and development of the city. Jawaharlal Nehru, India's first Prime Minister Pretty loved the Dehradun and visited the place many times. Before 1947 India independence Dehradun, Kumaon and Garhwal were part of united stated later it was known as Uttar Pradesh. In 2000, Uttaranchal state was created; Dehradun was made its capital, now Uttaranchal is renamed as Uttarakhand.

Population Growth Record of Dehradun city: In 2000 when Uttarakhand made a separate state that time Dehradun was made its capital. There were sudden jumps of population. In 1991-2001 decadal its increases by 39.73% before that 1981 and 1991 the decadal changes in population was 21.33% and 21.85%. It is assumed that population of Dehradun after 2000 is expands almost 3%-4% every year.

Table 1: Dehradun Population growth graph in thousands

Census Year	Urban Status	Area in Sq. kms	Persons
1961	M.B.	31.08	126,918
1971	M.B.	31.08	166,073
1981	M.B.	31.08	211,416
1991	M.B.	38.67	283,537
2001	M. Corp.	52.00	426,674
2011	M. Corp.	68.18	569,578

CASE STUDY : 175 YEARS OLD HOUSE OF MS. IRA SINGH (EX-NEPAL'S KING DAUGHTER)

One of such houses that still exist are conserved and flourished with the essence of life by a resident in Dalanwala - Ms. Ira Singh. The house is about 175 years old and was bought in 1960 the resident's father. Built on a land of 10 Bigha used to have an adjoining area for agriculture purposes that was sold due to, let's say, urbanization. Initially, the house consisted of about equal sized typical 4 rooms that were in fashion in the colonial times but a verandah was constructed later through the thick walls made of stone, mud and lime. The partitions in the interior of the house were mostly calculated and the ceiling was jack roof trusses. The house was facing north with orchards on the west and agricultural land on the east side. With staff quarters at the back side, there was stone pavement that connected the back of the house with the 'used to be COW SHED' which was now converted into a set of two room with attached bathrooms but still it had a little essence of cow dunk in the air. The façade was completely bare and one could clearly see the use of bricks only around the cavity of walls for the placement of windows and doors and the stones fixed with mud and lime in the wall. The first floor of the house was the typical plan of the ground floor which was converted into four suites with attached toilets. As stated by Ms. Ira Singh, the flooring was just a thin layer of plain cement which had a wide crack from the door entrance to the center of one of the rooms. Instead of using the mainstream concrete reinforcements as a remedy for the crack, she put all her efforts in searching for another alternative that was not just economical but also a natural DIY solution. Although being called stubborn a lot of times, she made a mixture of 4-5 kilograms of lime, 2 bags of surah (brick dust), 3 kilo Uradhi dal

(black gram), god (jiggery), tobacco, molasses and bale that was not available in the market so she grew it in her house itself and kept this mixture for 3 weeks till it was firm enough to be used as a filling in the crack by using shehtut (mulberry) twigs to beat it into the crack and it actually worked and the fix was as solid as cement. Apart from the materials used and the architectural elements that are emphasized, the house is mostly self-dependent when it comes to water supply because rain water harvesting system is inculcated along with the recycling and reuse of waste water and grey water and an underwater tank. It has been taken into consideration that the house works in an economical way as far as possible by least amount of energy consumption on a daily basis. As quoted by her, —My aim is to keep the original integrity of the building intact along with advancing the livability in an efficient eco-friendly atmosphere. Showing her concern for the environment in Dehradun, she also states that, —This is a natural phenomenon; nature takes back what's hers. The places in Dehradun don't remind me of my childhood anymore. It's saddening how the city with such large scenic beauty has now transformed into just another pile of concrete with a label of urbanization. It was a privilege to find such a house that still has the soul of Dehradun and to meet an owner like Ms. Ira Singh who pours her heart out to make the house breath with life of its own. Some other existing old buildings of Dehradun are just some crumbling ruins with brightly painted facades, elaborate brickwork, arched windows and ornate doorways revealing the remains of a more decorative and seemingly playful era — one eclipsed by the dullness of today's prefab structures. The town presented a beautiful picture wherever you went with its low rise bungalows and small houses, plenty of space, greenery in abundance, clip clopping tongs on gently sloping roads, rolling lawns, low boundary walls, trees laden with fruit, plenty of birds and not too many people or vehicles in sight. Some things like water logging, slums, too much dust, and noise from the roads, mosquitoes and crime on the roads were unheard of.

COMPRESSION OF DEHRADUN NOW AND THEN

Below are the photographs showing the comparative views of the Dehradun city. Below at the right side showing the images of city before the 2000 and at the left side approx 25 years back images have been shown. In the top pictures of the Rispana River present condition and other picture showing river condition 25 years back.

THE COMPARISON OF 2001 & 2018 CIRCLE RATES OF LAND AS PER MDDA (MISSOURI DEHRADUN DEVELOPMENT AUTHORITY)

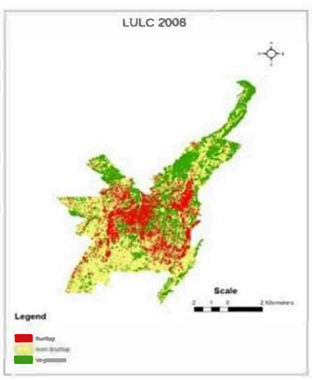
S. No	Area	2001- land circle Rate per sq meter		2018- land circle Rate per sq meter	
	Name of the Area/ landmarks	**Less than 100 sq m**	**From 100 sq m -250 sq m**	**0-50 sq m.**	**From 50 sq m - 350 sq m**
1	Rajpur Road (from clock tower to RTO)	2400	2300	30000	50000
2	Kothal Gate	650	550	24000	20000
3	Paltan Bazar	2400	2100	30000	27000
4	East Canal road	1500	1400	26000	23000
5	Subhash road	650	550	26000	23000

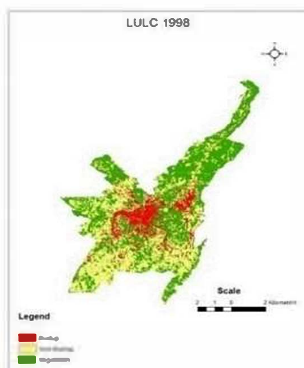
6	Haridwar road (Prince Chowk to Rispana)	1900	1200	24000	20000
7	Jhandaji	750	650	26000	23000
8	Indira Nagar colony	850	750	18000	14000
9	Vasant Vihar chowk	700	600	18000	14000
10	Ballupur Road	1700	1200	24000	20000

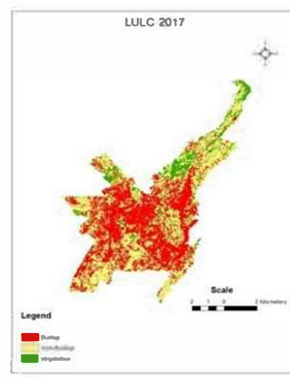
Above is the table showing the increase in circle rates of land circle per sq meter as per the MDDA. The circle rate which is in 2001 is Rs 2400 /sq m is now Rs 30000/sq m now as per 2018 circle rate.

ASSESSING LU/LC OF YEAR 1998, 2008 & 2017

Based on collected GIS images in 1998, vegetation class founded the largest category with coverage of 27.38 sq.km, i.e. 47.78% of the total study area. The Built up area with 06.72 hectares (11.72 %) and agricultural land and open fields, 23.21sq. km. (40.50 %) occupied second and third position respectively. In, 2008, non-built-up areas founded the largest category with coverage of 26.89 sq.km, i.e. 46.93 % of study area. Agricultural and open lands and vegetation class, 18.60 Sq.km (32.45 %) second in area coverage. In 2017, non-built-up areas are the largest category with 26.60 sq.km coverage, i.e. 46.21 % of study area. Built up area is second with 25.32 sq. km i.e. 44.18 percent and vegetation class stands third with 5.39 Sq.km (9.61 per cent) area coverage. Below results are presented in form of maps and charts.





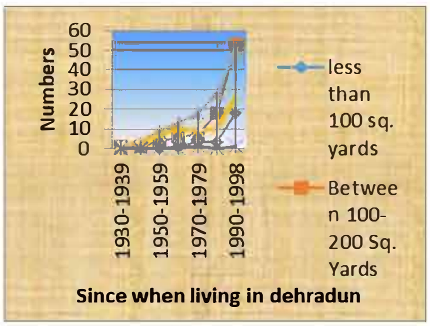


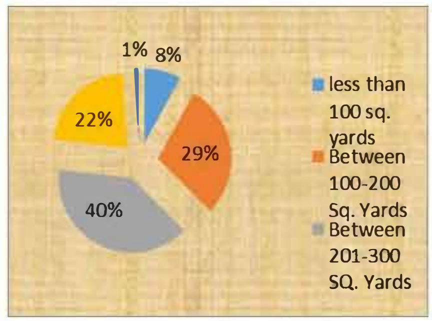
SOCIO-ECONOMIC ASSESSMENT OF PLOT AREA

It was apparent from the information that only 8% of the dwellings have less than 100 sq yards plot area, 29% of dwellings have plot area between 100-200 Sq. Yards, 39% have plot area between 201-300 Sq. Yards, whereas 22% of dwellings have more than 300 Sq. Yards of plot area. Hence, it is evident from the study results that maximum dwellings in Dehradun have large plot area. The maximum respondents have plot area between 201-300 sq. yards. Respondents are Happy with water supply services of the city. They are not satisfied with increasing cost of land/housing. The detailed information pertaining to plot areas of Dehradun residents with their years of living i.e. since living in Dehradun is tabulated below:

S No.	Since when living in Dehradun	Plot area										Total	
		less than 100 sq. yards		Between 100-200 Sq. Yards		Between 201-300 Sq. Yards		More than 300 Sq. Yards		Any other			
		Nos	%	Nos	%	Nos	%	Nos	%	Nos	%	Nos	%
1	**1930-1939**	0	0%	1	1%	0	0%	2	3%	0	0%	**3**	1%
2	**1940-1949**	0	0%	1	1%	3	3%	3	4%	0	0%	**7**	2%

3	**1950-1959**	0	0%	3	3%	9	8%	7	10%	0	0%	**19**	6%
4	**1960-1969**	1	4%	6	7%	13	11%	10	15%	0	0%	**30**	10%
5	**1970-1979**	3	12%	7	8%	18	15%	9	13%	1	50%	**38**	13%
6	**1980-1989**	3	12%	18	20%	28	23%	10	15%	0	0%	**59**	19%
7	**1990-1998**	18	72%	53	60%	49	41%	**27**	40%	1	50%	**148**	49%
	Total	**25**	100%	89	100%	120	100%	68	100%	2	100%	**304**	100%
		8%		**29%**		**39%**		**22%**		**1%**		**100%**	





CONCLUSION AND RECOMMENDATIONS

In review research would like to share the residents of Dehradun are not satisfied with decreasing environment quality and increasing cost of land /housing and rent of property. The research question answer is also found majority of residents are satisfied with infrastructural conditions and socio-cultural effects with the growth in Dehradun. To conclude, Architectural style of the residential areas is changing; to accommodate the increasing requirement of housing agricultural and open areas are converting into residential colonies. The architectural style the city residence planning from horizontal planning changes into vertical planning because of shortage of land in Dehradun. The apartments and group housing is now a day in trend in the city. In the research the architectural model is built for the future prediction and if the growth / built up areas in the city will be increased with the same rate then Dehradun will totally lost its natural beauty.

- Restrict unplanned and uncontrolled development of the city and to prepare a guideline for future development.
- Focus on the environment friendly built structures.
- New innovative design permitting in which multipurpose use of spaces to accommodate the increasing population.
- A national level database should be prepared to keep record / monitoring of land uses/ land division to achieve proper utilization of space can be achieved.

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RESIDENTIAL NEIGHBOURHOOD ASSESSMENT IN THE CITY OF ABU DHABI AND AL AIN, UAE WITH FOCUS ON OUTDOOR THERMAL COMFORT (OTC).

Lindita Bande[1]*, Anwar Ahmad[1], Mouaz Mohamed[1], Yosan Asmelash[1], Kholoud Mohamed Howaishel Alsereidi[1], Afra Saeed Hamad Alnuaimi [1],

[1] Department Architectural Engineering, United Arab Emirates University, Al Ain, UAE
lindita.bande@uaeu.ac.ae ; 202070051@uaeu.ac.ae ; 700036565@uaeu.ac.ae ; 201950001@uaeu.ac.ae ; 201801385@uaeu.ac.ae ; 201810183@uaeu.ac.ae ;

ABSTRACT

Abu Dhabi and Al Ain are two important cities of the Emirate of Abu Dhabi, UAE. They have gone thru major increase of the built environment over the last 50 years. These changes impact the development of neighborhoods, especially residential neighborhoods. The morphology of this urban blocks also impacted the heat island effect (UHI). UHI is one of the contributors to climate change. Therefore, having sustainable neighborhoods means reducing the UHI and make cities more livable.
The methodology to be followed in this study is as per the below steps:

- Residential blocks in Abu Dhabi and Al Ain
- Analysis of current conditions & Proposal for UHI reduction thru different strategies
- Modelling and Simulations
- Create and analyze the models in Rhino Grasshopper
- Findings and results

The aim is to divide the work for the two cities and then analyze the current conditions of the neighborhoods. Based on the findings different strategies can be applied in the residential blocs in order to reduce the surface temperature of the streets and buildings, therefore reduce the UHI effect. This strategies consider urban shading devices and trees. Having sustainable neighborhoods has a direct impact in making cities more livable and improving the climate change. The main tools to be used are rhino/grasshopper. Thru advanced software, the findings can be optimized and contribute to more sustainable neighborhoods.

Keywords: residential neighborhood, hot arid climate, OTC, rhino grasshopper, sustainable city.

INTRODUCTION

Abu Dhabi, the capital of the United Arab Emirates, is a fast developing city. It is the largest emirate, where it reaches 972 km² (375 sq mi) in the area and 2.91 million in the population (*SCAD GeneralPublications*, no date). It features a hot-dessert climate, which characterizes intense sunny summers and mild winters. Rian is rare, but humidity is alternatively high during the year. There are few days of rain per year in an average, and several weeks of dense fog when the season change. The southern part of the emirate is passed by the Tropic of Cancer; therefore, it falls within the tropics. However, its dry climate is far to be classed as tropical. (Birge *et al.*, 2019)

The city has expanded in the last decades from the main island towards the suburb. The downtown is a mix of high rise, mid-rise, low-rise building. Meanwhile the spread towards the airport or towards the Baniyas area is mainly low rise. In Abu Dhabi, 55% of the urban landscape is villas neighborhood (single dwelling), and it remains the main preference in GCC (Birge and Berger, 2019). Most of these neighborhoods are homes for local Emiratis who form 19% of the total population of the emirate. Some of these neighborhoods' houses were built in the nineteens, and their façades are characterized by small windows inserted inside the wall This has been changed in the new buildings since it has been noticed that homes built post-2000 have full glazed façades.(Bande, Cabrera, *et al.*, no date) However, UHI (Urban Heat Island) values have been increasing due to the excessive use of cars in the main island. Also, the building typology and design contribute to this phenomenon. The air condition units in many occasions are located in the ground floors. This increases the heat between the buildings making the surface temperature in the city higher than the suburbs. (Ali, Alawadi and Khanal, 2021). In that regard, the Abu Dhabi authority has developed plans and enacted policies to provide the groundwork for the sustainable development of the city (Brković and Milaković, 2011).

AL Ain has been a transiting location in the region with the contribution of the oasis and the low humidity, elements that cooled the temperatures during the harsh summers. Al-Ain is noted for its infrastructure, which is mid-rise and low-rise building typology (Haggag and Hadjri, 2005) (Yagoub, 2004). The most notable elements of the infrastructure in the city are the roundabouts that connect the neighborhood to the main street network. Currently, due to the expansion of the city the roundabouts are being replaced with traffic light. Due to several points of attraction, Al Ain has become a tourist destination for residents in UAE but also from outside the county. (Eid and Elbanna, 2018) (Bande, Manadhar and Marpu, 2019).

The urban heat island effect is a form of heat buildup phenomenon that occurs in metropolitan areas because of human activity and urban building design. This happens when natural areas are replaced with densely packed heat-absorbing structures, pavement, and other surfaces. This raises the cost of energy consumption, material flow, energy flow, heat-related illnesses, mortality, and air pollution. The urban heat island effect is caused by solar radiation being absorbed by the built surfaces of tall buildings, concrete structures, roofs, and streets, and then being released as heat. Built-up areas with higher heat energy levels from the surrounding environment are referred to as "urban heat islands. (Mirzaei and Haghighat, 2010)(Bande *et al.*, 2019)

The urban heat effect is influenced by several factors. One factor that plays a role is the reduction of the amount of natural landscape in an urban area to a minimum. Shading can be provided by vegetation, water features, and trees, making the region colder. However, in an urban area, sidewalks, roofs, buildings, roads, and parking have a dry, hard surface, resulting in less shade and moisture from natural landscaped areas, resulting in a temperature rise. Another influential factor is the properties of the material; compared to trees, flora, and other natural surfaces, ordinary human-made materials utilized in urban settings have low reflectivity and a high heat energy output (Makvandi *et al.*, 2019).

Referencing to a study on the UHI in the downtown Abu Dhabi, there are several factors contributing to the continuous increase for the heat in cities. The goal of this study is to use a calibrated model to highlight the effects of suggested energy efficiency improvements on a villa and to show that, owing to the importance of the urban heat island effect, the model must be run using urban weather data rather than rural weather data to be correct. (Bande *et al.*, 2021)

This research aims to analyze the cities separately, the current conditions of the selected districts, make the modelling of the various strategies and have results analyzed in order to define the best strategy to improve OTC. These strategies consider urban shading devices and trees. This study is a continuous work from a previous research done for the city of Abu Dhabi (Bande *et al.*, 2019).

METHODOLOGY

The research follows a simple methodology where each phase is connected to the other in a linear form. The study starts with the neighborhood selection and assessment, then weather analysis of both cities, the modelling thru rhino, and simulations thru rhino, grasshopper. The aim is to understand the district physiognomy and the connection to the surface temperature, solar radiation, and the impact on Outdoor Thermal Comfort (OTC) thru the measurement of UTCI (Universal Thermal Climate Index). By applying two main UHI mitigation strategies such as shading devices and trees, it can be defined which strategy might be more effective for specific neighborhood typology. This study is a continuation of a previous study that analyses the impact of such strategies in the city of Abu Dhabi. The two strategies are selected based on the most used urban planning elements in the UAE (Bande, Guerra Cabrera, *et al.*, no date).

Case Study Selection

The districts selected located in the main island of Abu Dhabi as well as in Yas Island and in the development of the inner desert area. Since the city expanded from the main island towards the desert on the eastern and southeastern side, four out of 6 selected districts are taken from the main island. Based on the literature review the UHI phenomena is notable in the city center, therefore most of the neighborhoods are taken from downtown Abu Dhabi. The building distances among each other and the internal areas between the buildings vary. Table 1 gives a description on the current conditions of green and shading structure of this selected neighborhood. The district 5 and 6 are low rise corresponding to most of the neighborhood physiognomy build in the expansion of the city of Abu Dhabi towards to the desert.The selected case study are 6 districts located in the city of Al Ain. Since the city center has also a mix of building typology between mid-rise and low-rise, the districts are selected from various areas of the city. The typology is low rise and midrise Buildings. Table 1 shows the districts main characteristics.

Table 1: Districts Details

District	Building Typology	District Area m2	Green Area/ Number of trees	Shading Structures
Abu Dhabi City Districts				
E-10 East Al-Dana	High-rise Mid-rise	240538.41	3 trees	N/A
E-11 East Al-Dana	High-rise Low-rise	228650.71	13 trees	N/A
Al-Nahyan	Mid-rise	128110.19	37 trees	N/A
Al Mamoura	High-rise	255834.91	35 trees	3
Yas Acer's phase 01	Low-rise	131185.32	112 trees	13
Al-Falah	Low-rise	237930.36	327 trees	N/A
Al Ain City Districts				
Mreifa compound complex	Low rise	58,105.34 m²	11	n/a
Al Radi Street	Low rise	91,480.27 m²	46	n/a
Jebel Hafeet complex	Low rise	4.52 km²	10	n/a
Al Mada	Mid-rise	24,062.25 m²	10	n/a
HBZ Stadium Area	Mid-rise	187,645.1 m²	120	3
New look medical center	Mid-rise	249,259.45 m²	65	n/a
Mreifa compound complex	Low rise	58,105.34 m²	11	n/a

UAE Climate

In the UAE the climate tends to feature a desert climate having cool winters and hot and dry summers. It has a hot and dry climate with humidity which comes from the Persian Gulf. The climate is characterized as hyper arid in general. Different bioclimatic zones exist inside the country. In compared to the southern and western regions, the north-eastern portions have higher mean precipitation rates and lower temperatures. The climates of the UAE are comparable to those of other parts of Arabia, with low mean precipitation rates and rising mean annual temperatures from Kuwait and Riyadh to Dibba and Muscat along a north–south gradient [6] The daily average temperature in the capital city of Abu Dhabi, the capital, fluctuates from 18 degrees Celsius in January (so we are at the border between the subtropical and tropical climates) to roughly 35 degrees Celsius in August (*Data sources - Climate-Data.org*, no date)

Abu Dhabi climate is more humid than AL Ain city doe their geographical location. Abu Dhabi is a coastal city and AL Ain is a desert city.(*Al Ain climate: Average Temperature, weather by month, Al Ain weather averages - Climate-Data.org*, no date)

Modelling and Simulations (2020 Graphs)

The district selection was done based on the relevance location. The models of this districts were difficult to find in free online forums, therefore the packages were purchased from GIS website. The initial scale of the district taken into analysis was scaled down due to the time consuming of the simulations and the irregularities of the geometries. The simulation in this study refers to the base case where the solar radiation in the street surface is analyzed, and the case with applications of shade in the main streets and inner districts courtyards. Rhinoceros 3D- Rhinoceros, often known as Rhino or Rhino3D, is a three-dimensional CAD program.(*Rhino - Grasshopper - New in Rhino 6*, no date)

Grasshopper- The Grasshopper visual programming language is used in the Rhinoceros 3D application. Grasshopper is generally used to create generative algorithms in the form of boxes and arrows; boxes are considered as entities, while arrows are used to indicate interactions between them. (Qingsong and Fukuda, 2016)

There were several flaws in the file, including the fact that the 3d models were mostly for non-residential buildings, and those for residential areas were inaccurate in some cases and had to be remodeled; additionally, it was difficult to locate neighborhoods in the model because it didn't specify locations or have any labels, and select a specific building/s; and it was difficult to locate neighborhoods in the model because it didn't specify locations or have any labels, and it was difficult to select a specific building/s. The scripts were easy to run at times and took hours at other times; it all relied on the GPU strength of the computers used. To sum up, grasshopper may be able to use the various results offered in this paper in their research. Figure 1 shows Python language script for the solar radiation simulation. Figure 2 shows the model of the low-rise neighborhood and buildings in grasshopper. Figure 3 shows the plan of the models in rhino grasshopper.

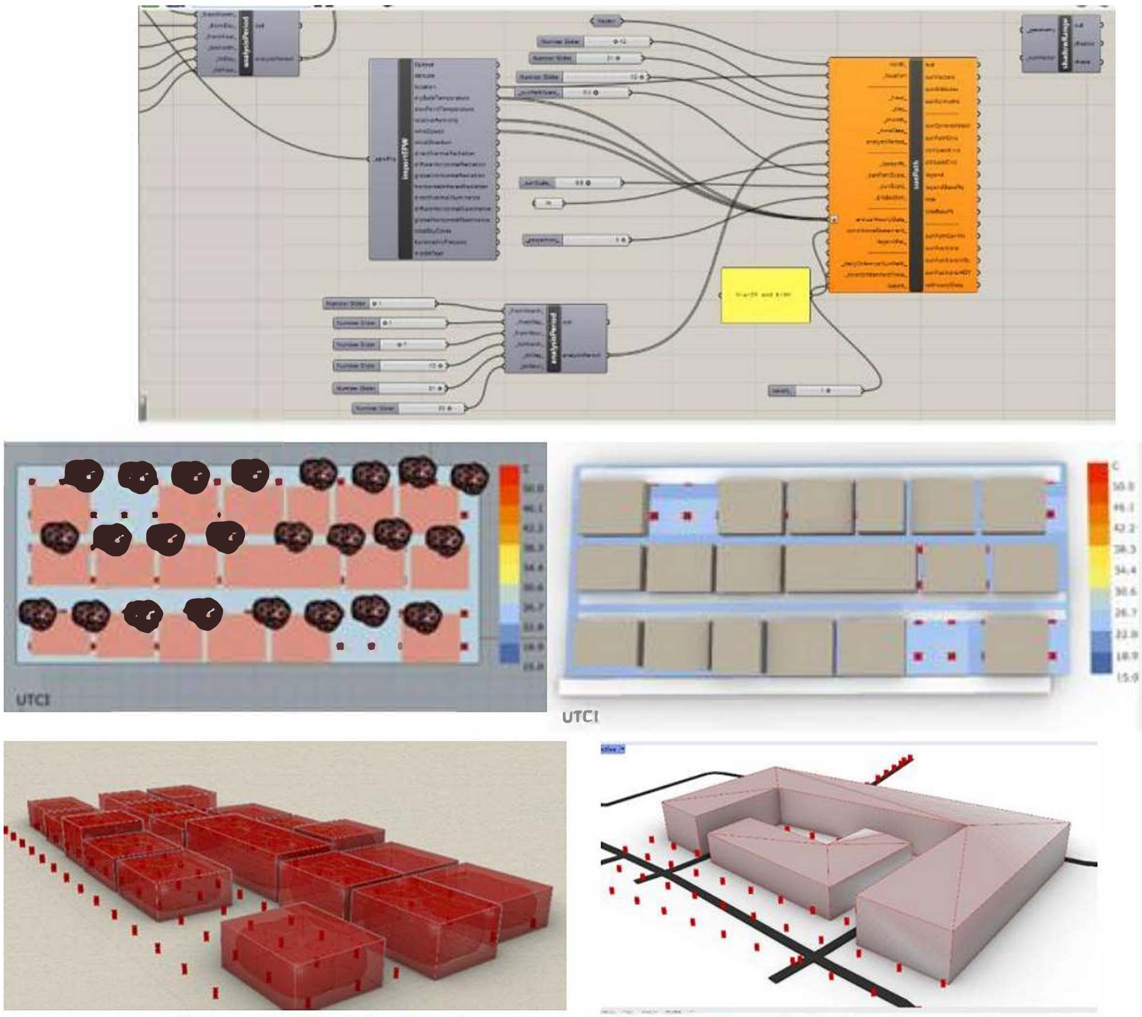
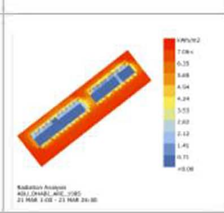
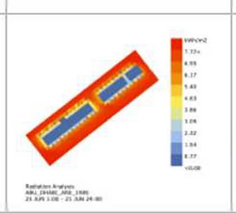
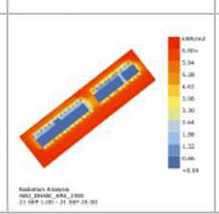
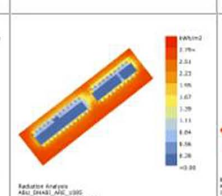
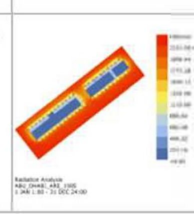


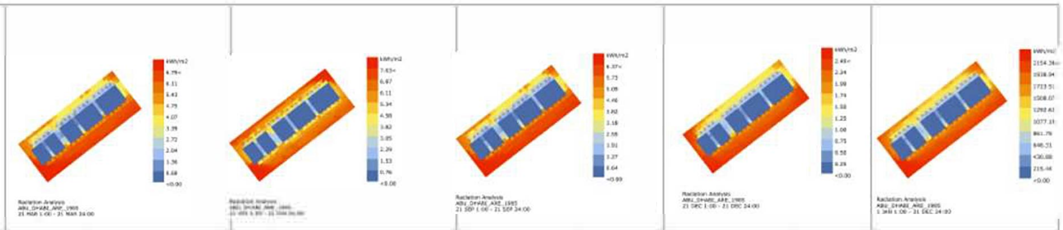
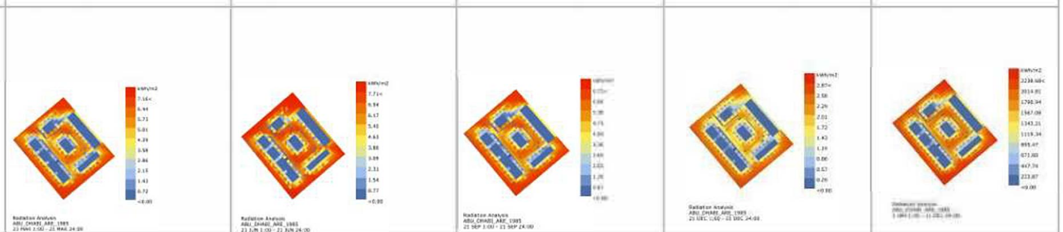
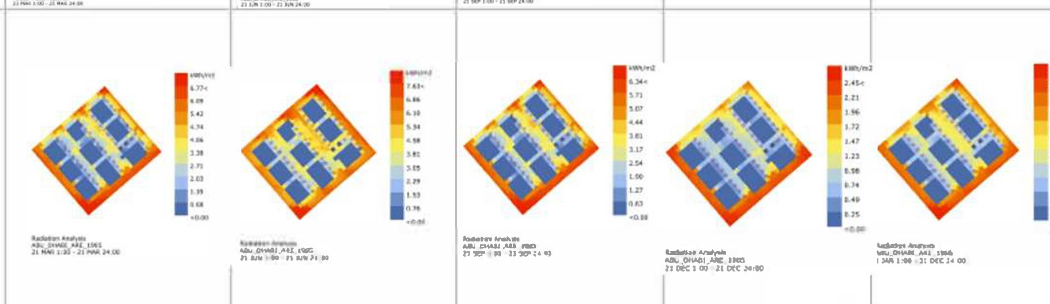
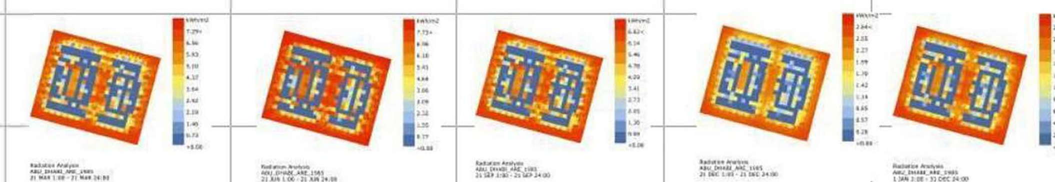
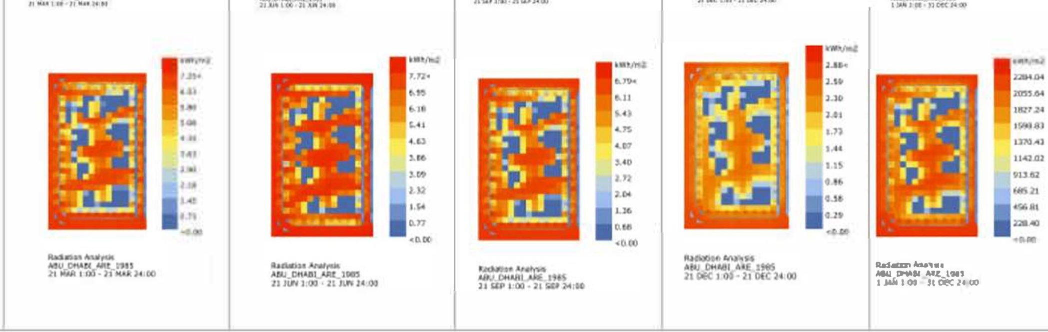
Figure 2. Model of the low-rise neighborhood and buildings in grasshopper.

RESULTS

The results of this study are shown in the tables below. Table 1 refers to a graphical representation of the large-scale radiation neighborhoods analysis. Table 2 shows the small-scale neighborhoods with trees radiation analysis. The values of the solar radiation and UTCI are shown in table 5 and 6.

Table 2. Small scale neighborhoods with trees radiation analysis.

District	March/21	June/21	September/21	December/21	Yearly
E-10 East Al-Dana					

E-11 East Al-Dana	
E-20-02 Al-Nahyan	
E-25 Al Mamoura	
Yas Acer's phase 01	
Al-Falah	

The difference in color it can be observed that the shaded and trees scenarios have colder colors (blue tones) compared to the base scenario. However, table 5 shows the solar radiation and UTCI values for Abu Dhabi. Table 6 shows the solar radiation and UTCI values for Al Ain. As it can be noticed from the values, there are changes on the yearly values. Even though the values might seem low, if a specific month is analyzed (in this case March as the month that represents the change of the season from the winter to summer) then the values are significant. For the city of Abu Dhabi: The biggest impact in reducing the solar radiation based on the yearly values is the Yas Acer's phase 01 neighborhood, values move from 1269.01 W/m2 to 1124.53 W/m2. This refers to the base case and the trees scenario.

Followed by Al Falah District with values that change from 1219.49 W/m2 to 1091 W/m2. In this case we refer to the base case and the shaded scenario. Meanwhile for the UTCI the best value in terms of decreased value refers to Al Falah district with a form of 0.3 Degrees Celsius. Yas Acer's phase 01 neighborhood follows with a drop of 0.2-degree Celsius bases on average yearly value referring to the tree scenario. Both these districts are low rise. For the city of Al Ain: The biggest impact in reducing the solar radiation based on the yearly values is the HBZ stadium neighborhood, values move from 779.5 W/m2 to 478.9 W/m2. This refers to the base case and the trees scenario.

Followed by Al Mada complex with values that change from 939.4 W/m2 to 690.6 W/m2. In this case we refer to the base case and the shaded scenario. Meanwhile for the UTCI the best value in terms of decreased value refers to Mreifa compound district with a form of 4.2 Degrees Celsius. HBZ stadium neighborhood, follows with a drop of 3.1-degree Celsius bases on average yearly value. Both these districts are midrise. Mreifa compound has low rise buildings. These values refer to the trees scenario.

Table 5. Solar radiation and UTCI values for Abu Dhabi.

District	Parameter	Base Case		Shaded Scenario		Trees Scenario	
		March	Yearly Value	March	Yearly Value	March	Yearly Value
E-10 East Al-Dana	Average Radiation	85.39	1109.09	79.55	1034.23	78.97	1024.11
	Average UTCI	24.70	29.20	24.57	29.08	24.58	29.09
E-11 East Al-Dana	Average Radiation	79.62	1042.70	78.49	1023.94	77.29	1010.03
	Average UTCI	23.79	28.37	23.75	28.33	23.73	28.31
Yas Acer's phase 01	Average Radiation	97.19	1269.01	87.28	1136.62	85.67	1124.53
	Average UTCI	24.32	28.85	24.13	28.68	24.12	28.67
E-20-02 Al-Nahyan	Average Radiation	80.42	1049.01	73.40	954.40	74.56	974.43
	Average UTCI	24.34	28.87	24.23	28.77	24.18	28.72
E-25 Al Mamoura	Average Radiation	63.67	842.53	58.58	777.01	57.63	765.32
	Average UTCI	23.47	28.08	23.38	28.00	23.39	28.01
Al-Falah	Average Radiation	92.85	1219.49	82.00	1091.00	83.76	1107.82
	Average UTCI	24.97	29.45	24.77	29.26	24.67	29.17
District	Parameter	Base Case		Shaded Scenario		Trees Scenario	
		March	Yearly Value	March	Yearly Value	March	Yearly Value
Mreifa compound	Average Radiation	**83.30**	**947.60**	**66.93**	**773.74**	**78.30**	**918.00**
	Average UTCI	25.90	30.80	25.51	29.97	20.20	26.60
Jebel Hafeet	Average Radiation	77.10	932.10	79.66	936.63	65.30	796.00
	Average UTCI	26.40	30.80	25.49	30.47	25.80	30.20
Al Mada complex	Average Radiation	78.70	939.40	58.56	690.60	71.60	852.80
	Average UTCI	25.90	30.30	27.75	32.02	25.40	30.30
Al Radi St	Average Radiation	59.30	691.20	59.92	718.62	52.50	630.70
	Average UTCI	25.60	30.00	25.61	30.07	25.20	29.60
HBZ stadium	Average Radiation	67.70	779.50	70.23	820.70	40.60	478.90
	Average UTCI	25.70	30.10	25.85	30.29	20.20	27.00
New Look Clinic	Average Radiation	69.10	797.40	57.64	663.00	66.10	792.30
	Average UTCI	25.30	30.30	24.37	28.94	25.30	30.30

DISCUSSION

The focus of this study was to divide the work for the two cities and then analyze the current conditions of the neighborhoods. Based on the findings different strategies can be applied in the residential blocs to reduce the surface temperature of the streets and buildings, therefore reduce the UHI effect. These strategies consider urban shading devices and trees. Having sustainable neighborhoods has a direct impact in making cities more livable and improving the climate change. The main tools to be used are rhino/grasshopper. Thru advanced software, the findings can be optimized and contribute to more sustainable neighborhoods.

The results show that the neighborhoods respond better in term of solar radiation reduction to the trees application. This response is bigger in the city of AL Ain. It can be explained with the lack of humidity in the city. Applying trees can have higher impact in reducing UHI but also improving OTC. The yearly values are quite significant. However, more data need to be added in the processing of the results. Data such as surface temperature can be linked better to the OTC. In the city of Abu Dhabi, the most significant impact is on low rise areas, due to the large, exposed areas to the sun. However, in this city the difference between one strategy and the other is quite narrow. This can be explained due to the high humidity in the city. Adding more trees might not necessarily reduce drastically the surface temperature and OTC. The software that was used for the modelling was grasshopper and it was challenging in terms of difficulty and time consuming. However, despite the challenges faced during this study data collection, modelling and simulations, the results are relevant for the local authorities and the private sector. The impact of the strategies into the climate change is relevant. Cooling down the cities is a global mission. UAE has National Agenda in decreasing the city temperatures for Abu Dhabi, AL Ain, Dubai, RAK, Fujairah and the other cities in the country. This study is also relevant for other cities in the region such as: Doha, Manama, Riyad, Cairo, Muscat.

CONCLUSIONS

The aim is to analyze the current conditions of the selected neighborhoods in Abu Dhabi. Based on this analysis the research focus is to understand which strategy can reduce more the solar radiation on the streets of the neighborhoods, therefore reduce the surface temperature and have an impact cooling down the city. This research findings show that by applying several types of strategies the city neighborhood can have better outdoor thermal comfort and they can be more livable. The script used in this tool has an open access and can be applied from other research in the academia or in the industry. The city of Abu Dhabi is making efforts in cooling down the temperatures and this finding can be a supportive data on the strategy to be applied in a specific type of neighborhood.

The results showed that the low-rise districts have better results from both strategies applied. This can be justified with the fact that the Highrise areas have more shade on the streets due to the height of the buildings. However, the midrise districts such as HBZ stadium neighborhood also showed a positive impact in solar radiation drop based on the trees scenario. This due to the large distance among the buildings. Based on the results and discussions, further sensitivity analysis must be conducted for more realistic results. Also, information about the materials of the selected neighborhoods shall be considered to have applicable results for future improvement of districts in both selected cities. More work is need in the future in making more accurate models in mezzo scale for each block.

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ASSESSMENT AND ATTAINMENT STRATEGY OF SOCIAL SUSTAINABILITY IN EXISTING URBAN SPRAWLING EMIRATI NEIGHBOURHOODS

Baraah Hamdoon[1], Khaled Galal Ahmed[2*], Masa Noguchi[3]

[1]Architectural Engineering Dept., College of Engineering, United Arab Emirates University, Al Ain, UAE, Fax: 15551, 201770200@uaeu.ac.ae
[2*] Architectural Engineering Dept., College of Engineering, United Arab Emirates University, Al Ain, UAE, Fax: 15551, kgahmed@uaeu.ac.ae – Corresponding Author
[3]ZEMCH EXD Lab, Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, VIC 3010, Australia; masa.noguchi@unimelb.edu.au

ABSTRACT

Social sustainability is a fundamental pillar of the sustainable urban form of neighbourhoods. Most of the existing Emirati neighbourhoods were planned with sprawling urban form that have adversely affect the attainment of the principles of sustainable urbanism including social sustainability. This research aims to propose a strategy for social sustainability redevelopment of sprawling urban forms of existing Emirati neighbourhoods. The research starts with assessing the degree of the consideration of the essential principles of social sustainability and indicators in the design of a model sprawling urban form that was repeatedly developed for Emirati citizens in different cities in the United Arab Emirates. The investigated main social sustainability principles are Density, Mobility, Accessibility, and Spatial Connectivity and Integration. Al Dhaher local community located in the city of Al Ain was selected as a case study. The research adopted both qualitative and quantitative investigation tools including field observation, map analysis, and Space Syntax analysis through DepthmapX simulation software. The research investigations have revealed that only one out of the four defined main principles of social sustainability in Al Dhaher neighbourhood is partially achieved, while the remaining principles are poorly achieved. Based on its results, the study presents a six-point strategy to improve the attainment of social sustainability in the redevelopment of not only the investigated case study but rather in local urban communities in the UAE in general which share more or less the same sprawling urban form.

Keywords: Social Sustainability, Neighbourhood, Urban Redevelopment, Walkability, UAE.

INTRODUCTION

Many of today's urban neighborhoods are experiencing noticeable deterioration in quality of life and hence require urgent actions to enhance their livability and sustainability. This could be achieved through developing more sustainable urban forms that can meet various social and environmental demands including mobility, accessibility, and minimized vehicle usage (Galal Ahmed and Alipour, 2021). Sustainable urban development and specifically social sustainability are extremely contextual and vary according to the differences in the urban context. Social sustainability is dependent on the urban form design criteria of neighbourhoods but most influentially the mobility networks because they achieve both enhanced accessibility and better physical activity, and hence enhance the wellbeing of the residents (Park *et al*, 2019). A well-connected mobility network allows for efficient movement, encourages an active lifestyle, and enhances social integration (Bartoon, 2000). Recently, the United Arab Emirates (UAE) has adopted sustainable development in all its development plans, especially Emirati citizens' housing development. Accordingly, many ambitious sustainable urban development initiatives have been launched such as ESTIDAMA rating systems for sustainable built environment and the UAE's announced local Sustainable Development Goals 2030 Plan (The Official Portal for the SDGs in the UAE, 2022). As a result, several recent housing schemes have been developed in a more sustainable manner (Galal Ahmed, 2017). But unfortunately, in the meantime, the large stock of existing Emirati housing neighborhoods has been largely developed in sprawling urban forms resulting in various environmental, social, and economic sustainability-related problems for local communities. Associated with low population, dispersed and car-dependent development, and the lack of mixed land-use, urban sprawl is unsustainable development that harmfully impacts social sustainability of urban communities (Bhatta *et al*, 2010). The vast catchment distances between houses and locally provided amenities on urban sprawl has led to reduced accessibility and confined social interaction (Pendola, 2017). In addition, sprawling urban forms have damaging effects on human health such as obesity and chronic diseases (Everything Connects, 2014).

RESEARCH QUESTIONS AND METHOD

As mentioned above, the majority of the existing Emirati neighbourhoods were conventionally designed based on sprawling urban forms, low population density, and almost full dependence on private automobile transportation. As this is expected to adversely affect social sustainability in these neighbourhoods, the research posed two questions. First is "*how socially sustainable is the urban sprawling form of Emirati existing neighbourhoods*". This was answered through assessing the status quo of the degree of achievement of the main four social sustainability principles of Density, Mobility, Accessibility, and Spatial Connectivity and Integration, in a representative case study of these conventionally designed neighborhood. Second question is '*what is the strategy that might be applied to enhance social sustainability attainment in these neighbourhoods*'. This was answered through the outcomes of the social sustainability assessment for the selected existing Emirati neighborhood case study of Al Dhaher neighbourhood located in Al Ain City (Figure 1). The neighbourhood was among the early designed and developed Emirati citizen's neighbourhoods in the UAE. This proposed strategy is anticipated to be applicable to all neighbourhoods with similar urban contexts in the UAE and maybe also in other Arabian Gulf countries.

Completed by the early 2000s, Al Dhaher neighbourhood is a good representative model for the repeatedly developed sprawling urban forms in the UAE and it presents a good opportunity for defining a strategy for potential more socially sustainable urban redevelopment. To undertake these investigations, an appropriate theoretical framework for the defined social sustainability principles and indicators was first developed based on relevant literature and local guidelines. Afterwards, the appropriate qualitative/quantitative assessment tool(s) for each indicator was assigned. Among these tools are design drawings analysis, satellite maps analysis, and field observations recorded through photographs and notes during site visits. Space Syntax spatial syntactical analysis quantitative tool was also utilized through DepthmapX software to measure the indicators of mobility (specially walkability), accessibility, and spatial connectivity and integration. This analysis is conducted using the Axial Map of Al Dhaher neighbourhood developed by AutoCAD 2021analysis. The Accessibility was evaluated through the Metric Step Depth analysis (Dettlaff, 2014) while the Spatial Connectivity and Integration were measured by the integration indices on both global and local levels according to the defined catchment distance radii (Xia, 2013).

MAIN PRINCIPLES OF SOCIALLY SUSTAINABLE URBAN NEIGHBOURHOODS

Density: Density is an essential aspect in defining a neighborhood's social sustainability and urban livability (Bibri *et al*, 2020). It could be defined in multiple formats including the number of residents, dwellings, or the built-up area, on one unit of land (hectare, acre, etc.). An important density measure is the Floor Area Ratio (FAR). It is estimated through dividing the total built-up area over the overall development site's area (Lehmann, 2016). Appropriately dense urban development would minimize automotive reliance and contribute to more sustainable nonmotorized means of transportation. Bartoon (2000) recommended the gross population density of 40 to 50 pph as an appropriate population density. The combination of various housing types, such as single-family houses and apartments, will secure a healthy social mixture that could support the different services in a neighbourhood, its public spaces, cultural events, and mass transportation.

Residents can enjoy the best standards of quality of life if high-density houses are located near the center of the neighbourhood, where most neighborhood's local amenities are provided, and low-density houses are located further away. In this way, all residents can enjoy walking easily to places where they can casually encounter their neighbors and buy their daily needs (UAE Well Residential Communities Manual, 2019). Moreno *et al* (2021) pointed out that the consideration of suitable density in neighbourhood planning will aid in defining the optimal number of people and their appropriate local services and utilities.

Mobility: A socially sustainable neighbourhood encourages efficient modes of mobility such as walkability, cycling, public transportation, for accessing services on short excursions. The dependence on private automobile in existing neighbourhoods could be resolved when people embrace walking and cycling culture and this would in return require rethinking the current mobility networks to create more walkable and bikeable streets (Moreno *et al*, 2021). Sustainable mobility would also promote a healthier lifestyle for the residents helping them avoid obesity and chronic disease (Weng *et al*, 2019). With comprehensive well-designed mobility networks, residents will have equality in accessing all locally provided amenities. As defined by Galal Ahmed and Alipour (2021), both macroscale walkability measures including the numbers and types of the local amenities and their walkable distances, and the microscale walkability standards of urban design features that contribute to the creation of a pedestrian-friendly environment, should be achieved in walkable neighborhoods. The appropriate catchment distance between any dwelling in the neighbourhood and the local facilities and transport nodes should be within a range of 350 m to 800 m (Bartoon, 2000). Moreno *et al* (2021) assumed that the essential neighborhood facilities should be located close to its center to be easily accessed by residents in less than 15 minutes on foot or by bicycle. According to Labdaoui *et al* (2021), the appropriate consideration of walkability microscale measurements in the design of pedestrian walkways helps to make them more comfortable for walking. These include primary facilities like ramps and sidewalk widths, as well as encouraging features like lighting posts, sitting benches, soft and hardscape landscaping, and traffic signs and road markings for cyclists and pedestrian zones (Abu Dhabi Urban Street Design Manual, 2017).

As for neighborhood's mass transport, the implementation of social sustainability entails minimizing automobile reliance and encouraging the use of public transportation. In this regard, Abu Dhabi Urban Planning 2030 asserted the importance of the integrated mass transit for the residences. Transit stops and stations shall be located such that they are easy to access by foot in close proximity to the higher-density areas. Appropriate walking distances and catchment areas for the various public transport modes range from 350m for buses and light rail transit (LRT) to 500m for metro stations (Abu Dhabi Urban Planning Council, 2015). On the other hand, to reduce the reliance on private cars and to achieve safe mobility, the internal streets must be planned to have reduced speeds of up to 30 km/h, and traffic calming measures must be provided to reduce the speed of private cars and ensure safety for pedestrians and cyclists (UAE Well Residential Communities Manual, 2019). In addition, car parking should be exclusively allowed to residents of the neighbourhood near their dwellings. Meanwhile, essential parking lots should be provided for all users including people of determination with multiple access points for pedestrians to reduce walking distances with shading structures (Abu Dhabi Urban Planning Council, 2014b).

Accessibility: Common measures of the socially sustainable urban form include liveliness, response to residents' needs, and easily accessible services and facilities. Accessibility refers to these places being within walking distance and accessible by dedicated, appropriately designed, and safe to use sidewalks and bike lanes. Accessibility implies that the locally provided services and utilities be evenly distributed and be accessible for all (Galal Ahmed and Alipour, 2021). Hence, the presence of accessible amenties is a necessary factor to support convenience, health, social life, and belonging (Moreno *et al*, 2021). Centers of neighbourhoods are usually considered as the best locations of a wide range of clustered retail, office, and cultural and community facilities. A neighborhood center should be within a range of 5 to 10 minute walk, which serves the convenient needs of the local community. Meanwhile, the District Centre and Sub-regional Centre should provide higher order amenities (Abu Dhabi Urban Planning Council, 2014). As per the UAE

Well Residential Communities Manual (2019), a socially sustainable medium-density neighbourhood is expected to have the minimum types of locally provided facilities located within the appropriate catchment distance.

Spatial Connectivity and Integration: In socially sustainable neighbourhoods, small clusters of dwellings usually create a well-connected mobility network that allows pedestrians to walk directly to their destinations through well-connected streets and pedestrian walkways. Studies have shown that closely connected streets are necessary to motivate people to walk and be physically active. Spatially connected neighbourhoods usually have a good quality of life for their residents because they enhance comfort and reduce the inconvenience caused by the burden of daily mobility (UAE Well Residential Communities Manual, 2019). In addition, residents can rely on services provided in nearby neighbourhoods if those neighbourhoods are well-spatially connected (Alipour and Galal Ahmed, 2021). The more integrated a street and/or alley space is, the more movement it would have. This enhances movement and choice while enabling diverse areas of the neighborhood's urban design to serve a mutually supportive function (Carmona *et al*, 2003). In general, spatial integration and connectivity are estimated according to social gatherings and the provided commercial services (Adi *et al*, 2020). The spatial integration value is an effective indicator of predicted residents' movement within a neighbourhood.

Table 1: Developed framework for the essential social sustainability principles in neighbourhoods.

Principles	Indicators	Measuring tools
Density	Estimated gross population density to be within 40 to 50 pph. Mixture of housing types. Local provision of daily amenities, services and facilities in the neighbourhood center.	MA MA MA, FO
Mobility 2.1 Walking	Appropriate and connected pedestrian lane. Shaded, well-lit and pleasant pedestrian routes leading to transport nodes, services, and facilities. Safe and clear pedestrian lanes. (min-width of pedestrian lane 3.5m - max width 7.5m) Ease of access to public transportation facilities, community facilities, public open spaces. Provision of Services and facilities within suitable catchment distance.	MA FO FO SS MA/ SS
2.2 Cycling	Appropriate and connected cycling and scooter lane Shaded, well-lit and pleasant pedestrian routes leading to transport nodes, services and facilities. Ease of access to public transportation facilities, community facilities, public open spaces. Safe and clear cycling lane. (Min-width 2m – max width 4m) Provision of Services and facilities within suitable catchment distance.	FO FO SS FO MA/ SS
2.3 Public Transportation	Transit stops and facilities shall be accommodated within the streetscape according to the DMAT requirements (see DS-108 ADPRDM). Availability of affordable and reliable public transport system that provides access to the neighbourhood, district and city centers. Accessible and connected transport corridors and nodes (350m catchment distance).	FO FO MA/ SS
2.4 Private Vehicles	Calmed Street traffic inside the neighborhood. Set speed limits for higher density urban areas (e.g., 30km/h)	FO FO FO

	Provide sufficient parking for all community facilities accessible for all users, in accordance with DoT standards and PRDM landscaping and screen requirements.	
Accessibility	Ease of access and strong connection to/ between all community facilities with suitable catchment areas. Provision of integrated uses connected to public and private transportation systems. Consider safe, convenient, and well-designed walking and cycling lane access to amenities for all ages and physical abilities.	SS SS FO/ MA
Spatial Connectivity and Integration	Dwellings integrated with amenities and local facilities Spatial connectivity with the adjacent neighborhood	SS MA

Legend: MA= Map Analysis, FO= Field Observation, SS= Space Syntax by DepthmapX

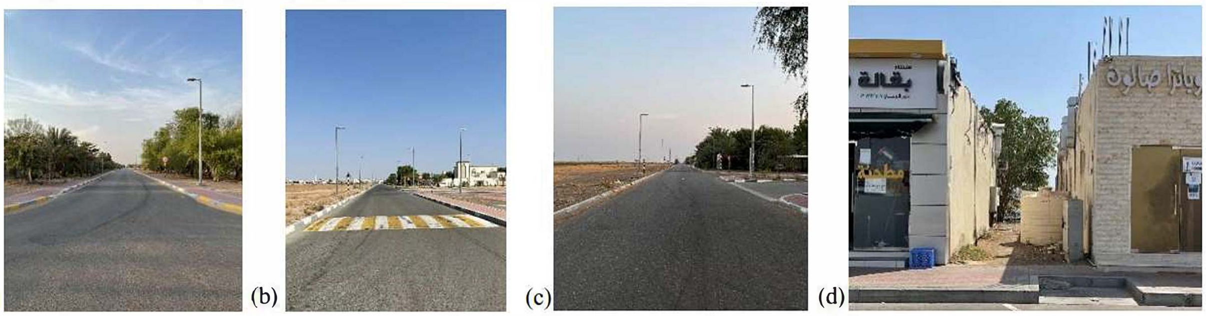
SOCIAL SUSTAINABILITY ASSESSMENT OF AL DHAHER NEIGHBOURHOOD

Density: Developed on a total area of about 285 hectares, Al Dhaher Neighbourhood contains 460 two-story single family housing plots with an area ranged between 45 × 60 m and 45 × 45 m each arranged in clusters of 10 to 16 plots congregated around semi-public open spaces (Figure 1). The neighbourhood accommodates about 3312 resident with a gross population density of about 11.02 pph. Therefore, it is far away from the ideal gross population density of 40 to 50 pph, as suggested in the first indicator in the theoretical framework. On the other hand, with its noticeably low FAR of 0.11, the urban form of the neighbourhood is significantly sprawled with a very low compactness ratio. In addition, the neighbourhood has only one standard typical house plot size with limited variations in built up areas. So, it lacks a mixture of housing types as the second evaluated indicator of the Density principle. The third investigated indicator was the provision of local amenities in the neighbourhood center. Currently, the locally provided amenities included a school and a kindergarten, a clinic, 10 mosques, outdoor physical exercise spaces, and retail shops distributed within the neighbourhood and on its outer fringes. On the other hand, the neighbourhood center and semi-public spaces within housing clusters still significantly having many vacant and undeveloped areas with no community facilities as shown in Figure 1. This analysis indicates that the principle of Density in the neighbourhood is 'Poorly Achieved'.

(a) (b)

Al Dhaher School

Mobility: While pedestrian sidewalks are present in the main streets, but the pedestrian realm is not sufficiently well-designed as evidenced by the satellite map analysis and as supported by field observations. The sidewalks lack many walkability microscale design factors for a safe, comfortable, well-connected, and well-maintained pedestrian realm. Shading trees planted by residents were noticed in some areas only within the neighbourhood (Fig. 2 a, b, c).

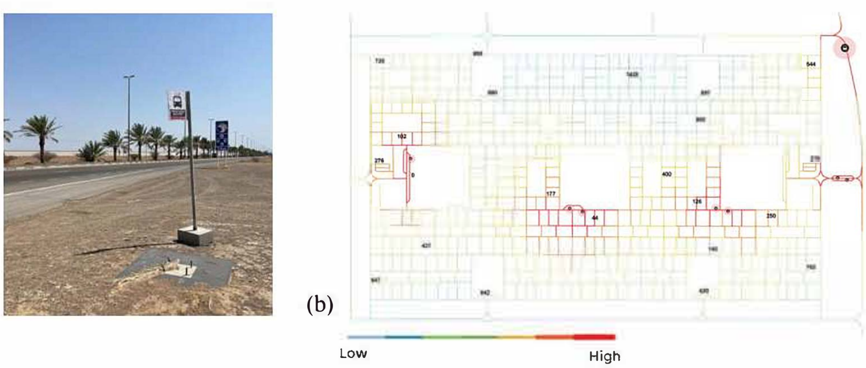


(a) (b) (c) (d)

Figure 2. (a, b) Main streets, (c) Secondary streets, and (d) *Sikka*.

The width of most of the sidewalks ranges from 1.5 to 2 m. Meanwhile, the internal secondary streets (Fig. 2) lack clear pedestrian lanes with almost no traffic calming measures. As illustrated in Figures 2, the 3 m to 9 m wide alleys (*sikkas*) are not pedestrian-friendly as they are poorly lit and occasionally blocked. The wide *sikkas* are mostly used as car access. Furthermore, the neighbourhood lacks networks for cycling. Unfortunately, the affordable public bus transit for Al Dhaher neighborhood does not cover the whole neighborhood with its only 8 bus stops. One bus stop is located outside the neighborhood and the rest are distributed within the neighbourhood in the main streets. Conducted field observation showed a total absence of safe and well-designed bus stop infrastructure (Fig. 3a) as the design does not follow the requirements of the Abu Dhabi Public Realm Design Manual. Moreover, through the Step Depth and Angular Segment analysis in the Space Syntax's DepthmapX urban simulation tool (Fig. 3b), it is evident that more than 80% of the dwellings are not located within the appropriate 350 m catchment distance. The highest value given to the street segments of the nearest points/distances to the bus stops ranges from 0 to 450 m, while the lowest value ranges from 460 m to 1435 m. So, one could claim that the urban form of Al Dhaher neighborhood is not considering encouraging mass transportation usage. Field observations indicated that the absence of efficient traffic calming measures allowed many drivers reach speeds over 30 km/h. In addition, car parking spots are widely spread in the neighbourhood especially near the local amenities, thus they encourage the private cars usage. So, the principle of Mobility is "Partially Achieved".

(a)



(b)

Figure 3. (a) A Bus Stop in the main street (b) Step Depth Segment Analysis: Bus-Stops distances to residents in Al Dhaher neighbourhood.

Accessibility: Step Depth Angular Segment analysis was utilized through DepthmapX to assess the values of walkable distances for different amenities within the neighbourhood (Fig. 4). The highest value of segments is marked in red, and the lowest value of segments are marked in blue.

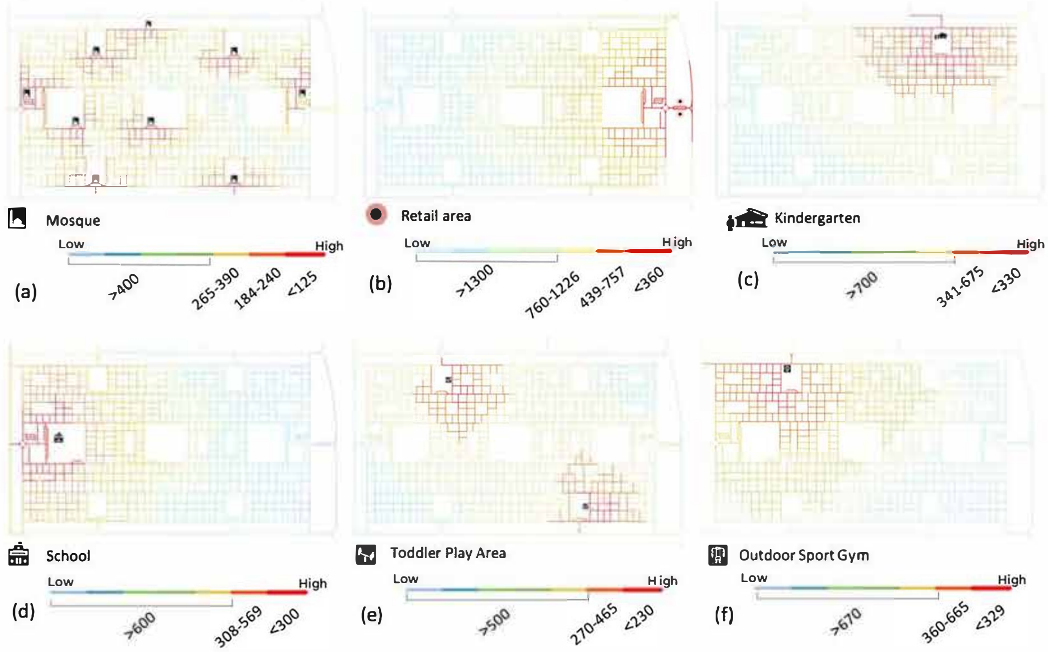


Figure 4. Step Depth Segment analysis: The accessible distance for: (a) Mosques, (b) Retail areas, (c) Kindergarten, (d) School, (e) Toddler Play area, (f) Outdoor Sports Gym.

As shown in Figure 4a, only mosques are mostly located within the 800 m catchment distance. Figure 4b shows that more than 50% of the dwellings are not within the appropriate walkable distance for the retail areas (shops, library, cafes, cafeterias, groceries, etc.). Meanwhile, more than 60% of the dwellings are not located within the 350 m catchment distance for the kindergarten. Also, about 40% of the dwellings are out of the walkable distances of 800 m for schools, as illustrated in Figure 4d, and about 50% of them are not within the Toddler play area catchment distance of 350 m. Fig. 4f indicates that about 70% of the dwellings are not within the walkable distances of 350 m for the outdoor sports gym. Field observations showed that many street alleys are unpaved and poorly maintained. So, it is concluded that spatial connectivity and integration principle is "Poorly Achieved".

Spatial Connectivity and Integration: The DepthmapX 'Integration' analysis indicated that the neighborhood's street network had a significant degree of spatial connectivity in the secondary streets (Fig. 5).

Figure 5. Spatial integration (global Integration) of Al Dhaher neighbourhood street network.

The Integration-Rn analysis map for the whole neighbourhood shows that the secondary street on the west, east, and south sides have higher levels of global integration. Additionally, the main retail area on the north side is not totally integrated, with the main streets near the principal local services and amenities having low Integration values. Field observations and map analysis affirmed that the neighbourhood still have several undeveloped lots and limitedly provided amenities in numbers and types in the center. Also, map analysis disclosed the lack of integration and connectivity between the neighborhood and its adjacent. So, with some exception, the spatial connectivity and integration principle is "Poorly Achieved".

DISCUSSION AND CONCLUSIONS

This research initiated and applied an assessment method for the main social sustainability principles in Al Dhaher neighbourhood as a repeatedly developed sprawling urban form in the UAE with the ultimate goal of establishing tailored strategies for better attainment of social sustainability in existing sprawling urban neighbourhoods in the UAE. The applied assessment method was guided by the initiated theoretical framework encompassing the indicators of four main principles of social sustainability of Density, Mobility, Accessibility, and Spatial Connectivity and Integration in urban communities. The Case Study research method with the relevant mixed qualitative and quantitative investigation tools were utilized in the assessment of the defined indicators and principles. The analysis of the defined social sustainability principles and indicators, as detailed in the conceptual framework, has revealed that Mobility is 'Partially Achieved', while the other three principles; Density, Accessibility, and Spatial Connectivity and Integration, have been found to be 'Poorly Achieved' in the investigated urban sprawling neighbourhood.

Based on the investigation results, a set of recommended strategies/guidelines, that aim to enhance the attainment of social sustainability in the investigated and other similar neighbourhoods, has been developed in Table 2. The recommended actions encompass measures for enhancing density, land use, connectivity, and modes of mobility, particularly walkability and cycling. The improper distribution of uses has deprived large areas in the neighbourhood from amenities. So, infill land use can increase density in communities and is considered the most generally recommended action (Galal Ahmed and Alipour, 2021).

Table 2. A suggested strategy for realizing social sustainability in UAE's sprawled neighbourhoods.

	Design Strategies/ Guidelines	**Recommended Action**
1	Increasing density	Implementing an infill technique to take advantage of undeveloped plots/lands (increasing the FAR and the gross population density to be from 40 to 50 PPH)
2	Redefining the land-use plan	Providing an appropriate locational distribution of a combination of essential local services and amenities
3	Diversifying mobility modes	Adding cycling (bicycles & e-scooter) infrastructures Improving pedestrian network Improving access to public transport nodes
4	Improving accessibility	Reconsidering access of people of determination, elderly, children, etc Improving quality of services and public facilities Enhancing walkability and bikeability from dwellings to the educational, and recreational facilities
5	Enhancing the urban landscape	Reducing the impact of high outdoor temperature by shading strategies Improving pedestrian walkways design Improving street furniture (setting benches, etc.)
6	Diversifying Amenities and services	Diversifying services Improving quality of services

Moreover, introducing more commercial uses would result in higher numbers of pedestrians in the streets and thus would create a vivid public realm. This type of actions aligns with the goals of enabling more mixed-use development through extended commercial activity venues (Lerman and Omer, 2013).

Therefore, the infill approach entails redefining land use, which is a fundamental pillar of the urban form design that should be addressed when planning for neighborhood urban regeneration (Abu Dhabi Urban Planning Council, 2014). As a result of the inconsistent distribution of amenities and the quantity of locally provided facilities in the investigated neighbourhood, a recommended locational (re)distribution of the amenities and their required quantities is detailed in Table 3.

Table 3. Number and locational (re)distribution of accessible essential local services and amenities.

Type of Amenities	**No. of amenities within Al Dhaher Neighbourhood**	**More Needed No. of amenities in Al Dhaher Neighbourhood**	**Distribution in the site** (Edge, Center, Mixed)	**Max. catchment distances (m)**
Daily Prayer Mosque	9	-	Mixed	500
Grand Mosque	1	-	Center	1000
School	1	-	Center	800
Kindergarten	1	3	Edges	350
Community Park	0	1	Center	800
Toddler Play Area	2	5	Mixed	350
Outdoor Physical Exercise area	1	6	Mixed	350
Grocery	14	-	Mixed	600
Cafeteria	10	-	Mixed	800
Pharmacy	1	2	Edges	800
Library	1	2	Edges	800
Retail	11	-	Center	350
Clinic	1	-	Edge	800
Beauty Center	0	2	Mixed	800

In conjunction with the preceding actions, the integration of mobility networks and the improvement of their infrastructure would reduce travel lengths and encourage nonmotorized modes of transportation. Diversified and accessible forms of transportation would be required to achieve a socially viable regeneration of this and other similar sprawling urban forms. Urban regeneration for existing neighbourhoods to be more socially sustainable cannot be achieved without genuine and early community participation in the design and construction processes. This, as Pozoukidou and Chatziyiannaki (2021) claimed, would lead to more appropriate decisions that fit the specific social sustainability aspects of local communities. All in all, the application of the assessment process rendered it successful in evaluating the investigated principles of social sustainability in a way that could made it a reliable intended assessment method for all similar urban development contexts within the UAE, in other Arabian Gulf countries, and maybe in the Middle Eastern ones as well. Finally, it should be acknowledged that despite the selection of one representative existing neighborhood, this might not convey the whole picture about social sustainability in this sprawling urban context and hence in further research, investigating a larger number of neighbourhoods would allow the research findings to be more representative and generalizable.

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SUSTAINABLE MITIGATION MEASURES TO COUNTER CHALLENGES IN URBAN AREAS

Indra Kumar Singh[1], Aaditya Pratap Sanyal[2]

[1] Associate Professor, Department of Architecture, Planning & Design, IIT (BHU) Varanasi, Varanasi, Uttar Pradesh, indra.apd@iitbhu.ac.in
[2]Assistant Professor, Department of Architecture, Planning & Design, IIT (BHU) Varanasi, Varanasi, Uttar Pradesh, apsanyal.apd@iitbhu.ac.in

ABSTRACT

An urban ecosystem faces multiple challenges. These challenges arise from various factors like growing population, emerging technologies etc. Over the past couple of decades, both the above-mentioned factors have been grown up with a high pace. But, at the same time, we need both things for generating more economy. Which means, along with this development we need to find out the solutions for the growing & upcoming challenges. There has to be a team to identify and tackle the challenges. The team shall include people from various sectors like Government departments, design & planning sectors and stakeholders. In the following sections, the various measures to mitigate such challenges will be discussed. Few parameters can be incorporated with existing urban scenario such as Incorporation of agriculture and farming in urban areas, Amalgamation of various stakeholders, Making People Empathetic, not just the Cities Smart, Use of innovative new materials for smart infrastructure etc.

Keywords: Urban Design, Architecture, Technology, People, Cities, Systems level Thinking, Ecology

INTRODUCTION

'Urban'- a word with complex folds and layers. Until recently, several Metros used unitary services such as cycle rickshaws, telephone booths, single-screen cinema halls etc. which are now transformed or connected into more wholesome products or service ecosystems. It includes everything needed for easing better living in developing & developed cities. It is development in all those areas, which makes human life more convenient whether it is social, personal, professional, food, transportation, communication or entertainment. It supplies deepest comfort and convenience through design and development. In effect, urban development is a step towards more technologically and holistically advanced lifestyles. This advancement creates more opportunities to earn and in doing so attracts the rural population to be in an urban area with its shining lifestyle. To cater to this, a large brigade of people & systems is needed, who work continuously and in tandem to run the entire process of serving and supporting the urban cities. For e.g., Metro trains, public transportation, the staff of multiple governing offices, municipality, housing societies, cinema halls and shopping complexes etc.

Apart from all these, many people play think tank behind all these developments & systems, who designed these entire infrastructure, buildings, and products. They are Architects, Urban Designers, Urban planners, Town planners, Industrial and Product designers, and Engineers of various backgrounds. All these people work hard to create a better future. However, many unforeseen challenges arise from time to time due to growth and upcoming changes. These challenges need to be resolved in due course so that healthy, resilient, and convenient urban cities are supported and sustained.

CHALLENGES OF GROWING URBAN CITIES

There are multiple challenges faced in an urban area, most of which are driven either by population or emerging technology. With increased humans arriving in search of better lives and job opportunities, urban populations are growing on an everyday basis. About population-driven challenges, an obvious but important challenge is that of an over-burdened infrastructure that is expected to cater to every individual's or family's needs. With a daily growing population and continuously increasing demands of social and urban life, the city's existing systems such as Sewage, Road/ Rail networks etc. are overloaded every single day. This subsequently leads to failures and breakdowns. To support and keep these systems running, they need to be upgraded from time to time or redesigned completely.

Technology is also growing extremely fast. To support modern technology, new systems must be implemented every few years. For e.g., earlier there used to be copper wires for the internet and now there are fiber-net cables, which need to be laid throughout the city. In doing so, the copper wire becomes obsolete waste. For upcoming technology like 5G or higher, Urban planners may need to find new ways to incorporate towers. All these replaced items are becoming non-decomposable or non-biodegradable wastes. So, this e-waste is also becoming problematic for urban areas.

Few more challenges are listed below:

- Financial inequality in urban society
- Lack of affordable dwellings
- Less use of public vehicles
- Low importance to pedestrian & cyclist while designing the road networks
- Lack of public toilets on roads
- Lack of garbage disposal system
- Lack of social awareness in citizens towards basic rules like traffic rules, garbage segregation etc.
- Problem faced by utility vehicles in emergencies like ambulance, fire tender etc.
- Lack of greeneries like trees so facing imbalance in nature
- Low importance to all the other animals & birds creates an imbalance in the ecosystem

Apart from all the above-mentioned challenges, there is one which is the most important need of human life, is arranging food. Food is most important human need which is dependent on farming which is almost absent from the urban areas. Mostly, while picturing an urban area, it is imperative to imagine buildings, cars, road networks, and metros etc. but farming and agriculture is never considered as an element, which does not fit to overall schema.

Most urban development focuses on the comfort of humans but without consideration to flora and fauna. In the race of development, most of the ecologies that are supportive of animals and birds are ignored leading to extinction. Their food, shelters are reduced and many of them face serious trouble for their existence due to recently developed technologies like mobile towers. To keep the ecosystem, the balance of nature is particularly important.

PROBABLE SOLUTIONS TO THE CHALLENGES

To create a sustainable urban ecosystem, Government authorities and think-tanks of urban planners, architects & designers are already doing an excellent job by creating good infrastructure for support and service system like smart city projects, solid waste disposal and many other things. There are a few parameters, which need to be highlighted and designed to create a self-sustainable urban city. These parameters will also be probable solutions to the challenges noted in the earlier section. The parameters are discussed in the following section.

Think Self Sustained: Incorporation of Agriculture and Farming in Urban Areas

In an urban ecosystem, agriculture and farming are a highly neglected part although these should be integral to make it sustainable and keep the balance of nature. To create a sustainable urban ecosystem, it is important to have urban farming and to create shelter and food for birds and animals as well. Given the lack of space for traditional farming methods, innovative solutions need to be developed as an offset. Once, cities can cater to their basic needs by itself, it will truly become a sustainable urban area. The locally grown food is also the best for the consumers because it has all those nutrients needed to survive in the best way in that area. So, the concept of "locavorism" can be promoted by local urban farming.

In recent times, many innovative methods of farming have been developed, which require less space and provide more supply. The basic idea of all these techniques is to grow vertically or in multiple layers due to lack of open ground.

Few of the methods include:

Verti crops/ plantscapers: Vertical farming can be done on the facades of high-rise buildings, which in turn provides vegetable/ fruit supplies to its residents.

Hydroponics: this is a method of soil-less farming in which plants are grown in liquid nutrient solution or moist inert materials like *Rockwool* or *Vermiculite*. This can be done in multiple layers in a protected covered environment, so more production can be achieved in less space and the crop can be protected from the natural calamities as well.

Figure 1 Hydroponics
Source: created by Lastspark from thenounproject.com

Aquaponics: this method is like hydroponics, but it also allows the raising of aquatic animals like fishes, crabs etc. in the same farm. Fishes are raised on the bottom layer of a multilayer system & crops gets cultivated in the in a liquid nutrient solution in the above layers.

Aeroponics: this is also a similar technique, but the base of the plants is air or mist environment instead of liquid.

Also, we need to encourage the use of newly emerging technologies in farming like *GIS, GPS agriculture, agricultural sensors* and other farming software. These will help to understand the climatic conditions in advance. The newly emerging techniques in the farming which will lead towards a better production of crops & forms a sustainable, resilient urban city with its farming capabilities.

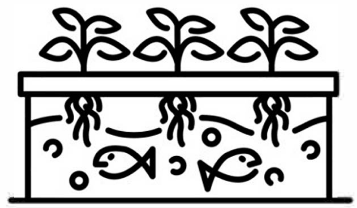

Figure 2 Aquadroponics
Source: created by Jonata Hangga from thenounproject.com

All Hands-on Deck: Amalgamation of the Thought Leadership of Urban/ Town planners, Landscape Architects & Product Designer

It is high time for more experts to work together so that a better world can be created with the advice of experts from various fields. To create sustainable ecosystem landscape architects can supply suggestions to protect the growth of flora & fauna. They can also suggest the way of using landscape in the footpath and road networks. Industrial/ product designers can design many things about the public space which will help to form a more livable city like street furniture, manhole covers, street/ footpath gym etc. They can also suggest the use of modern technologies & materials to design these products. By bringing together the minds of several experts or think-tanks, a more livable & sustainable urban city can be formed.

Figure 3 Meeting
Source: created by Eko Purnomo from thenounproject.com

***Smart cities, Smarter Inhabitants: Making People Empathetic, Not Just the Cities* Smart**

As of now, the Government has already proposed the development of smart cities in terms of infrastructure upgrades. But if the end-user would not be using it correctly, the result will not be achieved. For e.g.: in a recently developed area, the bicycle track was formed on both edges of the road and painted in a distinct color, but most people mistook it as a parking space. This may not have happened if the people knew its purpose in advance. So, it is especially important to make residents aware of the rules, signs of smart infrastructure & repercussions of not using it correctly. Also, most citizens are reluctant to follow traffic rules which are also an extremely dangerous situation. This needs to be inculcated in the mind of citizens from an early age. It can be achieved through regular workshops, seminars; surveys etc. and be part of the syllabus of schools.

Green Wave: Plant More Trees as per the Suggestion of Landscape Architects

Most of the cities are facing the problem of pollution nowadays. Many things like the use of electric vehicles, control on industries etc. can reduce this, but in a long run, it requires more trees to produce more oxygen. Few of the best oxygen supplier trees are *Banyan, Peepal, Jamun, Neem, Saptparni, Arjuna* trees. Planting these trees will not only increase the supply of the oxygen, but it also supplies shelter to many birds and tries to form the balance of nature.

Figure 4 Smart City
Source: created by Rasama studio from thenounproject.com

Figure 5 Green City
Source: created by BomSymbols from thenounproject.com

Footpaths: Multiuse and Transformational Spaces

In any city, the footpath is an integral part of the road network. It allows the pedestrian to walk and houses many things like a bus shelter, garbage bins, plants, trees, small shops etc. The multi-functional purpose of the footpath is particularly important to acknowledge. In the daytime, it acts as a pathway to pedestrians and in the night, it becomes a bed for the homeless. Therefore, it can be designed in a way that the homeless can survive in at night. Bus shelters may be designed to supply a shelter in the night even on a nominal charge basis. At many places, there are open gyms at footpaths, which is a good initiative. India is a country, which supports many smaller unmanaged economic sectors which provides skeleton to many low-class income segments. Footpaths are key to such small merchants to supply quick shop front and is of ease to passerby. Thoughtful consideration to such indigenous models and respecting them as part of the overall system-level design will help to shape better cities.

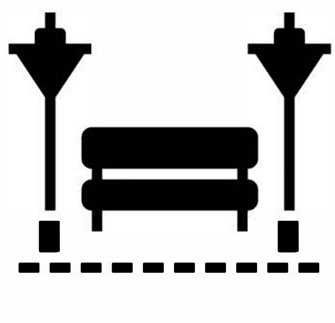

Figure 6 Pavements
Source: created by Eucalyp from thenounproject.com

Popularize Pedestrian Systems & Bicycles

As of now, most of the roads are motor vehicle friendly. However, these should be friendly to pedestrians and bicycles too. A smart city can only be developed by supplying equal weightage to all the user types. This will also curb pollution to a certain extent.

Sensitive and Convenient: Public Transportation

It is also a common sight in an urban area to see many people driving alone in their big cars to work. This only leads to chaos & pollution on the road along with consuming fossil fuel quickly. To promote the local public vehicles like bus, metros, local trains etc.but these vehicles should have reached to most of the areas so that people can commute easily with fewer friction points in overall journey. This can be achieved by studying the patterns of the commute from one part of the city during working and non-working days. Heavy vehicle movement can also get defined based on the location of important amenities and keeping the interaction to both public and commercial to a minimum.

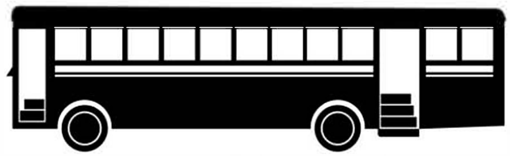

Figure 7 Public transport bus
Source: created by Octopolabs from thenounproject.com

Explore: Use of Innovative New Materials For Smart Infrastructure

To build a sustainable city, new materials & technologies need to be adopted like nonbacterial materials for public furniture. Garbage crushers can be installed in the inlet of drainage systems to avoid sewerage jam. It can be made functional with solar power. More use of solar power should be promoted. One of the best examples is the airport of Kochi, which is fully running on solar power. Besides, smart electricity meters and sensors should be used in the buildings that save a lot of electricity & energy. Use of the devices like *computers, mobile* with ***biodegradable sensors*** (technology is under development) will help the environment to cut down the e-waste.

Intelligent Technology: Design the Technology-Related Infrastructure in a More Useful Way

Design of the infrastructure related to technology like mobile network towers is also very important. Heavy heightened towers are placed over the top of multistoried buildings. This height achieves a high latency to supply cellular network. High latency means the number of towers will be lesser and one tower caters to a larger area. Sometimes network problems arise due to high latency. The recent technology 5G performs better in low latency i.e., there will be a greater number of small towers present in an area. Also, 5G technology requires lesser energy than its earlier generation and it provides faster internet with lesser energy consumption. Less energy consumption means saving of energy, less emission of greenhouse gases etc. To support the low latency, few objects like streetlight can be converted into the 5G mobile towers, which will be smaller than current towers & provide better network & internet with low energy consumption.

Figure 8 Technology
Source: created by SBTS from thenounproject.com

Culture-Driven: Happy Playful Cities

Playful and happy means engaging, and engagement brings care. If inhabitants become more caring and careful about the streets of the cities they live in, stronger connections for healthier communities will be built. Playful moments in the streets— from graffiti, to a group of kids playing in the water from a broken pipe to the hustle-bustle of the street vendors supporting the local economy on a street corner. The journey of helping playfulness in the streets can design the right conditions for the mindful use of amenities and public services in the city. Happy cities require courage, build trust, allow for discovery, and create communities. Playfulness is fundamental to social nature, so it is a useful framework for thinking through to build stronger cities and communities.

Figure 9 Happy People
Source: created by Gan Khoon Lay from thenounproject.com

CONCLUSION

It is assumed that by the year 2050, more than half of the country's population will be urban inhabitants. So, building a sustainable urban city is an emergency need for the present. To achieve this, humans' basic (food) and advanced needs (like internet) must be fulfilled to make parity with emerging technologies together. With the methods & ideas suggested above, it may be possible to achieve a better city up to a certain extent. But it is not only the job of thinkers to create a sustainable town; it is the job of the inhabitants as well. If a system is not be used correctly, it will collapse soon. It is imperative that technology in every field is used to educate the residents. We all together will be able to build a sustainable, resilient urban city, which will be able to fulfill all the needs of the residents by itself.

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A SOCIO-ECONOMIC PERSPECTIVE ON COMMUNITY RESILIENCE AND SOCIAL SUSTAINABILITY DURING THE COVID-19 PANDEMIC: THE CASE OF GUJRI MARKET, BANGALORE

Cecon Swain

Associate Professor, BMS School of Architecture, Yelahanka, Bangalore, INDIA, cecon.swain@bmssa.ac.in

ABSTRACT

The present paper investigates the emergence and dynamics of community resilience and social sustainability during the Covid -19 Pandemic in the Stephen's Square, better known as Shivajinagar Gujri bazaar an area full of scrap shops, huddled behind the Russell Market in Bangalore, India. The bazaar a community in itself spreads over approximately 3 sq. km, with around 600 shops generating approximately 360 tons of scrap every day. It employs more than 1,500 people, living mostly within a 3km radius and is administered by the Stephen's Square Merchants' Association (SSMA). Lack of scrapping and recycling policies for vehicles by the Indian Government before the Pandemic had its own challenges to this informal sector. The Covid 19 outbreak, lack of investment, improper coordination in the Merchant's association and poor Government Support during the pandemic has created an added socio-economic challenge and a context that instead of disintegrating the system at community level had rather facilitated self-organization and adaptive responses to the Pandemic. Emergence of new patterns of behavior, decentralized practices, learning processes and lessons gained at the community level from a temporal and evolutionary perspective have promoted an adaptation strategy that enhances community resilience for future crisis.
The investigations carried in the Gujri Market during the pandemic have employed research methods of exploratory basic qualitative study to engage in the understanding of how community level resilience and social sustainability is attained and strengthened through decentralization, self-organization and innovative practices. The socio variables of community resilience like collective efficacy, preparedness, place attachment, social trust, and social relationship have been studied along with economic resilience indexes shock counteraction and shock absorption. The study and findings aim at contributing the understanding of community resilience and social sustainability in informal sector by identifying the socio-economic resilience factors that facilitates responses to a Pandemic.

Keywords: Socio economic Perspective, Community resilience, Adaptive strategies, Gujri Market, Covid -19 Pandemic

INTRODUCTION

Historical Narrative of the City and underpinnings of the Gujri Market

Bangalore has a history of 2000 years and was considered to be founded in 1537 by a local chieftain Kempe Gowda who built a mud fort at the site. (Hasan, 1970) .The city's morphology closely corresponds to four distinct evolutionary phases—the native town (1537-1809) , colonial period (1809-1947) science & industry phase (1947-1980s) and the hi-tech phase (mid-1980s-present).The Gujri market's underpinnings can be established during the Colonial Period of the city. Around 1800's Bangalore came under the Mysore state ruled by the Wodeyar Kings with the help of the British Army who defeated Tipu Sultan in the fourth Anglo Mysore war .The pleasant weather led the British to set up the camp and established a military cantonment in the year 1806 to the North –east of the old city. The agglomeration of 15 villages developed into the cantonment and later into a city centre of 13 square miles .The single Nucleus City now turned into a twin city with distinctive characters. The Pete area catering to the Natives and the Cantonment prospered under the British with its own railway station, hospital and a municipal corporation (Willford, 2018) the expansion and development spurred civil growth and influx of various communities

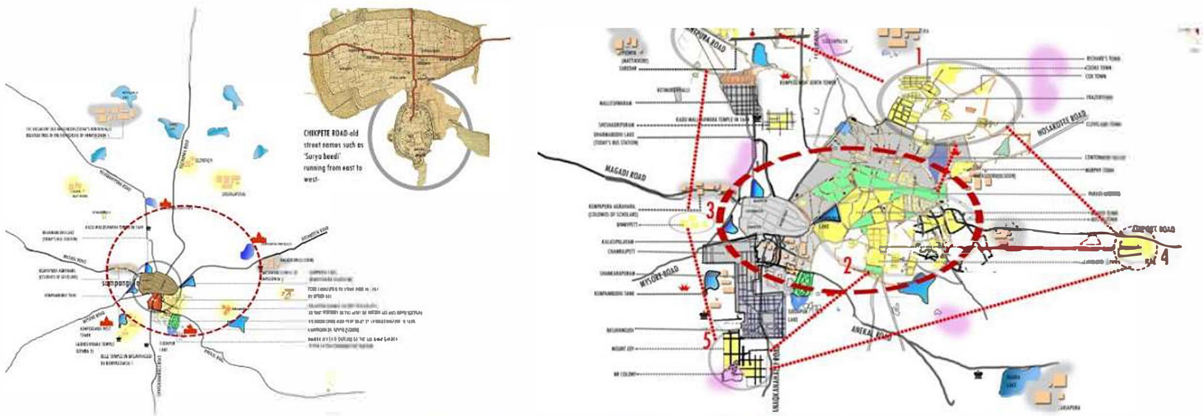

Figure 1. Reconstructed map of 1924 Bangalore map
Source: British library online Bangalore Maps & Author

The cantonment developed with wider roads and tree lined avenues .The streets were occupied by many shops and bazaars of varied ethnic communities like the Mudaliars, labbas, Kathiawaris and other merchant communities and contractors that supplied provisions and catered to British household needs. The predominant ethnic groups of that time were the Tamilians among the linguistic community and the Muslims among the religious group in the Blackpally, today's Shivajinagar area which contributed the most to the growing market. (Iyer, 2019) The Gujri Market and nearby areas was then acting as a full-fledged furniture repair market for the Britishers, as shared by Hajji Allah Baksh, 96year old who has been working in the scrapyard from 85 years at his shop in Stephan Market. The community was given due respect and was known to the Britishers by their name.

From the beginning of 1900's motor vehicles first started in appearing in the city. The predominant communities of the area around Stephan's square that nestled in the Shivajinagar explored this new opportunity and demands of the Colonials. They adapted to the market needs and then began to serve as a market for automobile repair and scrapping (Iyer, 2019). The number of vehicles were scarce in the early days and the roads were mostly dominated by horse drawn buggies and bullock carts. During the Second World War, Bangalore being far from the Japanese warships was selected as an airbase by the Britishers. Gujri Market played an important role in the scrapping of those airplanes too (Malavika Narayan, Feb 12, 2018) .The communities adapted to this demand of scrapping and the market started getting converted into a full-fledged scrapyard along with one of the major centre for all kinds of automobile parts..
The history of Gujri Market have always been constantly evolving and adapting to the market needs. Emergence of new socio-economic challenge have propagated integration of the system networks instead of disintegrating the system. At the community level self-organization and adaptive responses have been key in economic and social sustenance of the Market. The learning processes and lessons gained at the community level from a temporal and evolutionary perspective have promoted an adaptation strategy that enhances community's resilience for future shocks.

Market Dynamics of Post Independent Gujri Market

Post independent with various agencies of changes like the Technological changes in Transport ,ICT enabled markets and industrial innovation, New social networks and linguistic communities ,economic reforms , introduction of new administrative ,political and legal systems created a huge impact on these historical markets (Iyer, 2019)

Automobiles being an integral part of Bangalore city have enhanced the positioning of Gujri market not only as a scrapyard but a resource centre for spare auto parts of premium vehicles. It is now curtailed in the labyrinth of various shops catering to the automobile industry. (Malavika Narayan, Feb 12, 2018) These shops are only accessible through narrow lanes and is huddled behind the famous historical market, Russell Market in Bangalore, India. The bazaar a community in itself now spreads over approximately 3 sq.km, with around 600 shops generating approximately 360 tons of scrap every day. These shops are mostly small sized measuring 3sq mt -5 sq. mt whereas the medium sized ones are 10 sq.mt in area. The Rent tariffs averages around an amount of Rs.500/sqmt to 750/sqmt. (Darapaneni, 2021) Many Shops are inherited from the colonial times and are part of the family business. The Owners of these shops are mostly part of the joint family and the business have always been an integral part taken care by the male members of the family. The Indian society being collectivistic in nature have promoted social cohesion and interdependence and these traditional family system have been an excellent resource for economic sustenance and the capital maintenance of the Gujri market. However the society is constantly changing and one of the significant alterations is the disintegration of the joint family system and rise of the nuclear family extension system. These dynamics have also stirred the Socio economic resilience of the ever growing market systems of the Shivajinagar area. Display of social resilience indexes like place attachment and social trust have mostly been observed in the community in case of crises like the Russell Market Fire hazard or the communal tensions during the celebration of Tipu Sultan's anniversary but vulnerability indexes have never been measured or analyzed before to evaluate the socio economic resilience of the community.

The market now employs more than 1,500 people, living mostly within a 3km radius and is administered by the Stephen's Square Merchants' Association (SSMA).The Gujri market is now one of the largest scrapping market in southern India trading mostly two wheelers and four wheelers spare parts. The larger spare parts are mostly brought in trucks and Lorries during early morning or late evenings while the smaller ones are catered by the auto rickshaws who source it from various dealers that collects these from garages and scrapyards across the country. These scraps are then dismantled here, the waste is collected and the metal is sent for smelting (Malavika Narayan, Feb 12, 2018)

Figure 2.1 –The Gujri Market
Source: Author

The scrap market is governed by the Stephan square merchant association established in 1963 .It generally takes care of the cleanliness, maintenance and general ordering of the market .The shortage of spare parts for premium vehicles in Bangalore Open market have always been a concern for the owners as it increases the maintenance costs, though this was taken care by the Gujri Market, but it also started tagging Gujri Market as the Chor Bazaar (Thief Market).

The Merchant association consider this as the foremost agenda and have placed regulations for proper documentation for all the vehicles that are brought to the market for scrapping. Regular raids by the Police had previously created a perception that all stolen vehicles were channelized into the Gujri, constant vigilance and regulatory measures placed

The Gujri have always been a dynamic market system that was constantly adapting to the market needs and the community growing resilient to the market behaviors in the Pre pandemic years but these transformation have never made the market profitable and was always under constant urban stress to give away the core commercial areas for achieving better FSI in the name of urban growth and development.

The Study on Community Resilience in Gujri Market in the 2nd wave (April 2021) of Pandemic

The Pandemic and the nationwide lockdown have threatened the various sectors of the Country but the most affected was the informal sector. The Impact on Gujri market was very similar to the transformation and socio economic dynamics of Indian Bazaars. The economic impact of the pandemic on informal trading sector especially in the Gujri Market comes from the 'aversion behavior'. These actions affected all sectors of the economy and in turn, translate into lower incomes, both on the supply side (declining in the production) and the demand side. The higher concentrations of population aggravated the existing health scare, monetary concerns, poor health cover ages and lack of workplace safety stirred further social disruption in the early Pandemic phase .The 2nd wave of the Pandemic in Karnataka India started from prelockdown in 27th March to Post lockdown till 16th August 2021 (Darapaneni, 2021). During these phases one observes and analyses the adaptive characteristic of the entire community that was almost disintegrated in the early phases. In the later phases new emerging behavioral pattern is seen where the community engages and builds new networks and strengthen ties. The inherent social trust and informal social control are developed stronger.

Table 1-Timeline of Lockdown in Karnataka
Source: (Darapaneni, 2021)

Phases	State	Start – End Date	Duration (Days)	Restrictions
Pre-Lockdown	Pre-Lockdown	27 March 2021 – 26 April 2021	31	No Lockdown
Phase – 1	Lockdown	27 April 2021 – 09 May 2021	13	COVID Curfew
Phase – 2		10 May 2021 – 07 June 2021	29	Full Lockdown, Only essential services
Phase – 3		08 June 2021 – 05 July 2021	[illegible]	Night Curfew and Weekend Lockdown
Phase – 4	Post Lockdown	06 July 2021 - 16 August 2021 onwards	42	Only Night Curfew

RESEARCH METHODOLOGY

Primary descriptive qualitative datas was collected through questionnaire surveys for a sample size of 100 households to measure social cohesion and informal social control to find out sufficiency of collective efficacy of the neighborhood. The data is binary in nature . Observational datas in post pandemic was also carried to evaluate the impacts and new behavioral changes in the community Participation in various online forums to gather impacts of Pandemic in the Shivaji nagar's neighborhood. In person interviews and audio video recordings were conducted to gather datas for the research on the Gujri Market. The research conducted is exploratory in nature to identify the existing collective efficacy of the neighborhood for decentralized practices and self-organization that would have led to adaptive responses to the Pandemic

DATA ANALYSIS AND RESEARCH FINDINGS

Gujri Market provides employment opportunities to around 1500 people and their families. These marginalized community have an inherent social disparity due to varied educational qualification, employability and income status. As studied a population of approximately 6000 people are economically dependent on the Gujri Market .The study conducted during October 2021 to analyze and evaluate the Pandemic impact on the informal sector and especially on the Gujri Market generated datas that provides us an information that instead of disintegrating the system at community level, It had rather facilitated self-organization and adaptive responses to the Pandemic. Emergence of new patterns of behavior, decentralized practices, learning processes and lessons gained at the community level from a temporal and evolutionary perspective have promoted an adaptation strategy that enhances community resilience for future crisis. The community in phase 3 (08june 2021 -05 July 2021) started adopting new strategies.

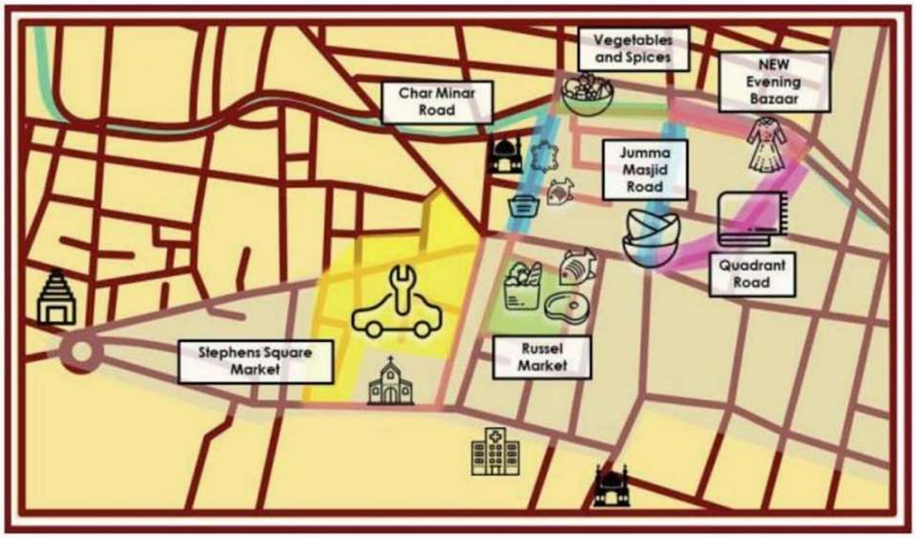

Figure 2.2 -the existing organization of various markets around Gujri market.
Source: (Malavika Narayan, Feb 12, 2018)

One observes community engagement in the early pandemic phase where the Stephan's market association intervened and provided monetary benefits to many families. It also generated funds by meeting local authorities and non-governmental organization during the progress of the Pandemic.

Self-organization in the community can be experienced. Many shop owners grouped together to create collaborated with nearby shop owners to provide essential items for daily usage .The communities of Gujri market and nearby markets around Charminar Road, Quadrant Road & Juma Masjid Road have always been a source for groceries, medicines, daily usage commodities but after the pandemic one observes stronger ties and engagement within the communities. Digitalization and demonetization during prepandemic days have been a hindrance to these communities but it helped during the Pandemic. Wattsapp groups were created for coordination of daily essentials, one also observes gender inclusivity where the women of most families interacted on regular basis to manage household needs. Networking among the community increased for improved values for community sustenance. Transfer of funds through UPI modes have increased triple fold during this time (primary data).

Table 2 .Questionnaire items used to measure social cohesion and informal social control

Social cohesion and trust	Informal social control
1. This is a close knit neighborhood	1. Neighbors would intervene if the Merchants association is threatened.
2. People in this neighborhood can be trusted	2.Neighbors would intervene if a fight broke out in front of their house
3.People in this neighborhood do not share the same values	3. Neighbors will intervene monetarily in case a nearby shop is affected by fire.
4.People here are willing to help their neighbors during medical emergencies	4.Neighbors would intervene if authorities are showing disrespect

Research conducted to identify the existing community social structure, social organization and behavior reflects strengthened collective efficacy. Which needs further investigations to define adaptive strategies of the community and its resilience index.

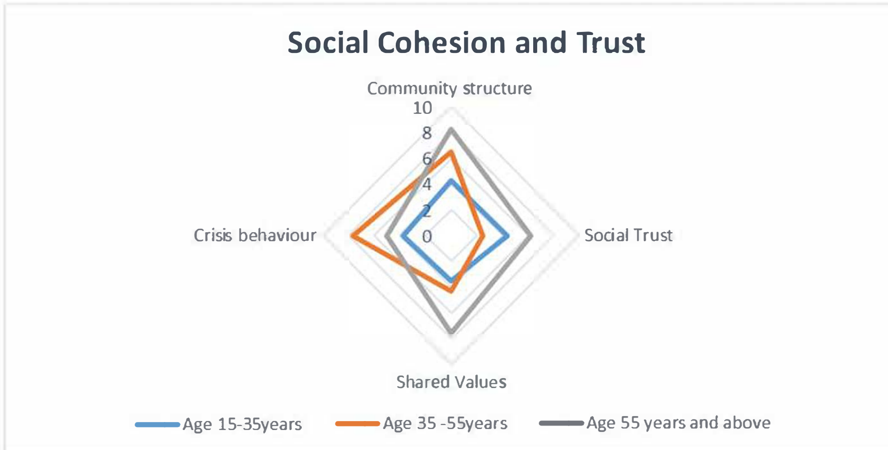

Figure 3.1

The community also have an inherent informal social control that increases during emergencies and crisis. This is indicative of the community response to sudden shocks and stress and might be a trigger response to the Pandemic. The primary data collected through interviews and questionnaire survey also reflects on the change in employability patterns. The population aged (>15years and above) who were previously engaged in the informal sector have adopted new occupation as delivery boys for the provisional stores in the neighborhood. Bowring Hospital on lady Curzon Road have been the employer for the local neighborhood through BBMP providing employment opportunities like ward attenders ,sample collectors ,Ambulance drivers and other paramedic services.

Patterns observed for economic sustenance:

1. Adaptation to digitalized mode for monetary
2. Change in employability patterns and adopting to new employment opportunities.

During the pandemic, employability and loss of job was another concern for the informal sector Monetary issues can disintegrate the integrity of a community and add more chaos to the ongoing health scare but what was observed that in the later phase of the Pandemic ,People above 15 years and with a minimum educational background and qualifications were employed as delivery agents for provisional stores who would consider them as their own delivering their own community with a minimum wage The case was not considered as child labor instead a way for the family to gain some monetary benefits for them and an opportunity for their neighbors to earn some .Adults above 20 years were mostly engaged into new job opportunities that generated during the health scare by the health facilities and Government as well as non-governmental organization. This is indicative of the communities' behavior to quickly absorb into new economic opportunities which have been historically observed in Shivaji Nagar area. The behavior pattern and adaptive responses for economic sustenance are the new lessons learnt and gained for the youth of the community.

CONCLUSION

The study suggested the Gujri market community adapts to sudden stress and shock. The Socio economic sustenance is higher in this low income groups and the informal sectors displays higher community engagement and social trust during emergencies and disasters leading to self-organizational patterns which can be indicative of adaptive behavior. Further investigation is required to measure the resilience indexes of this adaptive behavior. Collective efficacy which as a tool can be efficient to measure the social trust and informal social control and provide an insight to this community's socio economic resilience.

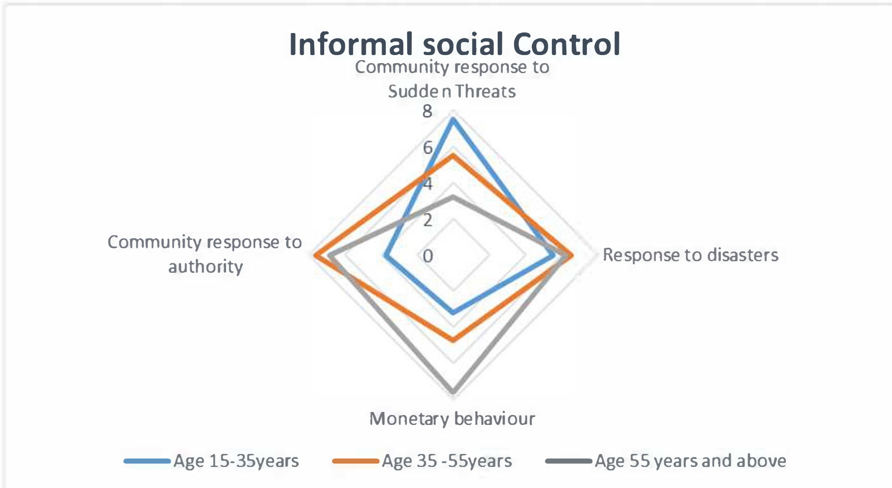

Figure 3.2

COMMUNITY SOCIAL STRUCTURE

Dense neighborhood

Residential stability

Low economic status

Ethnic homogeneity

Larger family structure

Place attachment

SOCIAL ORGANISATION

Local friendship networks and social ties

Ability to utilize digital modes during pandemic

Higher organizational participation

COLLECTIVE EFFICACY AS A TOOL

Social Cohesion and trust

Informal social control

ADAPTIVE CHARACTERISTIC OF THE COMMUNITY AND IMPLIED RESILIENCE

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CANYON STUDY: STUDY OF IMPACT OF KOCHI METRO RAIL PROJECT ON THE URBAN MICROCLIMATE OF KOCHI METRO CORRIDOR

Babitha Mohammed[1], A. Meenatchi Sundaram[2]

[1]Assistant Professor, BMSSA, Bangalore, Karnataka, babitha.mohammed@bmssa.ac.in
[2]Professor, NIT, Tiruchirappalli, Tamil Nadu, meenatchi@nitt.edu

ABSTRACT

The rapid urbanization in the developing countries have major effect on the climate of the urban areas. The urban designers and planners even though consider climate as a major element of design, it is seen lacking in many countries and in its designs. Bio climatic urban design is a necessity for a country like India as it accommodates 17.74% of the world population. And the emergence of urban heat island (UHI), usage of more mechanically ventilated buildings, degradation of ecology, extinction of flora and fauna etc. seeks the need for a greener and comfortable urban spaces. Kochi is one of the major cities in India where urbanization has taken over its land in an unbelievable pace, being Kochi Metro, its newest addition. The environmental impact assessment (EIA) of the project assess the land use, ecological impacts, water, soil, air pollutions etc., but not the climate change. The main objective is to understand the change in the street canyon of the Kochi city Metro corridor and thereby its impact on the outdoor climate. The simulation of the site is done in ENVI-met 4.4 for analyzing wind movement and solar gain and Sketch up for shadow analysis. The results from the study is used to analyze the effect of the Metro structure in the dense urban area of Kochi on the Mean Radiant Temperature and wind movement in the city, that determines the comfort conditions for warm and humid climatic zones. The design interpretation is also aimed by simulation of hypothetical conditions for different orientation and aspect ratios. This can help in achieving optimal design for dense urban center with metro rail and identify parcels of land for possible development with lesser climate interruptions. The study could be further expanded to understand the impact of urban developments on street life.

Keywords: Urbanization, Bioclimatic urban design, Canyon study, Orientation, Aspect ratio, Climate change.

INTRODUCTION

Urbanization is a trending topic of discussion all around the world, where all ideas of green architecture, energy efficiency, conservation of resources and sustainable development begins with the same. Urban areas have very recognizable climate from the rural areas now a days due to the transformation of green cover to concrete surfaces all around. The activities in urban areas are also intensive in heat emission, like the radiated heat from the concrete surfaces, human population, traffic and equipment, in turn increases the urban temperature. Development is inevitable, especially for a developing country like India, but researches proof on urban heat island of Indian cities and deterioration of urban climate due to urbanization, the situation in India cannot be denied in any circumstances (2) (19).

The local climate is affected by buildings, surface treatments, geometrics of structure, human and vehicular factors and other heat sources (1). Considering the amount of time that is spend by the people outdoor/ or in the urban areas, the study on outdoor comfort is very crucial (4). Therefore creating comfortable urban structure and outdoors have great importance. An attractive and accessible urban outdoor has many social, cultural and economic benefits. But an important question regarding the urban development is "Are the climate study and analysis considered by the authorities and designers while a proposal or design in urban areas is done?" A major reason for urban areas often becoming uncomfortable is that urban microclimate and outdoor thermal comfort are generally ascribed little importance in urban planning and design processes (16).

Urban design in warm humid climate: Canyon and Comfort

The climate of urban centers in warm humid climatic zones are characterized by high rainfall, high humidity, minimal diurnal temperature differences and lesser wind. Other than climatic factors the outdoor thermal comfort in urban areas is dependent on the physical elements of the urban spaces (13).

1. location of the town
2. density of the built-up area
3. average and relative height of buildings
4. orientation and width of the streets
5. special design details of the buildings which affect outdoor conditions
6. Design details of the open "green" areas

Canyon is deep cleft between cliffs. Urban canyon can be defined as a three dimension space form from buildings abutting the streets and the street, creating a canyon structure. The building of the urban canyons shade the streets and create thermally comfortable spaces. Orientation of the streets, aspect ratios, building projection etc. plays a major role in Urban climate comfort and can explained with the amount of penetration of solar radiation, wind flow, humidity of the region (11)(4)(13). These aspects of a well-designed street contribute to the solar penetration and shading as required, wind movement to overcome the stuffiness of humidity, thereby creating thermally comfortable urban spaces.

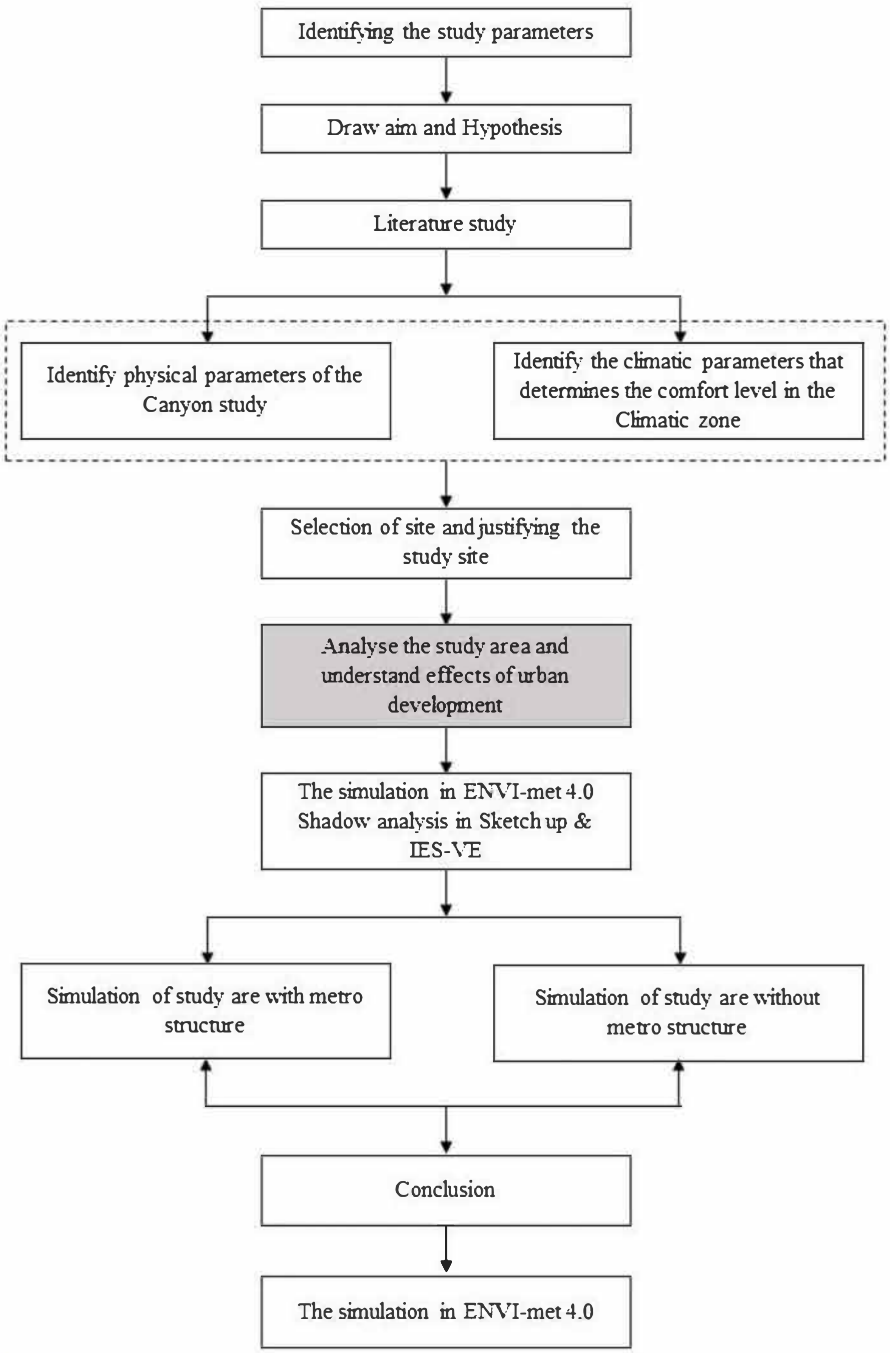
Kochi metro project

Kerala that comes in the warm and humid climate zone of India according to ECBC is one among the developing spots in India that is undergoing urbanization in an unprecedented pace with its latest addition in Kochi, the Kochi Metro Rail project. The Kochi metro project is the first metro in the country which connects major transit hubs of Kochi (road, rail and water). This has become a major part of the city and its street canyon today.

As per the environmental studies for the Metro project in Kerala, the high ground water level is a limitation for the projects to go underground. (Ground water level of Kochi: 5-15mbgl). This proves that the metro rail proposal completed and upcoming can be only above the streets, whereas metros pass through the urban density areas. As the Metro Rail in Kochi runs through the major transport line of the city becoming an interference in the street canyon of the urban area of Kochi, the upcoming developments are expected to be same. This inference in canyon of the city cause difference in the existing urban climate scenarios. But the environmental impact assessment report of the project talks about the impact of the project on the land use and green cover of the city, but not the climatic change (5). This study can help understanding the effect of the project on the climate of the city, especially on solar gain and wind movement, and it can open the scope for climate responsive design for further extension and similar projects proposals. Acknowledging the results from the earlier researches on urbanization, its impact on urban microclimate and thermal outdoor comfort, this study accounts the effect of a transit structure (metro rail) through the street canyon.

SCOPES AND LIMITATIONS OF THE STUDY

The study would open the scope of analysing the climate change in the city due to further extension in the metro project and modify the design features to provide a comfortable outdoor. And also the shadow analysis (pilot study) done in the research would provide insight of outdoor lighting and visual comfort in the urban areas. This can in fact help the designers to set comfortable outdoors and also understand its impact on social life. The extension of study further can open the scope for understanding other factor like air pollution, visual connectivity and segmentation of urban area to different levels and sections. But the current study is limited to one climatic zone and comfort determining factors like MRT and wind movement for the zone. The study has been limited to the effect of build elements and not vegetation. Also the time limit of the study restricted the data collection to summer season in the selected climatic zone.



METHODOLOGY

Figure.1: Methodology of the research **Source:** Author

SUMMARY OF LITERATURE CASE STUDY

Researches refers that thermal comfort changes with difference in solar exposure, with shaded and non-shaded areas. The shading from build structure and trees also enhance thermal comfort in urban areas. Wind speed is another parameter that determines the thermal comfort in urban area after shading. The wind direction and wind speed have the highest influence according to the street orientations. (10)(22)(15)(18).The urban geometry and topographical features alter the microclimatic conditions. The morphological factors of the city, like building height, width of the road, orientation of streets etc. along with the surface material and green cover affects air flow in the city and the heat balance of the city (9). For daytime analysis of thermal comfort, the comfort indices changes with aspect ratio (H/W) as solar radiation has more hand on the surfaces. Likewise shading decreased Physiological effective temperature (PET) value, pointing to the influence of width, height and orientation. The factors like vegetation, topography, surface materials etc. also changes the thermal comfort (15). Proper orientation of buildings and choice of suitable canyon aspect ratio provide a better thermal comfort and also improve wind flow, in turn help in dispersing pollutants (4). The permeability to wind movement and protection from sun are two major and crucial bioclimatic design strategies in warm humid climate. Wind movement is crucial in warm humid climate. The prevailing wind itself provide cooling effect in the city but the trade wind from NE and SW change the pattern of this wind movement. Controlling and directing the sea breeze into the city is the other way to enhance wind in urban areas. Solar protection is important for outdoor spaces also, by maintaining H/w ratio and the mutual shading or increasing tree in the walkways (20). Shade the city by compact planning of building and deep street canyon, but should consider wind movement and pollutant dispersion (Erik Johansson). The study prove that aspect ratio and orientation for solar access and wind shelter in winter and offering solar protection and airflow in summer (3).

STUDY AND RESULT ANALYSIS

The major site for the study is MG Road, Ernakulam, the densest area along the Metro rail stretch in Kochi. This is a mixed use area, commercial buildings along the street and residential area in the interiors with F.A.R of 2.0. The average width of the road in the study area is 15m, with average 2.5m wide footpath. The metro runs through the central line of the street, divide the street canyon to two sections vertically and horizontally. The Metro rail stretches to 9m above the street, being an urban concrete tree in the street canyon. The field measurements air temperature, humidity and wind speed were taken for two locations A and B in the Metro stretch marked in (*Fig.2)*. The data was validated with the results from simulation. The weather data are collected with the help of anemometer for wind speed at the height of 1.5m to 3m in the either selected locations in the city. The air temperature and humidity were recorded using psychrometer at the height of 1.5m.

The simulation is done for analyzing the difference in Mean radiant temperature (MRT) and wind speed in the street (At different levels 3m, 6m, 9m, 12m) with the Metro structure and without the Metro structure. The data form the site was validated with the results from simulation.

Figure 2: The stretch of MG road selected for the study (200m x 175m)
Source: Author

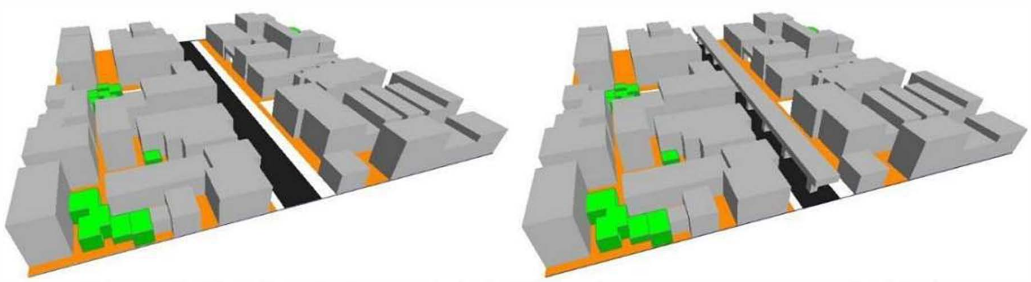


Figure 3: The Simulation models (without the metro structure and with the metro structure)
Source: Author

The simulations were carried out in the beginners version of ENVI- met. The Simulation done for 18th March 2019, 7am-7pm (12hrs). The input data were based on the meteorological data collected from internet sources and recorded data for the particular day. The temperature ranges from minimum 26°C to maximum 34°C, maximum wind speed is 4.5m/s, and wind direction North-west (135°) are the climatic data input of the simulation. After the simulation, the results were analyzed by Leonardo 2014. This helped in analyzing and comparing the results. The simulation was repeated for all four orientation and different aspect ratios and conclusions were derived based on that.

1. Simulation is done in 60 x 60 x 10 grid
2. Cell size 1dx=3m, 1dy=3m, 1dz=3m
3. The surface and the material conditions taken for the simulation is taken for the predominant conditions of the city
    - Asphalt road
    - Concrete pavements
    - Heavy concrete Metro structure
    - Moderately insulated building material

The Urban scenario considered for simulation are as follows:

1. ASPECT RATIO of the street canyon for study is 0.62
2. Total Height of Metro: 11m
3. Average Height of buildings: 15m
4. Average horizontal distance building to building : 24m
5. Orientation: NORTH-SOUTH

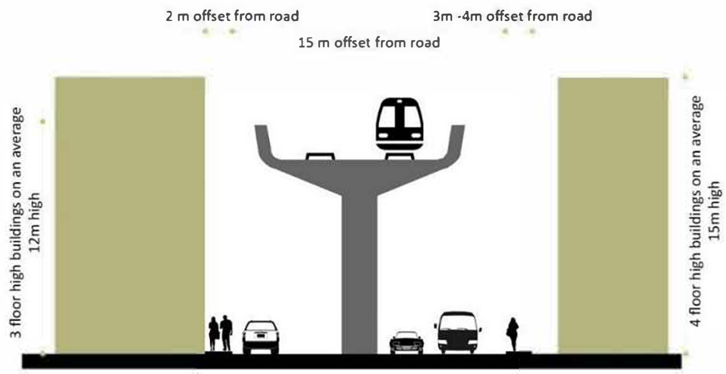


Figure 4: Street canyon and aspect ratio (H/W ratio) 0.62 for MG Road
Source: Author

Limitation with software:

The basic version of ENVI- met 4.0 holds few limitations for the simulation. Primarily the used version of the software has limited domain size of 60× 60 m grid. This version of ENVI- met does not consider change in wind speed and direction during the simulation. These parameters which were input at the initial stage of simulation are taken constant throughout the time of simulation. Also the vegetation is not considered by the Software.

Results: Validation

Validation of the data is done by comparing the parameters measured from the site and the data derived from simulation.

Location A	9.00 am	1.00 pm	5.00pm
Temperature (°C)	31.45°C	35.48°C	34.50°C
Humidity (%)	64.29%	49.76%	44.57%
Wind Speed (m/s)	0.8 m/s	0.09 m/s	0.51 m/s
Location B	9.00 am	1.00 pm	5.00pm
Temperature (°C)	33.79°C	36.39°C	34.50°C
Humidity (%)	55.03%	46.6%	37.28%
Wind Speed (m/s)	1.02 m/s	2.96 m/s	0.3 m/s

Table 1: Field measurements for the selected locations
Source: Author

The simulated air temperature shows a deviation of average 3-3.9 °C from the measured data approximately 13% and the trend of temperature change is proportionate to the measured value and the collected data. The deviation in the temperature is mainly due to the range of temperature input in the software for simulation, which is based on the average temperature of an hour in the particular day. But the measured temperature is the spontaneous temperature of the time of measurement.

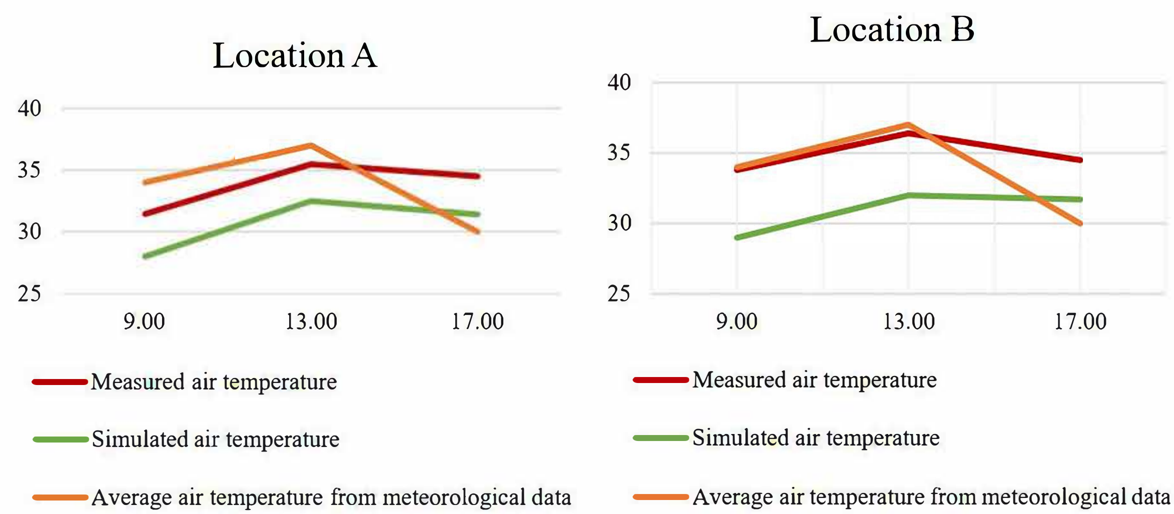


Chart 1: Comparative chart for Air temperature for Location A and B
Source: Author

Change in Mean Radiant Temperature

The major peak hours of the city with more pedestrian and vehicular traffic is 9hrs – 11hrs in the morning and 15hrs – 17hrs in the evening. The chart shows an average deviation of about 30°C in the morning and evening peak hours of the day in summer. In effect of addition of metro rail structure to the canyon of Kochi MG road has reduced the heat in pavement during morning and evening hours and heat in the vehicular path during noon.

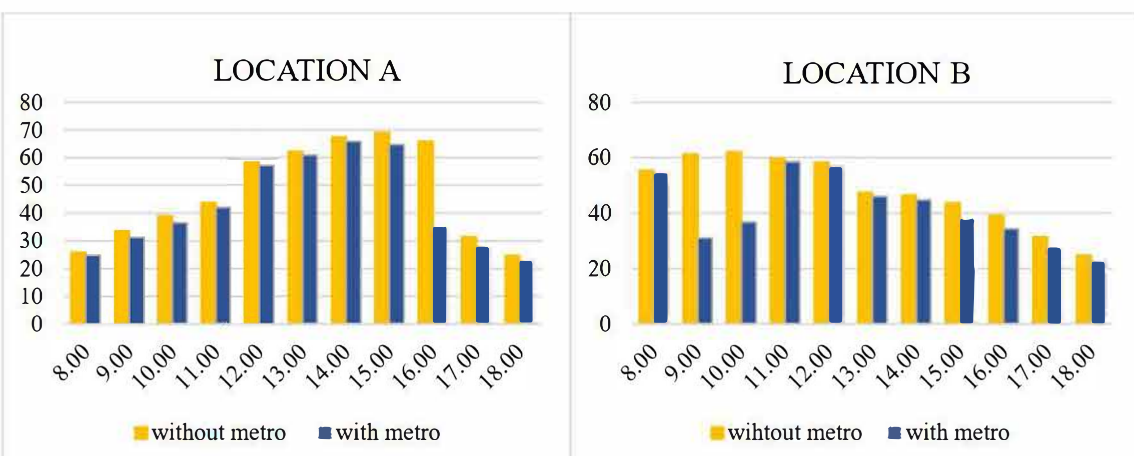


Chart 2: The Mean radiant temperature without and with the Metro rail for Location A and B
Source: Author

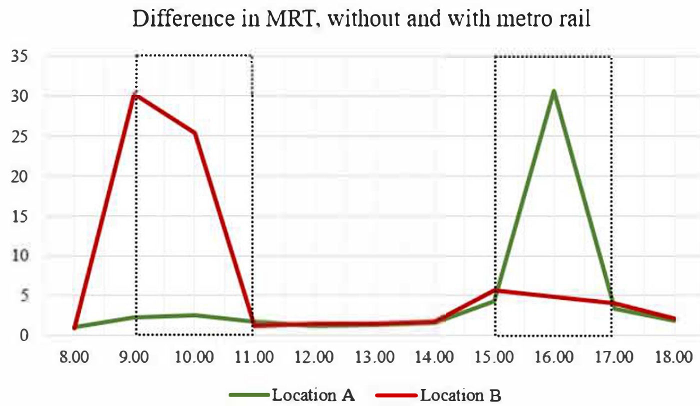


Chart 3: Difference in Mean radiant temperature without and with the Metro rail structure in the selected locations.
Source: Author

Change in Wind movement

The difference in wind speed in the study area due to the introduction of Metro rail structure around 0.8m/s to 1m/s for different timings in the urban area. The major difference in wind movement is mainly due to the compartmentalization of the street canyon by the metro structure. Though variation in difference in the wind speed for each aspect ratio is so negligible, wind speed in livable area reduces as the aspect ratio decreases (the width of the road increases), but the difference in the wind speed by the addition of metro structure is seem reduced as the aspect ratio reduces.

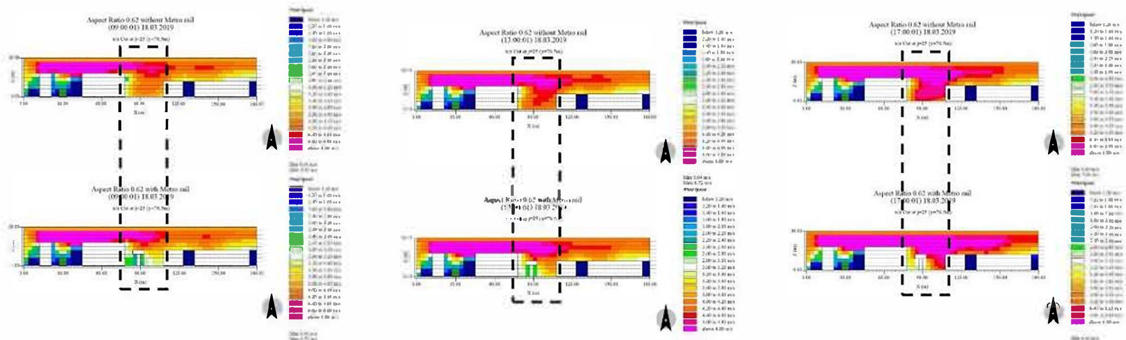


Figure 5: Change in wind speed for the selected site.
Source: Author

Table 1: Change in wind speed for the selected locations
Source: Author

HEIGHT	3m	6m	9m	12m
Wind speed change 09.00hrs				
Without metro	3.84m/s	3.94 m/s	3.96 m/s	4.12 m/s
With metro	2.86 m/s	3.14 m/s	3.42 m/s	3.64 m/s
Wind speed change 13.00hrs				
Without metro	4.32 m/s	4.36 m/s	4.4 m/s	4.42 m/s
With metro	3.12 m/s	3.16 m/s	3.46 m/s	3.82 m/s
Wind speed change 17.00hrs				
Without metro	4.4 m/s	4.6 m/s	4.62 m/s	4.68 m/s
With metro	3.7 m/s	3.9 m/s	4.2 m/s	4.4 m/s

Change in Relative humidity

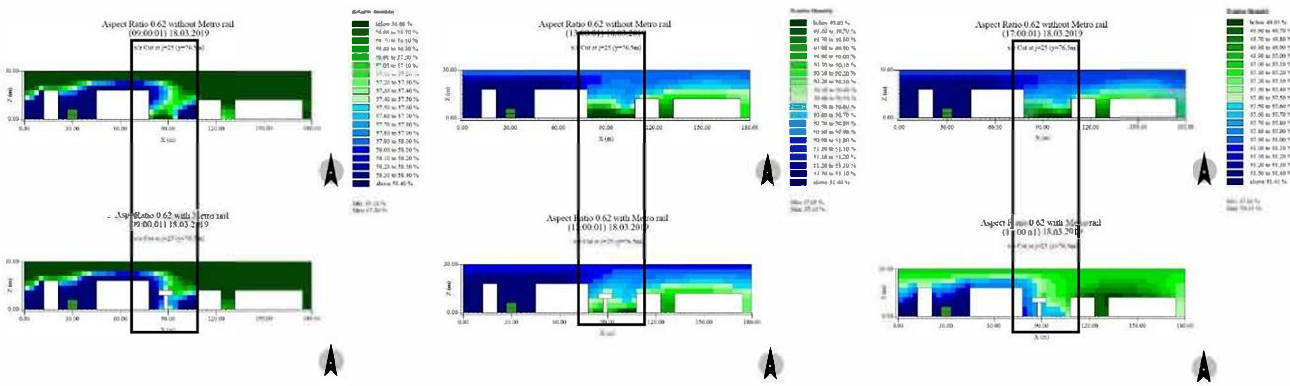


Figure 6: Change in Relative humidity for the selected site
Source: Author

The change in the wind speed is influenced by the humidity in the sections also. The sections without the metro structure has lesser humidity that those with metro. The average difference in the humidity is 2-3%. This increases the discomfort level in the streets for the people with sweating. This also hinders the pollution dispersion in the sections, by lesser wind movement and making the pollutants denser with moisture, in turn increase the discomfort for the vehicular passenger.

CONCLUSIONS

- Change in microclimate parameters like MRT and Wind movement (which influence climate of warm-humid climate zones) is seen in the urban stretch with and without an overhead Metro rail structure.
- The mean radiant temperature is seen decreased in the street due to the shadow casted by the metro structure, in turn reduced the air temperature.
- The mean radiant temperature is seen reduced to about 30°C on the pathways in the morning and evening peak hours and the vehicular road in the noon.
- This feature can be used in the design of urban cities by orienting the human movement, through appropriate zoning.
- The wind speed/ movement is also seen reduced in the street by 0.8 to 1m/s in the streets, that also leads to humidity to stagnant on the streets.
- The influence of metro on the movement of wind along the street is lesser as the pillars of metro are placed at distance of 25m from each other.

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EFFECTS OF GREEN INFRASTRUCTURE ON PARTICULATE MATTER POLLUTION CONCENTRATION — DELHI CASE STUDY

Atul Kumar[1], Mahua Mukherjee[2] Ahmad Rashiq[3], Siva Ram Edupuganti[4]

[1] Ph.D. Research Scholar, Indian Institute of Technology Roorkee, Dept. of Architecture and Planning IITR, akumar5@ar.iitr.ac.in
[2] Professor, Indian Institute of Technology Roorkee, Dept. of Architecture and Planning IITR, mahuafap@iitr.ac.in
[3] Ph.D. Research Scholar, Indian Institute of Technology Patna, Dept. of Civil and Environmental Engineering IITP, ahmad_2021ce05@iitp.ac.in
[4] Ph.D. Research Scholar, Indian Institute of Technology Roorkee, Dept. of Architecture and Planning IITR, sedupuganti@ar.iitr.ac.in

ABSTRACT

Economic development is induced by urbanisation, and land use change has negative effects on the built environment across a number of dimensions. In an urban setting, the degradation of the air quality is quite concerning; urbanisation is often directly associated to poor air quality. Numerous studies have shown that Green Infrastructure (GI) may enhance urban living conditions and air quality. In addition to offering a variety of ecological services, GI is crucial as a pollution sink. Among the 17 Sustainable Development Goals set out by the United Nations for 2015– 2030 calls for the protection and restoration of the urban landscape as a component of sustainable cities and commu nities. The concentration of particulate matter is what gives the air quality index (AQI) its higher value (PM). PM, which includes fine particulate matter (PM2.5) and inhalable particulate matter (PM10), is a key cause of poor air quality and is detrimental to human health. Particulate matter may be deposited and dispersed by GI at a variety of spatial scales and patterns. The objective of the research is to use correlation and regression analysis based on geographic information systems (GIS) to understand the influence of GI on PM pollution concentration using the case study of Delhi, the capital city of India. The research measures the spatiotemporal variation in PM concentration and Normalized Difference Vegetation Index value on a 1km by 1km Grid, its correlation and regression. The findings are crucial for developing urban green spaces, particularly in terms of the size and form of the green area.

Keywords: Particulate Matter, PM10 and PM2.5, Green Infrastructure characterization, GIS, NDVI

INTRODUCTION

Economic development is induced by urbanisation, and land use change has negative effects on the built environment across a number of dimensions. According to United Nations estimates, there are already 4.2 billion people living in urban areas, and by the middle of this century, there will be 6 billion(UNDESA, 2018). The current degree of haphazard development in the urban area is causing environmental degradation, especially in air and water quality and temperature rise. Recent rankings place air pollution first among environmental dangers, placing it seventh overall (Shaddick et al., 2020). The concentration of particulate matter is defined by a higher air quality index (AQI) score (PM). PM, includes PM10 and PM2.5 (PM2.5)(CPCB, 2014), is hazardous to human health and a leading cause of poor air quality. World Health Organisation reported that many cities worldwide had exceeded the threshold pollutant concentration level (WHO, 2018). As per WHO report- the global Urban Ambient air Pollution Database-2016, Indian cities are far beyond the ambient air quality mark. More than 99.3% of Indian population are living in conditions below the safe limit of air pollution. A report (Jayasooriya et al., 2017) estimated the annual cost of environmental degradation in India to be approximately $80 billion (INR 3.75 trillion). 77% of metropolitan areas in India, according to the Central Pollution Control Board (CPCB), violate the National Ambient Air Quality Standard (NAAQS) (PM10). India's average life expectancy falls by 1.7 to 2.6 years. In India, air pollution caused 12,400,000 fatalities in 2017 (DownToEarth, 2020). Poor air quality is often closely related to urbanization. The primary impact of urbanization can also be identified as the depletion of natural landscape or urban vegetation. Rising population density led to the high demand for infrastructures like housing, transportation, industries, and commerce. The unsustainable growth led to the loss of the pollution sinking zone, that is the vegetative region.

The impact and benefits of nature-based solutions are gradually emerging as appropriate alternative to urban risks including air pollution. The IPCC 2022 report gave prominence to greener cities as on of the three special aspects considering the future scenario of climate change (IPCC, 2022), and suggested tthat the traditional urbna organisation must need to change towards sustainable and more environment friendly urban planning. Sustainable cities and communities are the emphasis of SDG 11's formulation, whereas Protecting, restoring, and promoting the sustainable use of terrestrial ecosystems, managing forests sustainably, halting desertification, and halting and reversing land degradation and biodiversity loss are the objectives of SDG 15 (SDG, 2022). The mission's primary goal is to ensure and build resilient, sustainable cities while taking into account the increasing population, a lack of infrastructure, and a shortage of public open spaces and services. These objectives include, among others, the provision of sustainable public transit, basic services, public open spaces and amenities, economic possibilities, reduction of catastrophe risk, preservation of cultural and natural heritage, and mitigation of negative environmental effects (Gajjar, Sharma and Shah, 2021). Urban vegetation defined as Green Infrastructure (GI) of various typologies at considerable scale and configuration serves as a primary element of nature-based solutions (Bartesaghi-Koc, Osmond and Peters, 2019)(Butlin et al., 2011)(Sebesvari et al., 2019). Unlike traditional urban development strategies, GI simultaneously provides a variety of sustainability advantages, including as improved air quality, reduced urban heat islands, increased biodiversity, and improvements to human health and well-being(Chang et al., 2012)(Goodspeed et al., 2021)(Sturiale and Scuderi, 2019)(Pitman, Daniels and Ely, 2015)(Ahern, 1995). For developing cities as more resilient and sustainable GI serves as an essential tool it has multifunctional characteristics, only one need to implement this tool strategically(Ghofrani, Sposito and Faggian, 2017)(Mukherjee et al., 2021).

Several studies have suggested that Green Infrastructure (GI) can improve air quality and the living environment in cities. GI provides multiple ecosystem functions and services and plays a vital role as a sink for pollutants (Zupancic, Westmacott and Bulthuis, 2015)(Urban Climate Lab, 2016)(Janhäll, 2015)(Foster, 2011). A number of literature are available that state qualitative and quantitative functional potential of the GI, but most of the studies have been done in developed countries (Janhäll, 2015)(Zupancic, Westmacott and Bulthuis, 2015)(Zhou et al., 2019)(Tallis et al., 2015). Although green infrastructure has a win-win approach for urban problems, it needs to plan strategically to enhance the benefits of GI. Urban green spaces (GI) have been demonstrated to reduce concentrations of pollutants, particularly particulate matter (PM) and urban temperature. However, guidance on the application of Green Infrastructure for air quality and temperature management is limited, as is its application in practise. Complexities of modern cities make GI implication a bit difficult as GI implementation is highly site-specific and species-specific for particular identified problems. Enhancement of GI application can be augmented once the context-specific guidance is in place, which are not available in most of the cases, specifically for Asian Megacities(Parker, Elena and Baro, 2019). Air pollution life cycle has been characterized in three level from "emission – transportation – deposition", most of the study and approach of air quality improvement in an urban area has focused at the emission level mitigation strategies (CenterOverseasEnvironmentalCooperation, 1998). Studies have examined the connection between the ability of the natural environment to protect against air pollution exposure and the effects such exposure has on human health (Franchini and Mannucci, 2018) (Bowler *et al.*, 2010). Numerous research on landscape, or in the language of urban planning "green space" and "greenness," that is, Green Infrastructure, as interventions capable of defending human health from ambient air pollution at various scales, have been prompted by the urbanisation of the world and a growing awareness of the impacts of the natural environment on our health. Research into the physical, biological, and chemical underpinnings of how GI affects PM and its symptomatic relief is expanding quickly (Janhäll, 2015; Aerts et al., 2018; Egorov et al., 2016; Crouse et al., 2019; Wolf et al., 2020). The effect of structural characterization of GI on atmospheric pollutant elimination was studied in the physical mechanism (Lehmann *et al.*, 2014). Since air pollutants are more easily absorbed by vegetation than by smoother, impervious, artificial surfaces, the effect of GI on air pollution mitigation has been quantified on two broad levels: the plant level (Berardi, Ghaffarianhoseini and Ghaffarianhoseini, 2014) and the landscape level (Beatley, 2018) which further has been discussed on multiple urban scale (Fowler *et al.*, 1989)(Nowak and Service, 2002)(Neft *et al.*, 2016). In landscape level studies, The landscape level study discusses about the morphological and spatial relation of GI to remove pollution from atmosphere by the process of deposition and dispersion of pollutant at local scale, neighbourhood scale and city scale (Badach, Dymnicka and Baranowski, 2020)(Liang and Gong, 2020). McDonald et al. in his study suggested that important factors influencing the effectiveness of the air filtration by Green Infrastructure is location (spatial relation), and other morphological attributes such as area, shape, size etc. (Mcdonald *et al.*, 2007). Most of the studies quantify the GI landscape indicator considering three broad classes of metrics (i) Area Metrics (Total area, Largest patch index Number of patches, Patch density, Mean patch size) (ii) Shape Metrics (Mean Patch Shape Index, Mean Patch Fractal Dimension, Mean Contiguity Index) (iii) Aggregation Metrics (Mean nearest neighbour distance, Landscape shape index, Patch cohesion index, Splitting index, Landscape division index Effective mesh size, Aggregation index) and correlates with the spatial concentration of the pollutant, they also studied the deposition and dispersion mechanism(Mcdonald *et al.*, 2007)(Wu *et al.*, 2015)(Tu *et al.*, 2019)(Shi *et al.*, 2019)(Łowicki, 2019)(Liang and Gong, 2020). The present study discuss the landscape approach of green infrastructure mapping and its potential impact on the pollutant concentration.

DATA AND METHODOLOGY

The present study, opting the capital city of India, ' Delhi,' as a case study to understand the impact of GI Spatial patterns (in Spatial distribution term) on PM pollution concentration using GIS-based correlation and regression analysis (Ozarisoy and Altan, 2021). Geospatial data has been used to map the GI of the city using the remote sensing vegetation index, which is Normalize difference vegetation index (NDVI). The LANDSAT 8 Collection 2 series data has been used for preparing NDVI in the study area. The seasonal NDVI maps have been prepared by taking the average (mosaic) of all LANDSAT images in a particular season, and getting one mean image for every season. Central Pollution Control Board (CPCB) owned 38 air pollution monitoring stations data as shown in fig 2. has been used to map the daily mean PM10 concentration map on the GIS platform using IDW interpolation techniques. The air pollution monitoring stations are well uniformly distributed throughout the study area. ArcGIS 10.4 has been used to prepare the various spatial maps of NDVI and PM10, mean data values are extracted using zonal statistics tool in ArcGIS, and the extracted data has been further analyzed in MS-Excel. To extract the data from the processed images, a fishnet (grid) of 1km * 1km has been used. This ensures a fixed baseline for comparing the different parameters. The conceptual Flowchart of the work process has been opted as shown in fig 1. a Geographically Weighted Regression analysis was conducted to examine the correlation between vegetation density and PM10 concentration. Based on local regression and variable parameter analysis. The regression parameters of the model include the geographical locations of the data. The parameters at each individual point are estimated using the local weighted least squares approach (Wang and Wang, 2020).

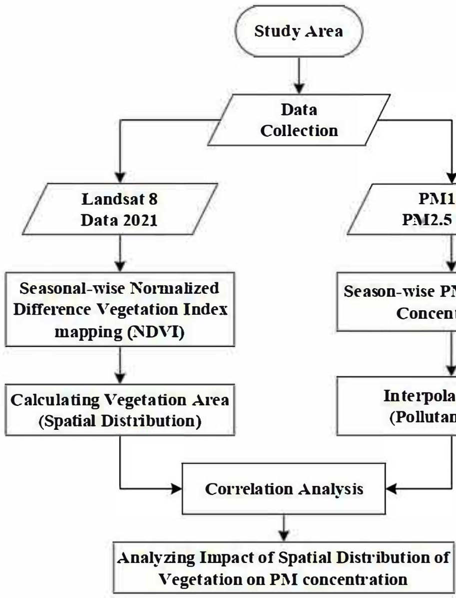

Figure 1. Conceptual Flowchart of the study methodology

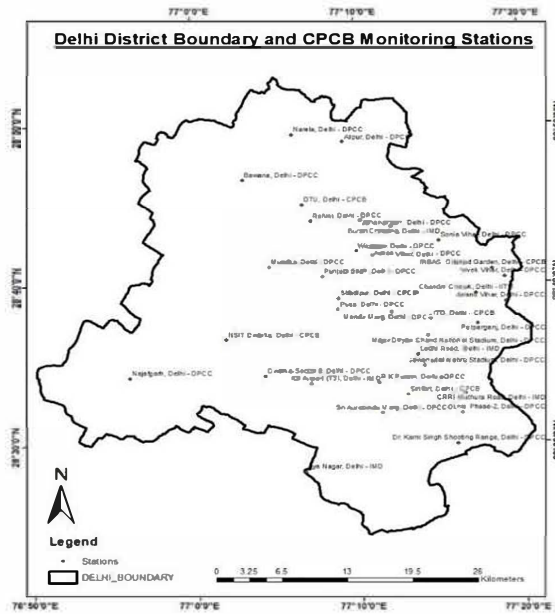

Figure 2. Delhi_CPCB 39 Monitoring Stations

CASE STUDY

Study Area

A union territory known as the National Capital Territory (NCT) of India is home to the city of Delhi. It had a total area of 1484 square kilometres and shared a border with two other states: Uttar Pradesh (UP) on the east and Haryana on the other three sides. The National Capital Region, which includes Delhi's metropolitan region and the nearby satellite cities of Ghaziabad, Faridabad, Gurugram, and Noida (NCR)(Guttikunda and Calori, 2013). The city may be found in the northern part of India at a latitude of 28.61 degrees North and a longitude of 77.23 degrees East. As shown in figure 3, it falls in the composite climate with two important geographical features the Yamuna flood plains in the north and east and the Aravalli ridges in the south. The city experience five seasons summer (April to June), rainy (end June to mid-September), Autumn (mid-September to November), winter (November to February) and spring (February to April) (DelhiTourism, 2022). Rapid urbanization and development in the capital city without concerning the environment create multiple urban issues in the region, such as Air pollution, water pollution, waste generation, degradation of landscape, etc. The World Health Organization (WHO) produced a report in 2014 identifying Delhi as the most polluted city in the world, citing air pollution as the city's most pressing problem (Saraswat, Mishra and Kumar, 2017) (Jalan, 2019). (Jain *et al.*, 2021)(Guttikunda and Calori, 2013).

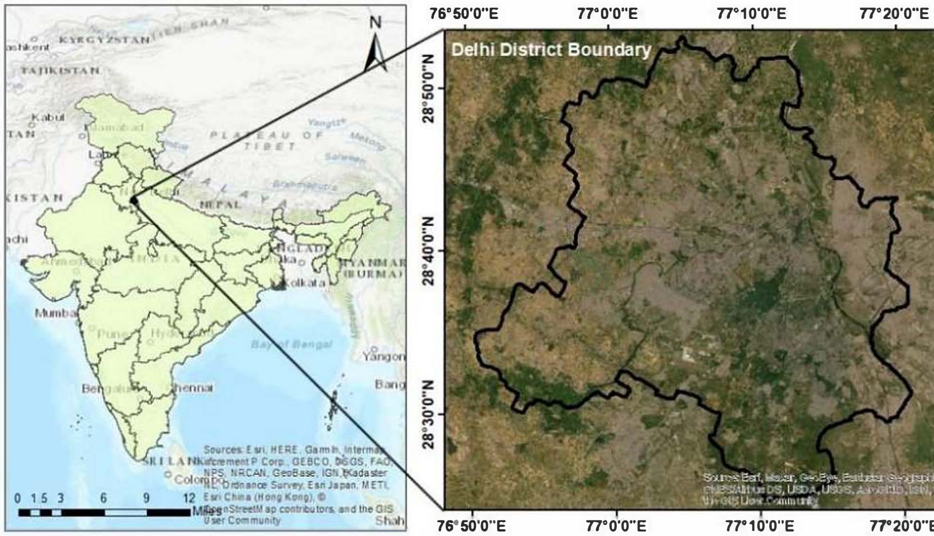

Figure 3. Study Area for Case Study DELHI (INDIA)

Green Infrastructure mapping

A Normalized Difference Vegetation Index (NDVI) is employed to bring out the GI in the study area as shown in figure 4, 6, 8, 10 & 12. Hyperspectral imagery enables clever manipulation of spectral bands to highlight or bring out a particular feature. In NDVI, the Near Infrared (NIR) and Red (R) bands are arithmetically manipulated to highlight the vegetation (Eq.1) (Reza *et al.*, 2014)(Gajjar, Sharma and Shah, 2021). This is mainly due to the fact that vegetation has high reflectance in the NIR and low reflectance in the R band. Since a normalized difference of the NIR and R bands is taken, the NDVI values range from -1 to 1. NDVI is used in the present study with the objective of green area mapping for the different seasons of 2021. Using ArcGIS for NDVI preparation means that the data can be viewed spatially and temporally.

$$NDVI = \frac{NIR-R}{NIR+R} \qquad (1)$$

Particulate Matter Concentration Mapping

There are 39 air pollution monitoring stations deployed throughout the city as shown in fig 2. All the stations are uniformly distributed in the town. These monitoring stations provide hourly and daily mean pollution concentration data. The data protocol suggests that each monitoring station has spatial resolution of one sq. km (CPCB, 2015) around the stations. Geographical Information System (GIS) based interpolation techniques have been used to map the particulate matter concentration in the area of interest as shown in figure 5, 7, 9, 11 & 13. The interpolation technique is used to predict values in the cells in a raster when there are limited sample data points (Shareef, Husain and Alharbi, 2016)(Bezyk *et al.*, 2021)(Singh and Tyagi, 2013)(Londoño-Ciro and Cañón-Barriga, 2015). The study used IDW interpolation techniques; this method estimates cell values by averaging the sample point value in the neighbourhood of each processing cell.

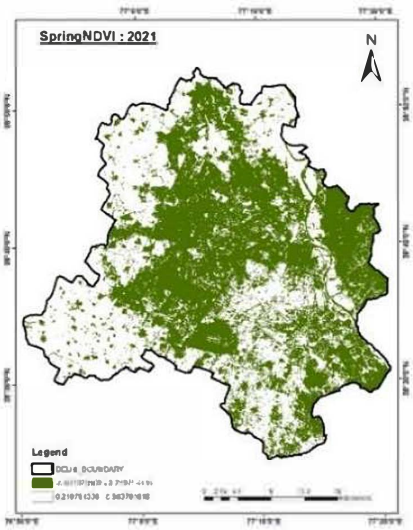

Figure 4. NDVI map 2021 Spring Season

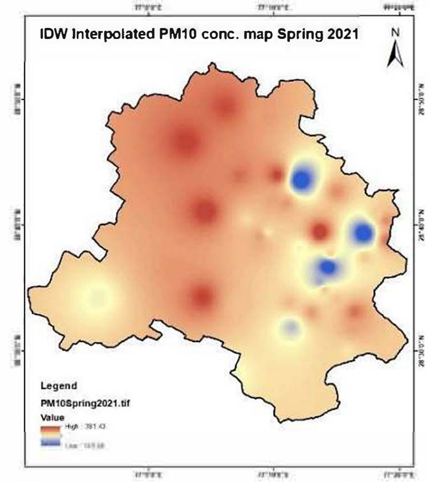

Figure 5. PM10 conc. map 2021 Spring Season

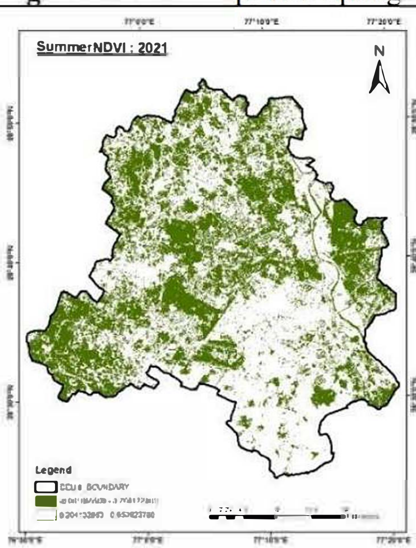

Figure 6. NDVI map 2021 Summer Season

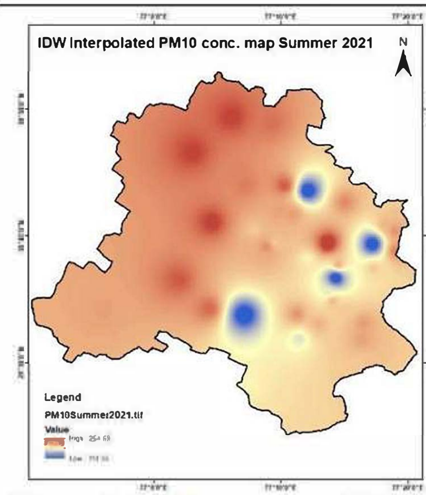

Figure 7. PM10 conc. map 2021 Summer Season

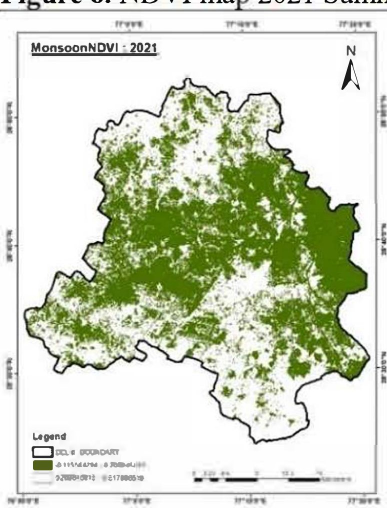

Figure 8. NDVI map 2021 Monsoon Season

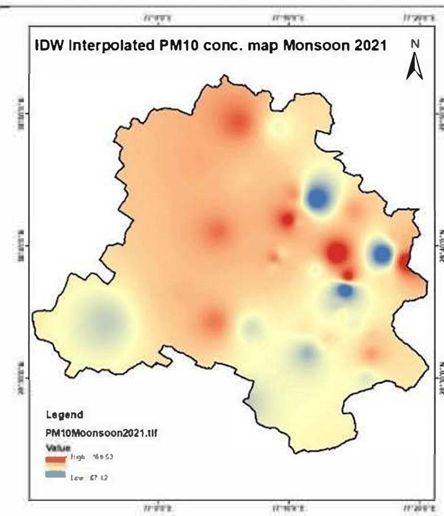

Figure 9. PM10 conc. map 2021 Monsoon Season

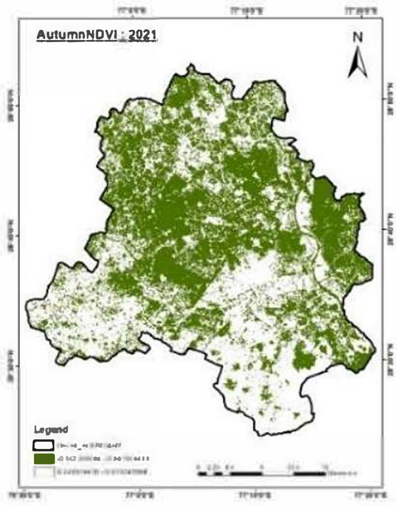

Figure 10. NDVI map 2021 Autumn Season

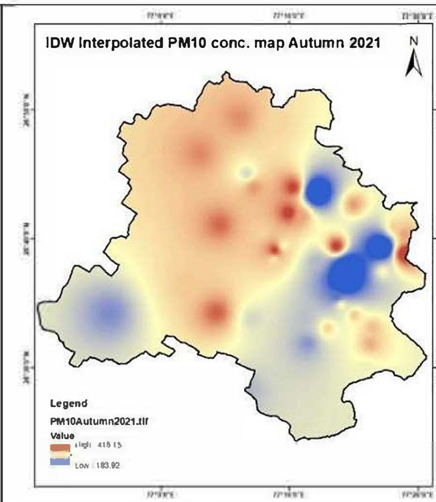

Figure 11. PM10 conc. map 2021 Autumn Season

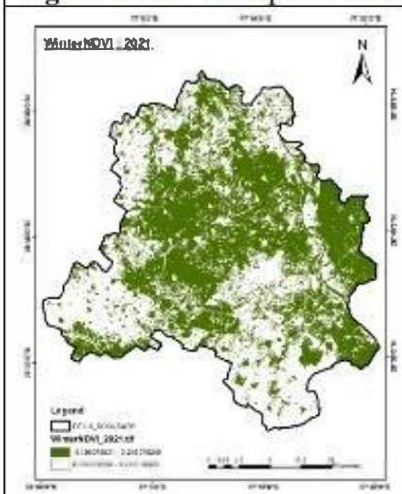

Figure 12. NDVI map 2021 Winter Season

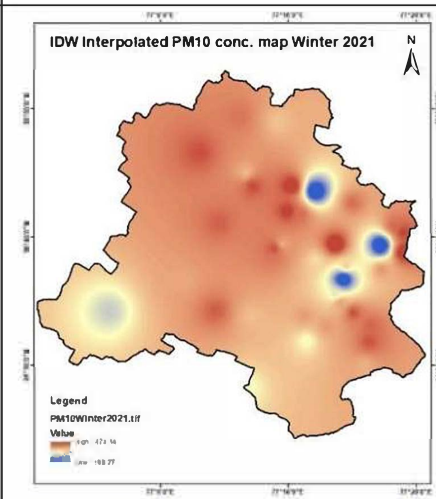

Figure 13. PM10 conc. map 2021 Winter Season

Analysis and Result

On the basis of NDVI and PM10 ground measurement results, linear regression is used to determine the correlation. The map of NDVI and PM10 concentration has been delineated considering the five seasons: Spring, Summer, Monsson, Autumn, and Winter for the year 2021. The 1420 points value of each map has been delineated using the point value extraction tool in ArcGIS. The relationship between the NDVI Vegetation Index and PM10 has been investigated seasonally as shown in figure 14-18. Correlation analysis shows a negative relation between NDVI and PM10 concentrations for all the seasons. Which state that higher the area of vegetation lowers the value of pollution concentration (PM10 conc.). The analysis showed that the correlation is stronger during the Autumn and Winter seasons than the Spring and Summer seasons. The PM10 concentration graph for each monitoring station can be seen in Figures 19-23. All the monitoring stations showed a higher value of pollution concentration than the ambient value suggested by WHO and National Ambient level concentration in all seasons expect Monsoon. During Monsoon, rain triggers the process of wet deposition of pollutants. Though the concentration of PM10 during the Monsoon season recorded is within the level of ambient concentration level, the correlation analysis showed a negative relation between NDVI and PM10. The correlation analysis result that the higher the spatial distribution of vegetation, high the process of surface deposition of PM10 particles. The Geographically wegited regression anlysis shows the strong relationship between the NDVI and PM10 concentration for all the month. The regressing coefficient of NDVI is negative, which indicates that the region with lesser value of NDVI lead to the increase in PM10 concetation spatially.

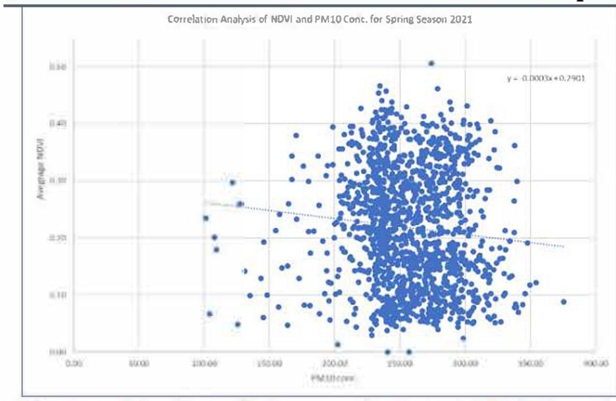

Figure 14. Correlation analysis of NDVI and PM10 for Spring Season 2021

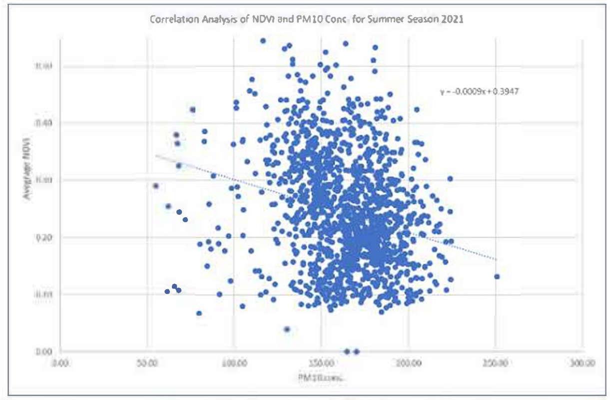

Figure 15. Correlation analysis of NDVI and PM10 for Summer Season 2021

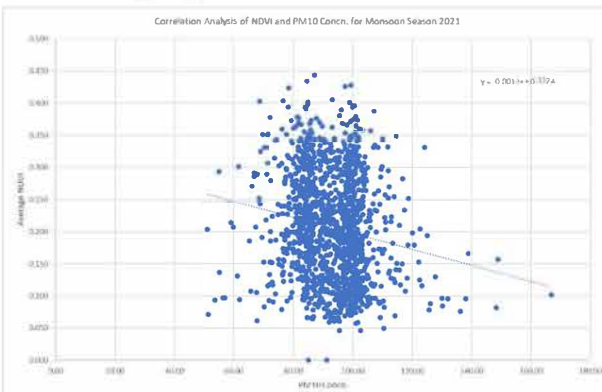

Figure 16. Correlation analysis of NDVI and PM10 for Monsoon Season 2021

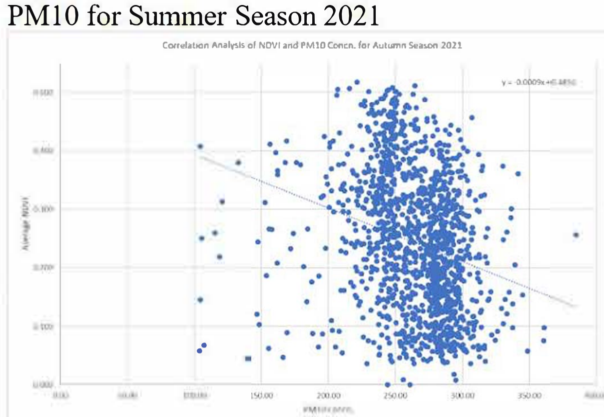

Figure 17. Correlation analysis of NDVI and PM10 for Autumn Season 2021

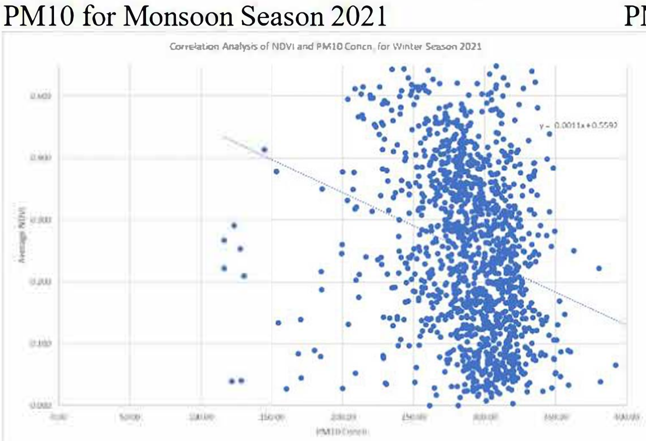

Figure 18. Correlation analysis of NDVI and PM10 for Winter Season 2021

CONCLUSION

The present study has been taken up with objective of finding correlation between the GI and air pollution (PM10). The present study's findings are crucial for urban green space development, particularly in terms of the quantity and design of green spaces.The NDVI map provide the current spatial distribution of urban vegetation in Delhi. It is well known that vegetation reduces the pollutant concentration by the process of deposition and dispersion. The results of present correlation study supports this statement by its finding that higher the aerial cover of vegetation, the higher the chance of pollutant deposition. Based on GI distribution in the city, problematic areas in the city can be identified considering air pollution concentration. Hence, the future scope of the study can be suggested as identification of design parameters of urban landscape for air quality improvement in the identified problematic areas. This will also ensure the fulfilment of the SDG goals by restoring the urban landscape.

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URBAN FLOOD RISK HOTSPOT ZONATION USING GIS-BASED TECHNIQUES

Ahmad Rashiq[1], Om Prakash[2], Atul Kumar[3]

[1] Ph.D. Research Scholar, Indian Institute of Technology Patna, Dept. of Civil and Environmental Engineering IITP, ahmad_2021ce05@iitp.ac.in
[2] Assistant Professor, Indian Institute of Technology Roorkee, Dept. of Civil and Environmental Engineering IITP, om.prakash@iitp.ac.in
[3] Ph.D. Research Scholar, Indian Institute of Technology Roorkee, Dept. of Architecture and Planning IITR, akumar5@ar.iitr.ac.in

ABSTRACT

Urban floods are a new category of floods plaguing the modern, fast-growing cities worldwide. Unplanned city growth leaving behind poor drainage fuelled by the increasing number of high intensity precipitation events due to climate change are the reasons behind the growing menace of urban floods. Some parts of the city are worst affected by urban floods than others, primarily because different factors accumulate and affect that part of the city negatively. The present study proposes a rank-based hotspots zonation framework for urban flood risk assessment using Geographical Information System (GIS) and Earth-Observation (EO) data. Different factors such as Land Use Land Cover (LULC), topographical features, and hydrological criteria such as Stream density and Runoff potential affect surface runoff. These factors combined with the NRCS-CN model help delineate hotspots zone on a grid of 1×1 km over the study area i.e., Patna city using rank based weight system. Hotspot identification helps classify most flood-prone areas, which can be further used to suggest risk resilience measures. In the present study, hotspots identified have been classified as high and medium risk based on weight values of 40 and 35 respectively, out of 50. Though extreme events leading to urban flooding cannot be stopped but such hotspot zonation maps will play a key role in predicting the severity of the flood and help plan the evacuation and relief response. The zonation maps would also serve as a guideline for infrastructural interventions in areas severely affected by floods thus making the city urban flood resilient.

Keywords: Urban Floods, NRCS-CN model, hotspots zonation framework, Urban flood risk assessment, Patna city

INTRODUCTION

Cities are at the forefront of economic development, characterized by a large population and fast-paced life. However, unplanned development and rapid population growth coupled with climate change have led to new problems. Urban floods are one such category of floods plaguing the modern, fast-growing cities worldwide. They are different from fluvial floods, as developed urban catchments lead to a higher buildup of runoff volumes in less time. The National Disaster Management Authority of India (NDMA) recognizes urban floods separately, differentiating them from fluvial floods (National Disaster Management Guidelines: Management of Urban Flooding., 2010). In the past two decades, many major Indian cities have been hit by disastrous urban floods resulting in the loss of lives and livelihood (Gupta, 2007; Rafiq *et al.*, 2016; Seenirajan *et al.*, 2017; Ilam Vazhuthi and Kumar, 2020). The Mumbai floods of 2005 and the Chennai floods of 2015 forced these megacities to close for days, resulting in massive economic losses. Not only that, but the floods claimed a large number of lives.

Urban floods are caused due to a multitude of reasons. These can include the high intensity of rainfall which overwhelm the poorly maintained and generally insufficient storm drainage systems. In India, storm drainage systems are generally designed for a return period of one to two years only (CPHEEO, 2019), which means that drains' accommodation and transportation capacities are frequently overwhelmed. Unplanned development significantly increases impermeable areas, resulting in increased surface runoff and flooding, a problem compounded in cities with flat topography. The lack of a systematic strategy to define and implement a holistic stormwater drainage scheme within a defined planning horizon has made urban areas and cities so vulnerable that even light and medium-intensity rain can trigger urban flooding. Climate change has also led to increased high-intensity rainfall events, while illegal waste disposal in drainage streams hinders the natural flow.

The sixth annual assessment report (AR6) by Intergovernmental Panel on Climate Change(IPCC) has stated that there will be an increase in pluvial floods due to the growing risk of extreme events due to climate change (Shukla *et al.*, 2019). In light of these trends, it is vital to assess the risk of urban flooding in order to quantify urban flood risk. The present study will help fulfill the sustainable development goals (SDGs) of reducing the exposure of the poor to extreme events (SDG 1.5), sustainable urbanization (SDG 11.3), and enhancing the institutional capacity (SDG 13.3). The study also follows up on the 'The Prime Minister's 10-point Agenda for Disaster Risk Reduction which was declared when India became a signatory to the Sendai Framework for Disaster Risk Reduction (SFDRR) in 2015. Risk assessment is the first rung of the ladder towards a proactive approach to disaster mitigation and risk reduction. These risk zonation maps serve as a foundation for early warning, relief, and rescue planning and prioritizing, as well as facilitating swift reaction and reducing the impact of a potential flood disaster (Forkuo, 2011). The use of GIS in flood hazard and flood risk modeling is one of the most efficient approaches (Luu and von Meding, 2018; Shadmehri Toosi *et al.*, 2019; Abdelkarim *et al.*, 2020).

STUDY AREA

Patna city, the capital and the largest city of Bihar, has been taken up as the study area for the present study. The city is located on the southern banks of the river Ganges and is home to nearly 1.7 million people as per the 2011 census. The dense unplanned urban areas and the huge population make the city vulnerable to the risk of urban floods. Consequently, the city was struck by an urban flood in September 2019, which plagued the city and affected the lives of thousands. The city was flooded following the heavy rainfalls on 29th September 2019 throughout the Patna district. As a result, the national disaster response force (NDRF) had to be deployed, and almost 5000 people were rescued. The city officials were left red-faced as the maps for colonial-era sewage lines were nowhere to be found. Although the deluge was blamed on climate change, it does not change the fact that the city is prone to urban flood risk. Hence, Patna city is a suitable site for the present study to demarcate flood hotspots.

DATA AND METHODS

Data used

Earth-Observation (EO) data includes LANDSAT 5 and LANDSAT 8 Collection 2 Level-2 images at 30 meters' spatial resolution. These have been used in the study to prepare the various remote sensing indices explained further. CARTOSAT Digital Elevation Model (DEM) (bhuvan.nrsc.gov.in) version 3 has been used to prepare the slope map for the study area.

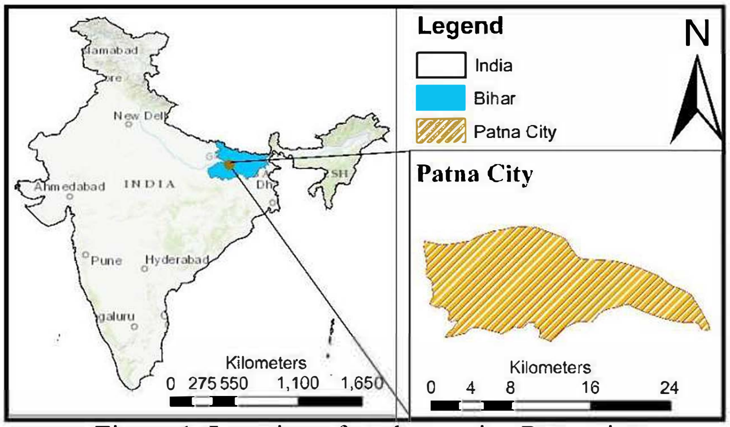

Figure 1: Location of study area i.e. Patna city

Rainfall data has been obtained from Indian Meteorological Department (IMD) (dsp.imdpune.gov.in) for various locations across the Patna district. The soil map has been downloaded from the Food and Agricultural Organization (FAO) portal and classified using the ArcSWAT library. The WorldCover 10m land use land cover data (LULC) has been processed using Google Earth Engine (GEE) (code.earthengine.google.com) platform. The remotely sensed data has been processed in ArcGIS 10.4, while MS-Excel has been used to analyze the data. The link for downloading the various datasets used in this study is provided in the reference section.

Remote Sensing Indices

The satellites capture the images of the earth in various bands. By clever arithmetic manipulation of these bands, it is possible to bring out or highlight a particular feature. Remote sensing (RS) indexes such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Builtup Index, and Normalized Difference Water Index (NDWI) exploit the different bands to highlight vegetation, builtup and water, respectively.

NDVI ranges from -1 to +1 (Xue and Su, 2017), with higher values signifying the presence of vegetation. It is given by Equation 1.

$$\mathrm{NDVI} = \frac{\mathrm{NIR}-\mathrm{R}}{\mathrm{NIR}+\mathrm{R}} \tag{1}$$

NDBI ranges from -1 to +1 (Zhang, Odeh and Han, 2009) with higher values representing builtup areas. This index has been vastly used in urban studies. It's given by Equation 2.

$$\mathrm{NDBI} = \frac{\mathrm{G}-\mathrm{NIR}}{\mathrm{G}+\mathrm{NIR}} \tag{2}$$

NDWI also ranges between -1 and +1 (Xu, 2006), with positive values signifying areas with water. NDWI has been used in detecting permanent water bodies. It is given by Equation 3.

$$\mathrm{NDWI} = \frac{\mathrm{SWIR}-\mathrm{NIR}}{\mathrm{SWIR}+\mathrm{NIR}} \tag{3}$$

In the above equations, Red (R), Green (G), Near Infra-Red (NIR) and Shortwave Infra-Red (SWIR) represent the different spectral bands captured by the remote sensing satellites.

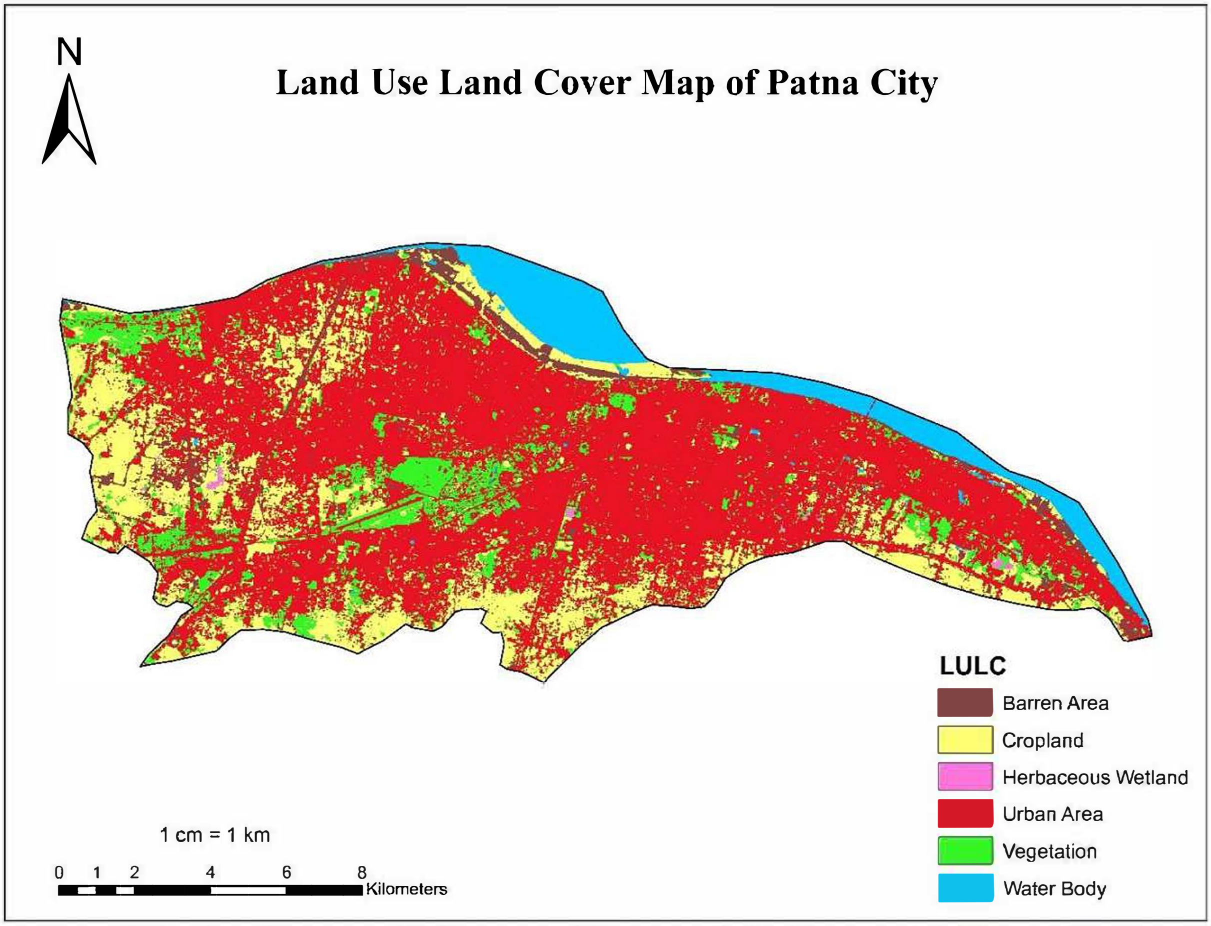

Figure 2: Land use land cover (LULC) map of Patna city derived from the WorldCover 10m data

NRCS-CN Runoff Model

To determine the rainfall-runoff characteristics, hydrological criteria in the form of a hydrological model is used in the present study. The model employed is NRCS-CN runoff model. This model helps examine the study area's hydrological, meteorological, and topographical aspects. Curve Number (CN) is a dimensionless number frequently used for calculating runoff depth due to rainfall (Othman *et al.*, 2013; Tailor and Shrimali, 2016; Singhal and Kumar, 2018; Al-Ghobari and Dewidar, 2021), and it was developed by the Natural Resources Conservation Service-Soil Conservation Service (NRCS-SCS). One of the key benefits of utilizing this empirical method is that it can account for land use land cover (LULC), hydrological soil group (HSG), and antecedent moisture condition (AMC). The perviousness of the surface is affected by land use, HSG by soil infiltration capacities, and AMC by the presence of soil moisture due to prior cumulative five-day rainfall. The maximal potential retention (S), initial abstraction (Ia), and runoff depth (Q) are all calculated using this CN.

$$S = \frac{25400}{CN} - 254 \tag{4}$$

$$Ia = 0.2S \tag{5}$$

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \tag{6}$$

For the present model, the events leading to the Patna floods of 2019 have been considered for preparing the hydrological model. The HSG group has been identified as C, which means more runoff can be generated due to the soil properties. The rainfall of 29th September 2019 was taken for runoff computation when the city of Patna experienced one of the worst urban floods in its history. The resulting soil condition due to the previous five days of rainfall is AMC-III. The curve number values have been corrected for slope (Huang *et al.*, 2006) and AMC (Woodward *et al.*, 2004).

Urban Flood Hotspot Zonation Framework

The different parameters viz. NDVI, NDBI, NBWI, Stream Density, and Runoff have been used for urban flood hotspot zonation framework in the study area. The flowchart in Figure 3 describes the process of hotspot zonation using these parameters. The zonal statistics tool in ArcGIS is used to compute the mean values of these parameters by overlaying the study area with a grid of 1 km × 1 km. Once grid-wise mean values of these parameters have been extracted, the data is exported to MS-Excel for further analysis. These values are then ranked based on their significance in the event of a flood from one to ten. For example, NDVI is arranged in increasing order, with lower NDVI values having greater rank as they are more vulnerable to floods than grids with higher NDVI values.

Similarly, NDBI is arranged in decreasing order, with higher NDBI values having greater ranks as they are more susceptible to flooding due to more imperviousness. Once the increasing/decreasing order is established for the parameters, these values are combined in groups of 10 and then ranked. So one grid will have different ranks for different parameters. These ranks are then added up grid-wise to get the final weight based on which the hotspot framework has been defined. The higher weights represent the more flood risk-prone grids. Grids falling over the Ganga river have not been considered in the final result. The identified hotspots are finally represented using ArcGIS.

ANALYSIS AND RESULTS

Historical changes in the RS indexes

Changes occurring in the remote sensing indices NDVI, NDBI and NDWI from 1990 to 2021 is shown in Figure 4. Figure 5 shows these remote sensing indices for the year 2021. The builtup area has increased from 29.9 sq. km. in 1990 to 48.5 sq. km. in 2021 while the vegetative cover has decreased from 64.5 sq. km. in 1990 to 48.7 sq. km. in 2021. The water cover has primarily decreased although some variation is seen. This is mainly due to the month in which the satellite images were taken as images in dry season will show less water. It can be seen that as builtup area has increased, it has come at the cost of the vegetative cover in the region. Loss in vegetation will result in less infiltration capacity of the soil as roots of the plants holds down the soil together. Also increasing impervious area (builtup area) will mean that more and more ground is now paved. Consequently, water instead of permeating will appear as runoff which in turn will increase flood volume (Gupta, 2007). These paved surfaces also offer less resistance to flow of water resulting in increased flow speeds (Armenakis *et al.*, 2017). Hence urban flood risk assessment is imperative in a growing city like Patna which is exposed to high flood risk (NRSC, 2020).

Urban Flood Hotspots

Figure 6 shows the NDVI and Runoff, two of the five urban flood hotspot parameters, overlayed with a grid of 1km * 1km to extract the mean values. Similarly, other parameters have been overlayed with the grid to extract mean values and carry out rank based weightage. Figure 7 shows the final hotspot zonation after doing the weighted analysis for these parameters as discussed in section 3.4. Urban flood hotspots have been identified as being prone to high risk and medium risk The cutoff weights out of 50 for high and medium risk are 40 and 35, respectively.

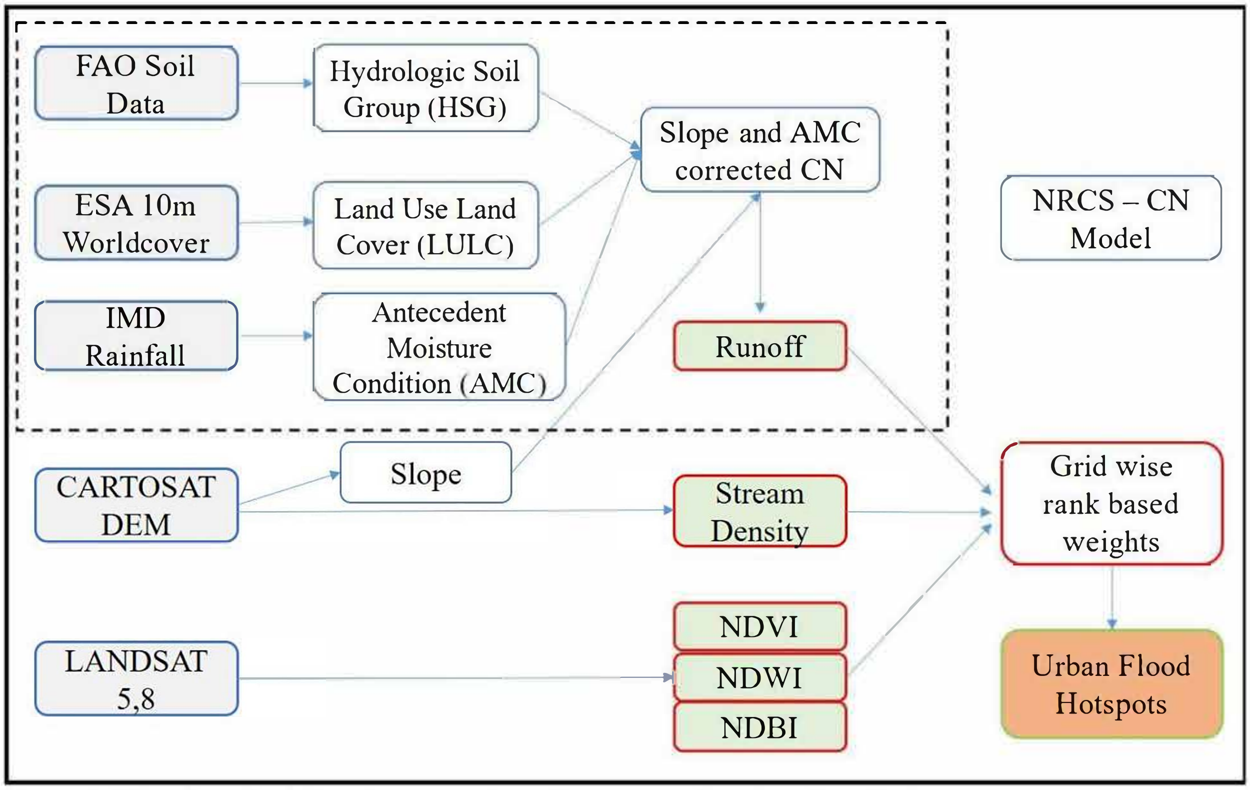

Figure 3: Flowchart depicting the steps adopted to prepare the urban flood hotspots

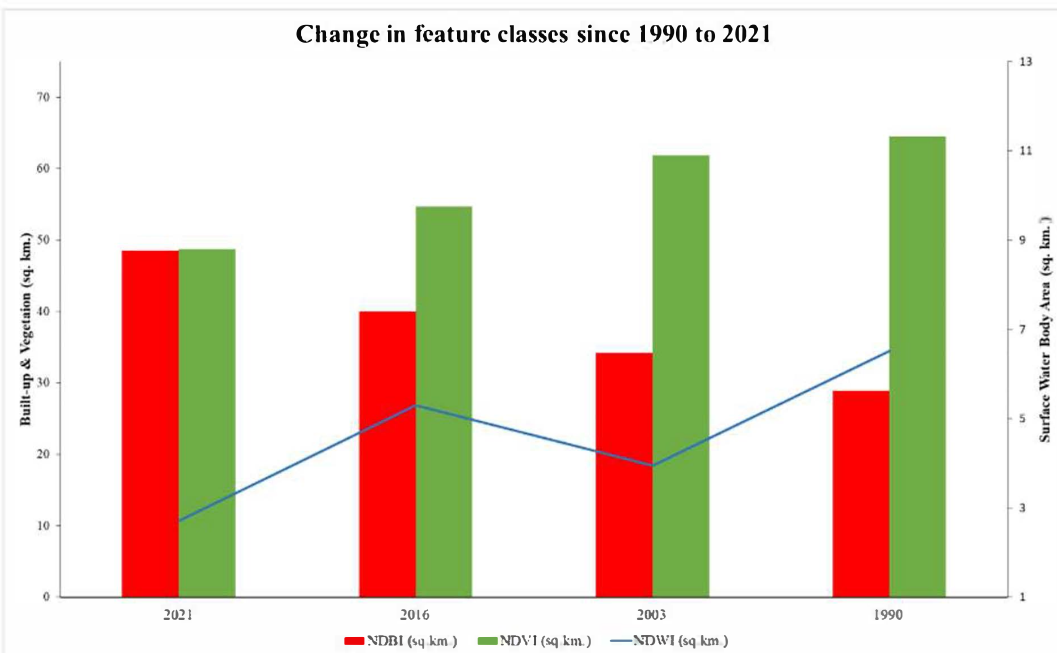

Figure 4: Changes in NDVI, NDBI and NDWI from 1990 to 2021 in Patna city

Validation of Urban Flood Hotspots

The urban flood hotspots identified in the study have been validated using indirect circumstantial evidence acquired from local residents and people involved in relief and rescue during the floods of 2019. The validation process ensures that the experiences of these people during the 2019 event falls in line with the urban flood hotspots found in the study. Areas in Patna city such as Ramkrishnan Nagar, Kankarbagh, Boring road, Nala road, Gandhi maidan, and Pataliputra colony, which have been reported to be flooded, fall within the medium and high risk urban flood hotspots (Figure 7). However, areas which are identified as hotspots but were not reported to have been significantly flooded require explanation. The most probable explanation is the presence of an efficient drainage network which is able to drain off excess rainwater quickly. Presence of significant vegetation and/or water bodies will also help absorb rainfall excess. Presence of significance vegetation also means less builtup or more water bodies. Overlaying the urban flood hotspots with NDVI map reveals that western, south-western urban hotspot and south-eastern grids have significant vegetation (less builtup) which explains why these areas did not report significant flooding.

CONCLUSION

The present study for urban flood risk assessment using a hotspot zonation framework works satisfactorily in identifying the flood hotspots. The performance evaluation results for Patna city for the urban flood of 2019 showed a close correlation between the identified hotspots from the developed methodology and the circumstantial field evidence obtained from SDRF. This zonation has been done through GIS based techniques using derivatives of EO data such as NDVI, NDBI, NDWI, Stream Density, and hydrological criteria in form of NRCS-CN runoff model. Decreasing percentage of NDVI and increasing percentage of NDBI is observed which is a cause of concern as the permeable surface decreases. The hotspots identified have been validated with locations actually flooded during the urban flood of 2019 in Patna city. Areas like Pataliputra colony, Boring road, Gandhi maidan classified as high risk hotspots were severely flooded during 2019. These areas show dense builtup. This validation has been done using the data provided by State Disaster Response Force (SDRF) which was deployed during the flood for relief and rescue operation. In a proactive approach towards disaster management, such urban flood hotspot zonation serves as a means to identify risk prone areas. This will help greatly in coming up with mitigative measures on a grid by grid basis depending on ensuing issue like less vegetation or lack of water bodies or dense builtup. City administration and planners will have a fair idea of locations for coming up with urban flood risk assessment. One of the major advantage of such a GIS based technique is that it does not require complex hydrological or hydraulic modelling and one can make use of freely available data. The technique can be further improved however by using high resolution data and smaller grid size. If data for drainage network is also available for the city, it can also be incorporated in this technique to further refine the results. Nonetheless, this GIS based urban flood hotspot zonation technique has successfully been able to identify urban flood hotspots in Patna city and can be used for suggesting remedial measures.

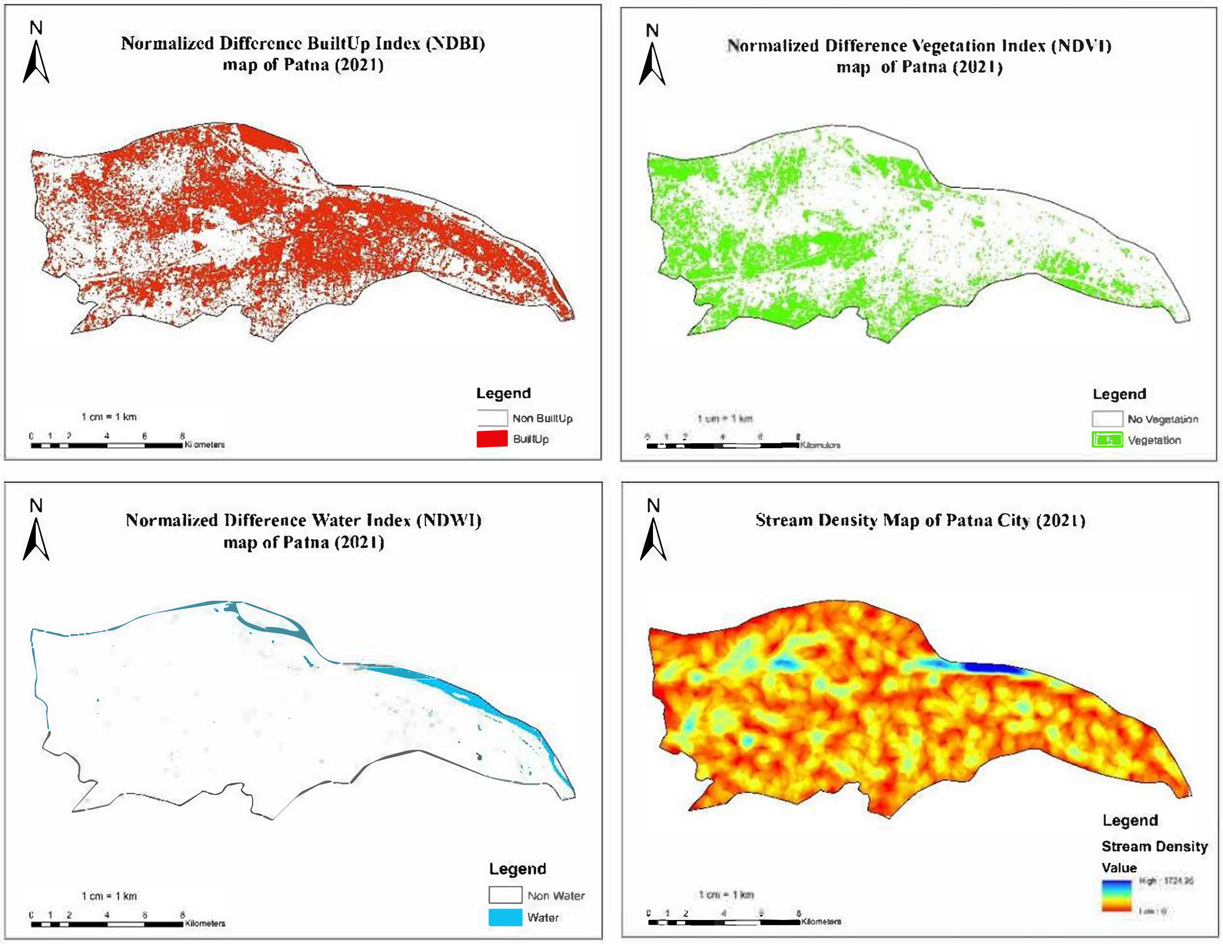

Figure 5: NDBI, NDWI, NDVI and Stream Density of Patna city for the year 2021

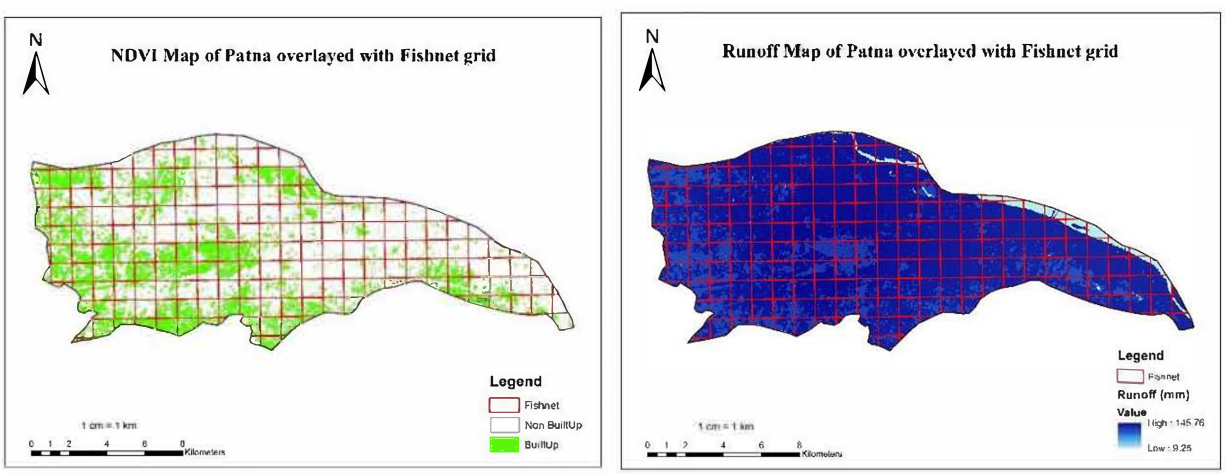

Figure 6: NDVI and Runoff map of Patna city overlayed with a fishnet grid of 1km × 1km

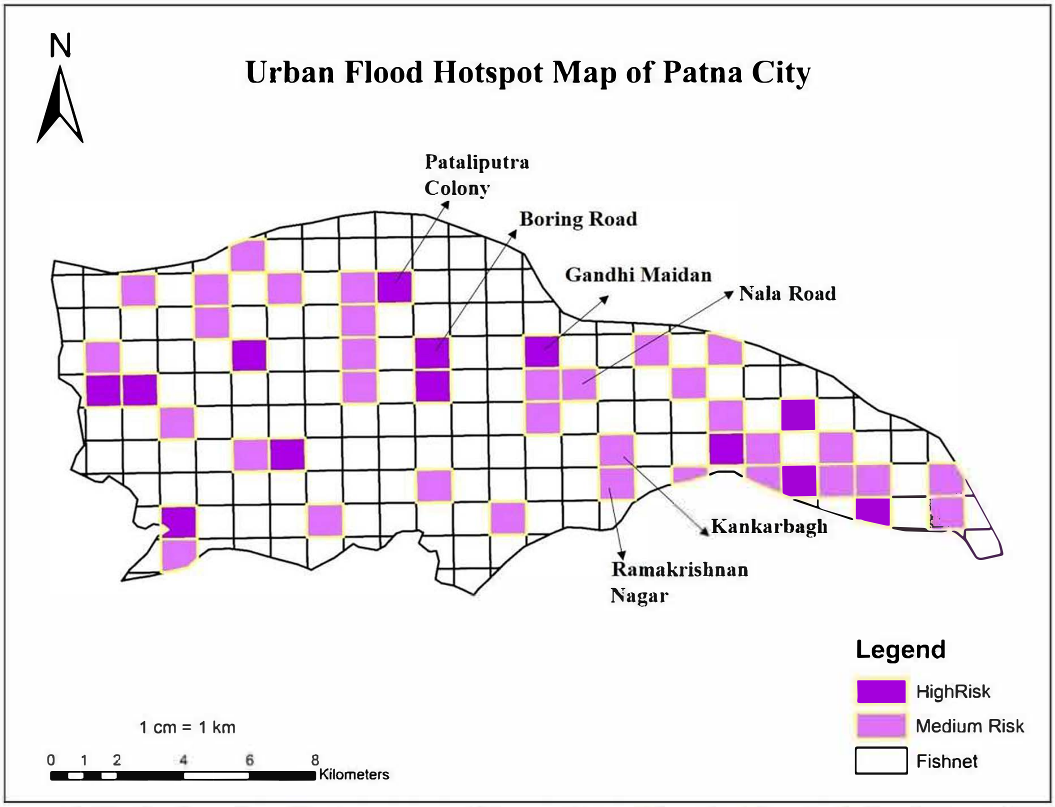

Figure 7: Final urban flood hotspot map of Patna city validated with actual flood sites of 2019

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A REVIEW OF ATTRIBUTES TO REINVENTING PUBLIC TRANSPORT PERTAINING TO URBAN MOBILITY AS SUSTAINABLE SOLUTION

Snigdha[1], Charu Nangia[2], Manoj Kumar[3]

[1] PhD Scholar, Amity School of Architecture and Planning, Noida, India,snigdhachaudhary2@gmail.com
[2] Professor, Amity School of Architecture and Planning, Noida, India, cdawan@amity.edu
[3] H.O.D, Professor, N.I.T, Patna, India, manojkr_nitp@yahoo.co.in

ABSTRACT

The rapid growth of India's urban population has put enormous strains on urban transport systems. One of India's major concerns is ensuring sustainable and efficient mobility of people, particularly in a progressively urbanised environment. City has been unable to deliver efficient, comfortable and affordable mobility options to its citizens. It is triggering to increase in travel demand and vehicular congestion that includes a number of modes and enables for efficient transfers in urban cities especially in mega and metropolitan cities.

An integrated multi-model strategy and last mile choices must be established and implemented to ensure network efficiency. Otherwise, a network's full potential is rarely realised, and a public transportation system's full potential neglected, causing riders to lag behind. In this alarming situation, it is imperative that a rapid paradigm shift undertaken in order to transit people away from private vehicles to public transportation.

There is an urgent need to reimagine and restructure the approaches, policies, regulations and concept pertaining to global mobility. The main purpose of this research is to assess the attributes of reinventing public transportation in the context of urban mobility, which is a long-term sustainable solution to last-mile options and traffic congestion around the globe, in order to improve public transportation and the physical environment for first-to-last-mile connectivity.

Keywords: Attributes of Last mile connectivity, Sustainable solution, Public Transportation, Feeder services, urban mobility

INTRODUCTION

The term "last mile connection" in the context of transportation refers to the completion of a journey made by public or mass transit, linking the point of origin and point of destination to stations or stops on the transit network. The provision of affordable and convenient last mile connectivity is a factor that demonstrated to have significant potential for increasing the quality and level of service of public and mass transit, but it is a field that has received little attention in Indian cities. There is extensive research to suggest that lack of good connectivity between mass transit stations and commuters' destinations may discourage commuters from using public transportation and have an adverse effect on ridership. The last-mile issue is more severe in underdeveloped nations, as mass transit systems frequently remain insufficiently linked with other modes of transportation, which exacerbated by the absence of a strong infrastructure for pedestrians and bicyclists. The first and last mile journeys' disproportionate time and cost implications are an indicator of subpar efficiencies, which linked to a lack of dependable connections, higher waiting periods, and steep transfer fines. Facilitating the construction of easy and secure access to transit facilities can result in substantial returns, as study by Brons. et al. in 2009 demonstrated. As mentioned by Cervero. in 2001, getting more rail transit users to abandon using private vehicles to access mass transit stations can have a number of positive effects, such as a decreased need for parking lots near transit hubs, a decrease in the total number of vehicle miles travelled, and a reduction in levels of traffic, air, and noise pollution. India's cities currently face a significant obstacle to sustainable mobility. Cities in India are seeing a rapid rise in the number of vehicles. It is rather alarming to note that from 1961 to 2011, India's population increased five times (from 79 million to 377 million), and the country's number of cities increased threefold (from 2,363 to 7,935). However, the growth of the country's vehicle population was marked by an astounding increase of about 200 times (from 0.7 million to 142 million) (CSE, 2013). The largest portion of them are the bigger cities, including metropolises and megacities, with Delhi clearly in the lead.

Evidence points to intermediate paratransit and new mobility services as potential significant players in closing the last-mile gap between mass transit and automobiles. According to Shaheen and Chan (2016), shared mobility services give passengers temporary access to transit services as needed. They draw attention to how on-demand services like car sharing, bike sharing, and micro-transit have altered how urban inhabitants use public transportation and connect to other modes. They provide access to mobility as a service, lowering the necessity for vehicle ownership and encouraging a greater dependence on shared and public transit modes by integrating with mass transit and providing dependable options of first and last mile connectivity. However, there is a lack of relevant data to assess the possible consequences of on-demand services on public transit, or their practicality in fixing the last mile issue. While several trials have merged innovative technologies and economic models to increase the service levels of public transport systems, most of them have been small-scale pilot projects that deploy new mobility services as feeders to public and mass transit networks.

Transportation system and patterns of land usage the distribution of land uses affects the transit system by disrupting travel infrastructure and mobility patterns. According to Duranton, Guerra, and Litman in 2016, land use patterns have an impact on accessibility, which has an impact on mobility, trip frequency, and travel demand. According to the study, urban cities have more manageable land use and a diverse transit system, whereas rural locations have less accessible land use and travel options, but mobility is less expensive per mile. In 2011, Todd Littman claimed that decisions involving both direct and indirect land use controls had been emphasised. In addition to having an indirect effect on development placement and design, the verdicts have a direct impact on land usage by altering the amount of land used for transportation facilities. There are many connections between land use and transportation.

PUBLIC TRANSPORTATION IN INDIA: AN OVERVIEW

The rapid growth of India's urban population has triggered an increased demand for transport in the cities and surrounding areas, with commuters taking multiple long trips each day. This has also meant an augmented need for public transport. Public transportation systems account for 30 percent of trips in cities with populations between one and two million, 42 percent in areas with populations between two and five million, and 63 percent in cities with populations over five million.

QUALITY ATTRIBUTES OF PUBLIC TRANSPORTATION

Definitions of public transport (PT) service quality attributes.

	Attribute	Definition
Physical	Reliability	How closely the actual service matches the route timetable
	Frequency	How often the service operates during a given period
	Speed	The time spent travelling between specified points
	Accessibility	The degree to which public transport is reasonably available to as many people as possible
	Price	The monetary cost of travel
	Information provision	How much information is provided about routes and interchanges
	Ease of transfers/ interchanges	How simple transport connections are, including time spent waiting
	Vehicle condition	The physical and mechanical condition of vehicles, including frequency of breakdowns
Perceived	Comfort	How comfortable the journey is regarding access to seat, noise levels, driver handling, air conditioning
	Safety	How safe from traffic accidents passengers feel during the journey as well as personal safety
	Convenience	How simple the PT service is to use and how well it adds to one's ease of mobility.
	Aesthetics	Appeal of vehicles, stations and waiting areas to users' senses

Source: L. Redman et al. / Transport Policy 25 (2013) 119–127

A large number of attributes proposed in attempts to define PT quality. These attributes may roughly be categorised as physical or perceived. Physical attributes measured without involving PT users, and assumptions made about the impacts on PT users. In contrast, to measure perceived attributes, PT user responses must be observed, either directly.

GLOBAL TRENDS CHALLENGES AND FORECASTS

Although the transition to a largely urbanised world formally recognised around the turn of the millennium, it took more than ten years to begin developing multinational regulatory frameworks on climate, sustainability, and biodiversity. Local and regional governments have aggressively embraced change alongside national governments, and occasionally even more actively. They are on the front lines of everyday difficulties, including a wide range of stakeholders and interest groups from civil society and the commercial sector. The most pressing concerns facing communities around the world include transportation, health, greener infrastructure, air quality, CO2 emissions, and greenhouse gas (GHG) emissions. As a result, cities are turning to faster environmental transformation and adaptation. This occurs in the context of broader global industry changes, such as digitization and the growth of on-demand mobility systems, which have a great deal of potential to help with the creation of new sustainable mobility strategies. Yet the world still needs to transition from fragmented experimental strategies to fundamental structural changes.

Over the previous ten years, the trend of car ownership has increased in the Commonwealth of Independent States. The motorization level of these nations is currently noticeably lower than that of industrialised nations, nonetheless, as initial reference levels were low. However, the ratio of automobiles per 1,000 people in several of these countries' largest cities is approaching 300--400, and it expected to continue to climb. The majority of nations have seen an increase in automobile usage as measured by the number of kilometres driven per capita along with the rise in the number of privately owned cars up until recently (and the trend continues in many).

In some regions of Europe, the opposite trend being driven by local governments and civil society, which see private automobile ownership and private car mobility, particularly in cars that run on fossil fuels, as significant barriers to sustainable lives. The recent significant social unrest in France, which brought on by the idea of raising the price on fossil fuels, particularly diesel, in order to finance a more carbon-neutral economy, demonstrates that the equation is not that straightforward. Along with the ideas, steps taken to lower the posted speed limits on the nation's roads. Car ownership isn't just seen as a lifestyle choice that may be altered to fit current trends in the peri-urban and rural areas surrounding France's major urban centres.

Global trends, whether they related to electro mobility, shared mobility, or active mobility, are altering mobility patterns throughout the UNECE member nations and having an impact on transportation systems and cars. Industry, society, and urban governance impacted by this. Urban patterns and mobility difficulties can rethought in many ways thanks to the economy's rapidly growing digitization, but doing so will require future cross-sectoral and multi-stakeholder collaboration.

ACCESSIBILITY AND DEVELOPMENT VERSUS CONGESTION

"A city living on total automotive dependence becomes dysfunctional, inefficient and inconvenient for life. The goal of the transport system is to move people, not vehicles"

Urban transportation experts concur that traditional and developed cities are no longer comfortable places to live as result of the unchecked increase in the usage of privately owned cars. Urbanization and population growth increase the need for transportation, population mobility, and the concomitant difficulties with access to some metropolitan areas, travel destinations, and transportation services. Large metropolitan road networks congested because transportation demand exceeds the capacity of the available road infrastructure. Major city administrations have long viewed expanding the capacity of urban highways through their rehabilitation and development as the primary method of reducing traffic congestion. The paradigm of "planning for vehicles in cities" served as the foundation for the respective transport planning theories that adopted during the century noted for "rapidly growing motorization." The practise has demonstrated that these attempts to address the problems of enhancing accessibility to urban areas and reducing congestion never produced long-term favourable results because of the creation of so-called "induced" mobility.

The reality of rising car ownership rates that have significantly exceeded the growth of urban road networks, as well as rising pollution and environmental damage brought on by increased road infrastructure, have underlined the need for a new paradigm for urban transport development. By shifting transportation demand toward safer and more environmentally friendly forms of transportation, or "urban mobility planning," the notion of "sustainable urban transport" or "sustainable mobility" aimed to maintain the population's mobility. However, despite all the advantages of this strategy, which already been largely adopted in many large cities, it is still a result of the specific transportation needs for which the public transportation system was created. Planning cities and transportation infrastructure around motor vehicle traffic continues to have significant negative externalities related to transportation activities in particular, resulting in 1,250,000 deaths annually from traffic accidents and 3,200,000 deaths annually from air pollution. It is obvious that we need to change the current transport paradigm and concentrate efforts on building vivacious, vibrant cities that can accommodate people's daily activities. A rising number of experts are beginning to recognise the significance of this method of urban planning.

FIRST/LAST MILE QUALITY ASSESSMENT

The initial and last miles of a public transportation trip are becoming more and more popular. This acknowledges that the passenger views the journey as a complete, from point of origin to point of destination, and that the success of the first and final miles (1LM) may influence overall trip pleasure. The success with passengers drawn to and kept on public transportation modes may have little to do with the quality of the modes themselves if the rest of the route is unappealing. This has significant implications for sustainable transportation goals. This could have effects on the efficiency and equality of transportation systems (Boarnet et al., 2017). Currently, there isn't a lot of research on the first/last mile and how it fits into the transit system. While a lot of study on the non-motorized environment has given solid insights into what required by pedestrians and bicycles, this research has less frequently focused explicitly on the first/last mile. Given that trip distances, purposes, and constraints may differ significantly between the two cases, it is unclear, for example, whether users of public transportation have the same preferences for and behaviour during the off-vehicle portion of a multimodal journey as for a trip entirely made on foot or by bicycle. The 1LM trip may consist of various modes, and may include a feeder bus or cab trip in addition to a walk or cycle component. The 1LM trip's multimodality raises a number of methodological issues, such as how consistently assess the quality of 1 LM experience and how to make meaningful comparisons between various cases.

The quality of the whole transit service measured in the transit literature using 1LM problems. As an illustration, the Transit Capacity and Quality of Service Manual (Kittleson & Associates Inc. et al., 2013) takes 1LM issues into account when determining how close stations and stops are to origins and destinations as well as how long it takes to get from door to door and what amenities are available to passengers. Although the concept of a multimodal service quality indicator is interesting, it is less helpful for researching the 1LM environment on its own because it combines the 1LM measures with those that pertain to the transit service. When it comes to route and station spacing, access distances are equally crucial in transit network design because the best layout trades off access time with overall journey duration (Ibarra-Rojas et al., 2015; Kuah and Perl, 1988).

ATTRIBUTES OF FIRST/LAST MILE ELEMENTS

First- and last-mile access has drawn a lot of attention in the literature on public transit. This includes a substantial body of research on factors like station spacing, accessibility to transportation, pedestrian environments, and cycling infrastructure (Beimborn et al., 2003; Karner, 2018; Liu et al., 2012; Zuo et al., 2020). Recent research interest has shifted to multimodality of public transportation, such as choice of access/egress modes including shared mobility options. This is due to the argument that an integrated multimodal public transit system can help increase transit ridership and expand the public transit catchment area (Bergman et al.,2011; Chandra et al., 2013; Krygsman et al., 2004; Shaheen and Chan,2016; Venter, 2020). Four broad categories can be identify to group the elements that influence the choice of access and egress modes that have been the subject of previous studies: 1) The trip's characteristics, 2) The traveller's socioeconomic traits, 3) The traits unique to each form of transportation, and 4) The traits unique to the built environment, infrastructure, and station area.

The most important parameters that affect mode selection are access and egress time and distance. When the distance is short, travellers must pick between walking and cycling, and as the distance gets longer, they typically opt for public transportation (Bergman et al.,2011; Givoni and Rietveld, 2007; Goel and Tiwari, 2016; Keijer and Rietveld, 2000; Rietveld, 2000). When the distance is less than a half-mile, Bergman et al. (2011) discovered that walking is the preferred means of access, whereas buses and light rail transit (LRT) take over for longer distances (greater than one mile). Goel and Tiwary (2016) discovered that for lengthier distances to metro stations, Indian travellers are more inclined to prefer buses and auto-rickshaws.

For the choice of mode, travel time is equally crucial. Additional travel disutility is a result of longer access and egress times. Commuters are less likely to take public transit if access and egress durations are disproportionately long (Cervero, 2001; Gutiérrez et al., 2011; Keijer and Rietveld, 2000; Murray, 2001; Zhao et al., 2003). However, interurban excursions take far longer than intraurban trips, and the amount of disutility caused by entry and egress delays is largely influenced by the overall trip distance (Krygsman et al., 2004). Higher access and egress times have less of a negative impact when the trip distance is substantially longer. The impact of time is partly dependent on the commuter's preferred major mode of transportation; commuters typically accept lengthier entry and egress periods if the primary mode provides a much greater level of service than the alternatives (Krygsman et al., 2004; Rietveld, 2000). According to certain studies, travellers' socioeconomic status also affects the access/egress mode they choose. The literature, which is scant, reports conflicting results regarding socio-economic characteristics. Age, gender, and income of travellers shown by Meng et al. (2016) to have a substantial impact on the last-mile mode choice from rail stations in Singapore. Male travellers are more likely than female travellers to bicycle and walk. The survey also discovered that older travellers are more likely to pedal than younger ones, and that lower-income travellers frequently pick bicycles over buses.

Among other aspects, attitudes and prior travel experience can also influence access/egress mode choice (Bergman et al., 2011; Wardman and Tyler, 2000). (Bergman et al., 2011; Wardman and Tyler, 2000). Several research study the role of built-environment elements in mode choice (Cervero and Duncan, 2003; Krygsman et al., 2004; Zhao and Li, 2017). (Cervero and Duncan, 2003; Krygsman et al., 2004; Zhao and Li, 2017). The research discovered that micro-level elements like trip origin, employment density, land-use mix, and transportation infrastructure near the station linked to mode choice. Additionally, crucial are the station's location and the features of the surrounding region, such as parking options. In Denmark (Halldórsdóttir et al., 2017) and the Netherlands, it was discovered that the presence of bicycle parking at the rail station greatly increased the likelihood of bicycle use (Givoni and Rietveld, 2007; Martens, 2007). The majority of earlier research on access/egress mode choice done in the U.S., the Netherlands, and China, with a particular emphasis on systematic feeder mode services, as well as bicycle and car modes. Few studies have been conducted in the context of developing nations in the Global South, where informal transportation modes like rickshaws and paratransit modes play a crucial role in providing mobility service to a significant number of people and where transportation supply characteristics are different (Goel and Tiwary, 2016; Rastogi and Rao, 2002). Additionally, the access or egress stage generally been examined in studies, with the access mode selection receiving more attention. However, connectivity on both ends is necessary for the total transportation service. Between the access and egress stages of travel, several forms of availability and user preferences may exist. By concentrating on the mode choice during both the access and egress phases of transit commuting, this study adds to the body of existing work (both bus and rail). The study also emphasises the parallels and discrepancies between entry and exit at the destination and at the activity end of journeys. The multi-modal public transportation network's deficiencies found through this study, and viable methods for enhancing transit performance developed as a result.

According to Reports and journals; Sustainable Mobility, First and last mil connectivity, Citizen Preferences, Frequency of service' and 'quality of infrastructure' are the top barriers to public transport among both men and women. Based on the case studies and the best practices around the globe, these are the following list of indicators from the research papers.

Table 1 : Define the Categories and attributes included in first/last mile quality assessment based on literature review.

Authors	Indicators
Litman (2018)	Regional accessibility, density, last mile connectivity, parking and mobility management and road design.
Newman and Kenworthy (1991)	Provision of infrastructure, high density and dependence on automobiles
Calthorpe (1993)	Mixed-use, high-density, nearness to public transit, walking environments and use of automobiles.
Li, Lin, and Hsieh (2016)	High-density, mixed land-use, walking environment and high quality of public highway transportation services
Parker, Mckeever, Arrington and Smith-Heimer (2002)	Moderate to high density, distance to transit, mix of residential, employment and shopping opportunities
Hale and Charles (2006)	Vibrant, dense, mixed use, quality public spaces and access to public transit
Higgins and Kanaroglou (2016)	Ridership
Cervero and Kockelman (1997)	Density (population density, employment density and accessibility to jobs). Diversity (dissimilarity index, entropy, vertical mixture, intensity of land use categories, activity centre mixture and proximities to commercial-retail uses). Design (street design, pedestrian and cycling provision and site design).
Ewing and Cervero (2010)	Destination accessibility (job accessibility by transit and distance to downtown). Distance to transit (distance to nearest transit stop)

Brooks et al. (2008)	Ridership, street design, public spaces, parking management, community involvement, affordable living, capture value of transit, station connectivity
Hancock et al. (2014)	Connect, innovate, efficient, place, mix and shift
Sun (2013)	Connectivity, Inclusivity, liveable environment
Times of India (2018),	Subsidised road taxes, free parking, integration of public transport systems
TOD (2017)	FSI, road density, population density, ground coverage, public domain, built form, block size, pedestrian track, cycle track, public spaces and parks, hawkers, on-street car parking, off-street public parking, BRTS stops, MRTS Stops and feeder bus stop
Self (local factors and daily practices of people)	Proximity to metro stations, building density, land-use diversity (vertical and horizontal), employment density, building height, building age, built typology, intersection density, Bus stops, auto rickshaw stops and cycle stations, street classification, property value and percentage of private parking.

CRITICAL ANALYSIS

On the above-mentioned research papers major emphasizes on the parallels and discrepancies between entry and exit at the destination and at the activity end of journeys. The primary focus of this study is on how transit systems affect land use, which raises crucial questions about the locations, types, and costs of development projects, as well as accessibility issues and traveler preferences and performance. By focusing on last-mile connectivity variables and mobility patterns, the study seeks to uncover the traits of urban transportation users, cars, modes, infrastructures, and services. The multi-modal public transportation network's deficiencies can be find through this study, and viable methods for enhancing transit performance can be identify as a result. Based on above literature review the attributes and indicators categorized to review the quality assessment to identify the intention of people from public transportation to private vehicles. These indices may be more useful in evaluating performance direction to reinventing public transportation pertaining to urban mobility as a sustainable solution once the cities are prepared to compete with essential understanding of sustainable practices across and within different sectors of urban development.

Figure 1. attributes and indicators categorized in quality assessment based on literature review.

CONCLUSION

Three pillars for a sustainable future for cities are social, economic, and environmental well-being. India still behind in developing a sustainable public transportation system, despite progress demonstrated across a small number of measures presented under all three indices. An integrated multi-model strategy and last mile choices must be established and implemented to ensure network efficiency. Otherwise, a network's full potential is rarely realised, and a public transportation system's full potential neglected, causing riders to lag behind. There is an urgent need to reimagine and restructure the approaches, policies, regulations and concept pertaining to global mobility. The main purpose of this research is to assess the attributes of reinventing public transportation in the context of urban mobility, which is a long-term sustainable solution to last-mile options and traffic congestion around the globe, in order to improve public transportation and the physical environment for first-to-last-mile connectivity.

The primary focus of this study is on how transit systems affect land use, which raises crucial questions about the locations, types, and costs of development projects, as well as accessibility issues and traveler preferences and performance. By focusing on last-mile connectivity variables and mobility patterns, the study seeks to uncover the traits of urban transportation users, cars, modes, infrastructures, and services. The strategies and recommendations for reducing traffic congestion, last-mile connectivity, and the environmental effects of transportation. To investigate the effects of these elements on commuters' travel characteristics and mode selection choices, it is possible to study specific station area qualities, such as density, land use mix, walkability, and station area to identify the attributes. The indices present key objectives to support each index's goals; however, they cannot viewed as subordinates to achieving sustainability indicators. In order to suggest ways for building sustainable cities, there needs to be a mindset shift because this contradicts the goal of these indices in measuring mobility patterns. India must give sustainability goals top priority in order to support city development plans. In this alarming situation, it is imperative that a rapid paradigm shift is in order to transit people away from private vehicles to public transportation.

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REVIEWING THE CORRELATION BETWEEN SOCIO-ECONOMIC CHARACTERISTICS AND DOMESTIC ENERGY CONSUMPTION OF DEVELOPING AND DEVELOPED COUNTRIES

Dorsa Fatourehchi [1]*, Masa Noguchi [1] and Hemanta Doloi [2]

[1] ZEMCH EXD Lab, Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, VIC 3010, Australia, Masa.noguchi@unimelb.edu.au

[2] Smart Villages Lab, Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, VIC 3010, Australia, Hdoloi@unimelb.edu.au

ABSTRACT

Despite the impact of energy use in buildings on carbon dioxide (CO2) emissions and global warming, oil-rich countries continue to rely heavily on fossil fuels as their main energy resource in contrast to other countries placing high energy costs on the consumers. As one of the oil-rich countries, Iran has historically been increasing energy use, particularly in the domestic sector, contributing to a large portion of CO2 emissions. Domestic energy use seems to be related to socio-economic characteristics. Iran has no exception, and without identifying such characteristics, it may be difficult to understand the increasing trend of its domestic energy use. To clarify the dramatic increase in Iranian domestic energy use, this study first compares different countries' characteristics related to their energy use patterns based on international databases. Second, their economic and socio-demographic factors will be analysed and explored using the relevant literature. Statistical data analysis between socio-economic characteristics and domestic energy use of countries are selected to understand the oil-rich nations' tendencies. This research is limited to the comparative study between socio-economic characteristics and domestic energy use patterns of Iran and other oil-rich countries with little consideration of the nation's policies and the impacts. Thus, the effect of the countries' dedicated policies and/or propaganda on energy use may require further studies.

Keywords: Oil-rich countries, domestic energy consumption, socio-economic and demographic characteristics, Iran.

INTRODUCTION

Following the enhanced greenhouse effect (IPCC, 1990), "Climate Change 5th Assessment Report" (AR-5) was published (IPCC, 2014), highlighting the critical role of human activities in global warming. These activities mainly include human consumption of different sources of energy, mainly fossil fuels. This has resulted in greenhouse gas emissions of environmental pollutants, amongst which CO2 has more than 50% of the contribution to global warming (IPCC, 2018). Therefore, a close correlation has been found between greenhouse gas emissions and human development (Costa et al., 2011).

IEA revealed one of the important sectors generating energy-related CO2 to be buildings, accounting for 17.5% of the overall emissions. Among different types of buildings, the housing sector has the largest contribution to CO2 emissions (IEA Net Zero by 2050 2021: 131) (Fig.1).

According to the report "SR15" (IPCC 2018: 3), the Paris target might be reached through 45% reductions in CO2 by 2030. Therefore, based on the IPCC reports, it can be concluded that amongst the several gases contributing to global warming, special attention needs to be paid to reducing CO2 emissions, as it has the largest share. It is worth mentioning that this global environmental externality is not limited to a specific country or region. In fact, some countries are causing additional challenges to long-term sustainability due to their social and economic trends (Dissanayake et al., 2020). In other words, such socio-economic developments can be correlated to the energy use of countries (Jakob et al., 2014). For instance, (Bhattacharjee et al., 2014, Guerra-Santin et al., 2016) noticed connections between residential energy consumption and the economy as well as households behaviour. In terms of economic perspective, there are countries that are allocating energy subsidies for different energy resources, aiming to reduce energy costs for their end-users. However, the low fuel prices have caused major external effects (e.g., local air pollution) in such a way that achieving net-zero emissions might be difficult in the future. In addition to the economic dimension, social and behavioural factors have also been recognised as critical factors influencing energy consumption worldwide (Ghofrani et al., 2021).

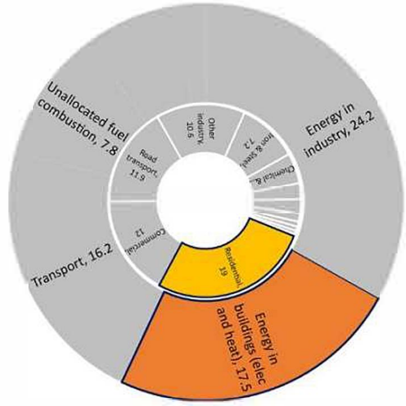

Figure 1. Building's GHG share (%) in the world.
Source: World Resources Institute, 2020.

Although the correlation between socio-economic factors and domestic energy use has been studied in different countries, this may become considerably case-specific with different situations between socio-economic characteristics and topics in domestic energy use. Moreover, despite the existing studies in terms of energy subsidies and their effect on energy consumption (Charap et al., 2013, Al Iriani and Trabelsi, 2016, Mousavi et al., 2017, Gazder, 2017), further investigations are needed to explore other socio-economic factors of a country on the outcome of households' energy consumption patterns. Therefore, this study aims to understand different countries' characteristics related to their energy use patterns and the way in which economic and socio-demographic factors could affect domestic energy use. Nonetheless, oil-rich countries' tendencies and the energy related behavioural patterns are vaguely known or well-defined in terms of the housing sector of Iran or in the global context. To address this issue, this study implemented a comparative analysis in the international context to explore the effective factors related to their energy use patterns in different developed and developing countries. Afterwards, their economic and socio-demographic factors were analysed and explored for further discussions of the results pertaining to Iran in terms of domestic energy consumption. The study's results can provide a further understanding of the critical factors affecting different countries' domestic energy consumption as well as future energy efficiency solutions for the domestic sector in oil-rich countries.

Energy-related subsidy status in different countries and Iran

Energy-related subsidies are mostly used in oil-rich countries to lower energy expenditures for end-users, aiming to raise living standards while increasing economic activity (Kaygusuz, 2012). However, such subsidies can also affect sustainability, by encouraging overuse of fossil fuels, because the highest energy subsidies are considered for energy resources of oil, electricity, gas, and coal (Fig.2). Amongst the countries with high energy subsidies, Iran is taking the lead in electricity and gas subsidies, making it not only the cheapest for subscribers, but the most important country to be further investigated in terms of energy consumption in a global context.

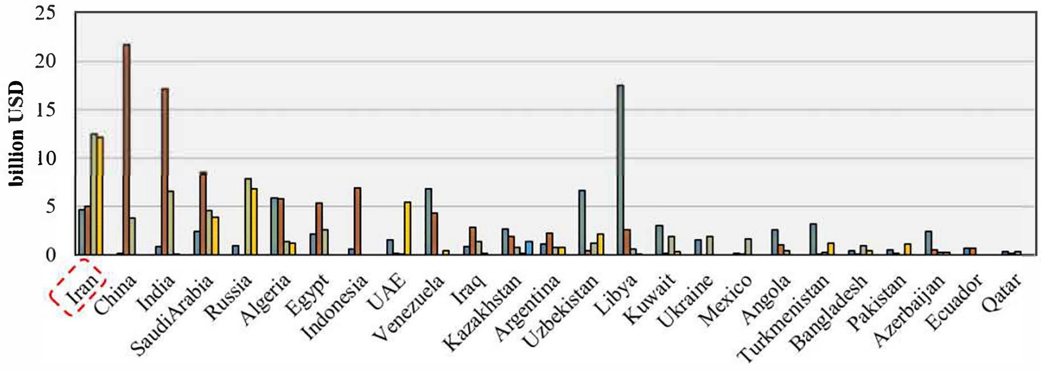

Fig. 2. Energy subsidies of countries by fuel type.
Source: IEA, 2021.

Overall, the energy sources in Iran are coal, natural gas, nuclear, crude oil, and renewable resources (Bernard, 2020). As a result, due to heavy subsidies, there is an increasing trend towards CO_2 emissions from natural gas in Iran as compared with other primary energies (Fig.3). This can be an expected result since power plants in Iran mainly consume natural gas for end-use natural gas and electricity production for lighting, cooling, and heating in buildings (Fig.4). This can demonstrate the reason behind the significant contribution of buildings in terms of energy consumption not only for the world but also for Iran.

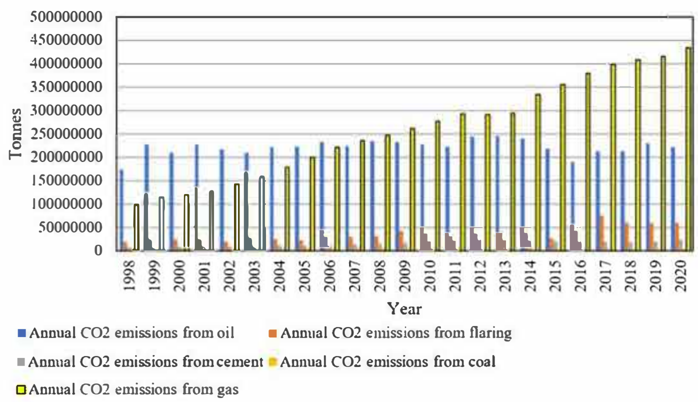

Fig. 3. CO_2 emissions by fuel in Iran
Source: Friedlingstein et al., 2021.

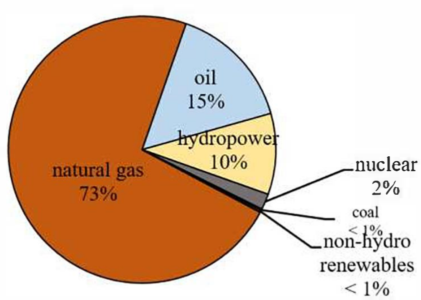

Fig. 4. The primary energy use in Iran by fuel type, 2019
Source: Bernard, 2020.

Dependence on different fossil fuels in different countries

As indicated previously, most of the oil-rich countries are heavily reliant on fossil fuels as their primary energy to generate electricity due to energy subsidies. This means that as the electricity price decreases, the dependence on different fossil fuels can increase in these countries. Therefore, as one of the cheapest in the electricity price, Iran has continuously relied on fossil fuels, which has caused a dramatical increase in electricity consumption from fossil fuels in Iran (Fig.5). According to the figure below, most of the countries had formerly dependent on fossil fuels in the past years. Therefore, it can be concluded that those countries without energy subsidies had a descending trend in their reliance on fossil fuels for electricity generation.

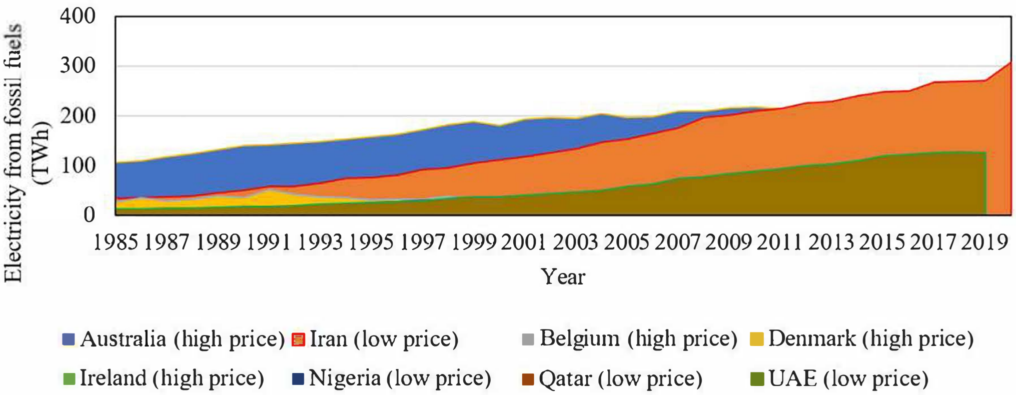

Fig. 5. Comparison of electricity generated from fossil fuels in low and high electricity price countries
Source: Jones, 2021.

The same as other oil-rich countries, fossil fuel consumption used to be high in developed countries such as Australia. However, this may raise a question in terms of a higher segment of fossil fuel use in Australia due to its lower population when compared to Iran. With a population of nearly 22.03 million in 2010, Australia generated more electricity from fossil fuels compared to Iran with 73.76 million people (World Bank, 2010). The comparative analysis between the three countries showed that the per capita in electricity use for Germany and Australia is currently higher than Iran. This can be justified by various reasons, namely the types of houses, climate, or other affecting reasons. However, although there was a high electricity per capita in those countries, a dramatic decrease in fossil fuel consumption was seen especially after 2011. This explains their shift in inclination towards using cleaner energy resources. Another important point which can be inferred from this comparison is that in later years, unlike Iran, Australia has gradually started to decrease the per capita electricity use by gradually growing its dependence on renewable energy resources over the years. In other words, although Australia's per capita consumption did not decrease, the dependence on fossil fuels decreased because of considerable investments in clean energies (Figs. 6).

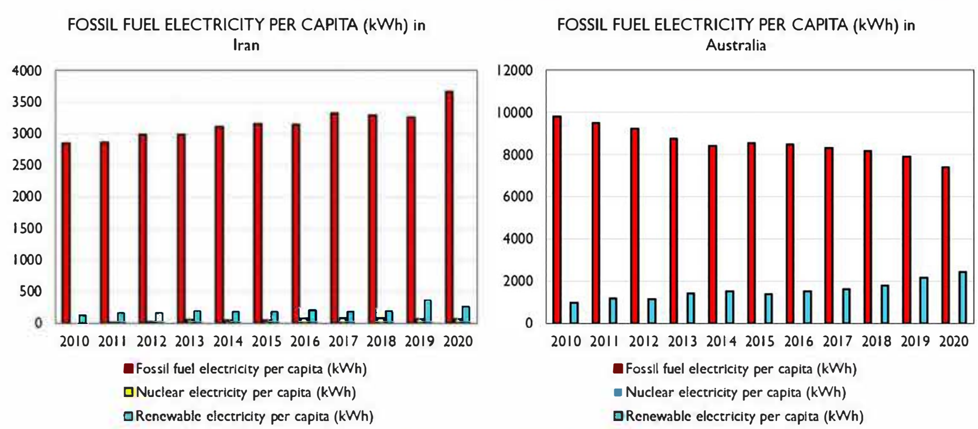

Fig. 6. Per capita fossil fuel electricity of Australia and Iran
Source: BP Statistical Review of World Energy & Ember, 2022.

It is worth noting that the same trend was seen in some countries with greater electricity costs, such as Belgium and Denmark (Fig.7). Their dependence on fossil fuels has decreased over time by investing in more clean energies. Though, in countries with smaller electricity costs, such as United Arab Emirates (UAE) and Qatar, fossil fuel use is growing over the years (Fig.8).

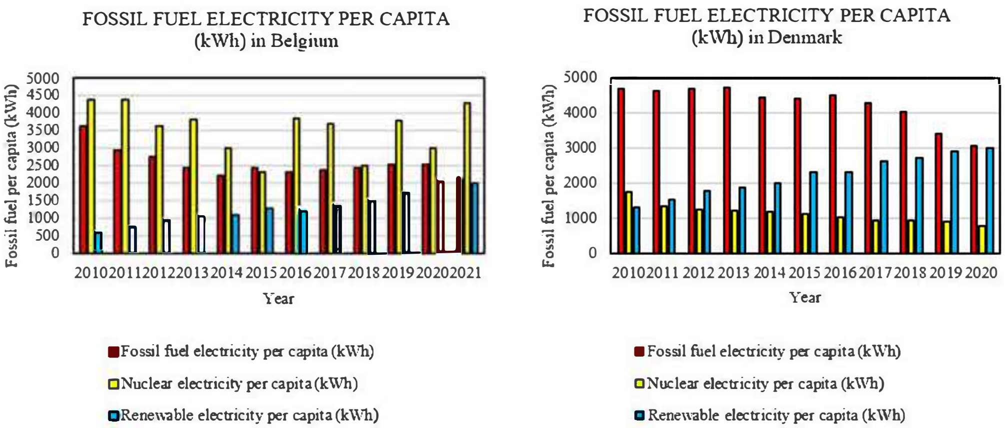

Fig. 7. Per capita electricity from fossil fuel in Denmark and Belgium
Source: Our World in Data 2021.

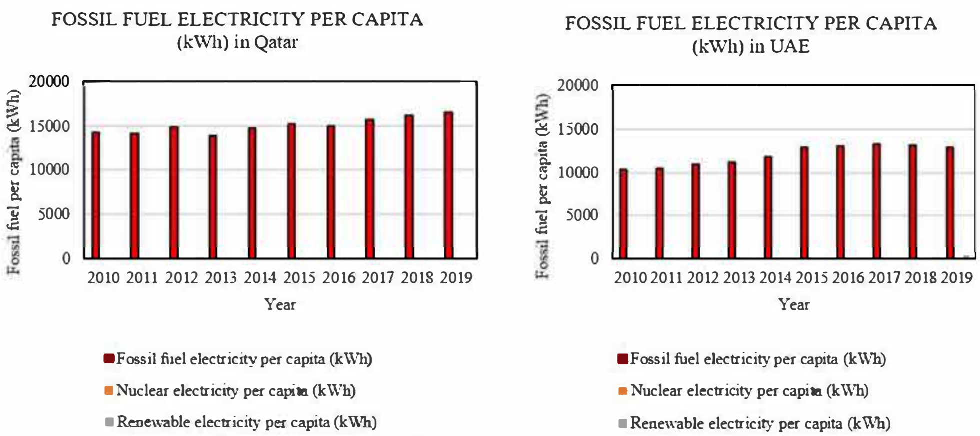

Fig. 8. Per capita fossil fuel electricity in UAE and Qatar
Source: Our World in Data, 2021.

Comparison between countries showed that Iran has a rising tendency towards fossil fuel dependence while reducing renewable energy consumption due to limitations such as a slow rate of renewable energy share, and low energy costs. This has negatively affected the climate while encouraging the behaviour of households towards considerable electricity usage due to lower electricity costs than in other countries. Therefore, subsidies have substantially impacted energy-related behaviour.

As a result of relying on fossil fuels, Iran mainly uses natural gas for end-use electricity for cooling and lighting as well as heating and cooking. According to the Energy balance report in Iran (2020) (Ministry of Energy, 2020), a larger share of CO_2 emissions belongs to natural gas in residential and commercial sectors (Fig.9). However, the comparison between the residential and the commercial buildings, a large portion of electricity from natural gas belongs to the former sector (Fig.10), making it one of the highest energy demanding sectors in Iran (Fig.11). Therefore, a large amount of CO2 emissions is attributed to the residential sector in this country.

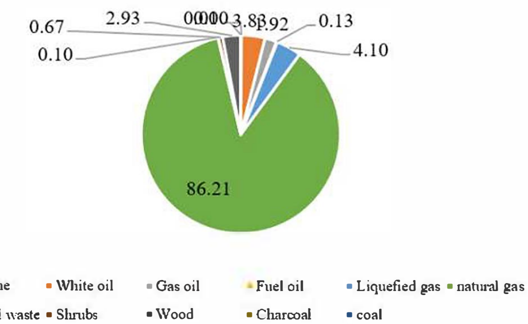

Fig.9. Share of different fuels on generating CO_2 in the domestic and commercial sectors in Iran **Source:** Ministry of Energy, 2020.

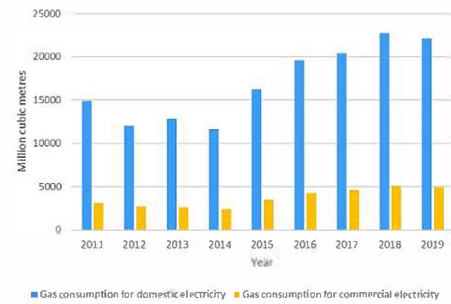

Fig.10. The amount of natural gas used for domestic vs commercial electricity generation **Source:** Ministry of Energy, 2020.

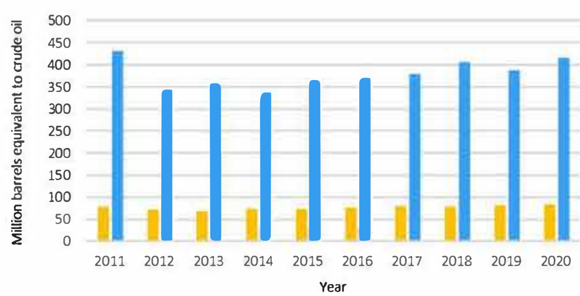

Fig.11. Energy demand in Iran's domestic and commercial sectors **Source:** National Statistics Centre of Iran, 2020.

Factors correlated with the trend in electricity usage in Iran

To discover the factors impacting the electricity usage in different countries with low and high electricity costs, this research compared Iran and Australia and gathered specific information regarding electricity consumption as well as household size from different resources to understand the important socio-economic factors affecting electricity use (National Statistics Centre of Iran, 2021, Australian Bureau of Statistics, 2017). It can be inferred that there is a correlation between the reduction in household size with the decrease in Australia's electricity usage, which is an expected result (Fig. 12). However, this correlation was not observed in Iran. Despite the reductions in the Iranian household size, housing electricity usage constantly had an increasing trend from 2011 to 2020. Therefore, Iran may not be efficient in electricity usage, which can be related to other important factors such as behaviour.

A necessary mental shift in Iranian households' electricity consumption

It seems that electricity prices can be associated with the reduced demand for electricity. However, when this study implemented a comparative analysis in terms of the price between Denmark and Iran, a significant gap was observed, which can clarify the increasing trend of Iran's electricity demand. Therefore, despite the dramatic growth in the electricity cost, a small portion of households' income goes to the energy cost

(Fig. 13). Based on the raw data from the Iranian National Statistics Centre, the lowest and highest income of households allocate 6.8% and 2.5% of the income to energy expenditures, respectively.

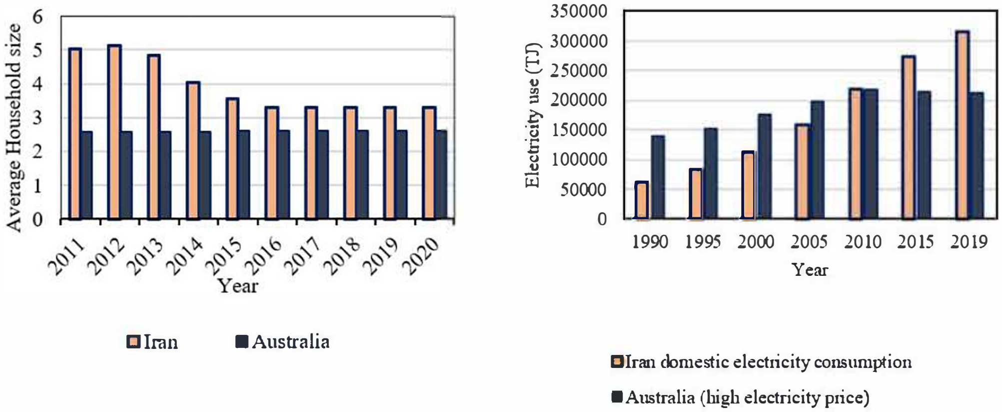

Fig. 12. Average size of the households compared to the domestic electricity usage in Australia, Germany, and Iran.

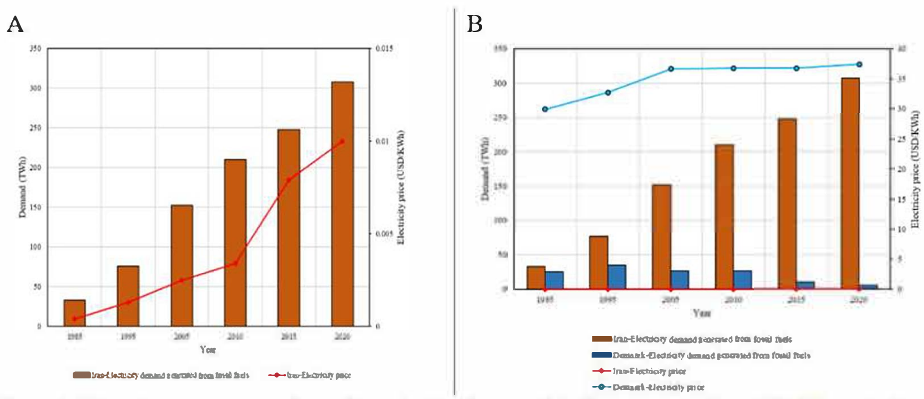

Fig. 13. A) Electricity price compared to electricity demand in Iran over time B) Electricity demand and price comparison between Iran and Denmark
Source: Ministry of Energy, 2021.

Following the growth of the electricity demand in Iran, it appears that there is a requirement for a mental shift of households to have a more conscious way of living by reducing electricity use. The reason behind this is that the behaviour might play a crucial role in affecting the electricity use in the housing sector in Iran.

CONCLUSION

This study investigated different countries' characteristics related to their energy use patterns and the way in which socio-economic factors could affect domestic energy use. For this purpose, this study compared different developed and developing countries to understand their tendency of energy use and the issues impacting Iran's energy use in a larger scale.

The comparison between high and low-price energy of different countries revealed that energy subsidies in oil-rich countries have negatively affected electricity produced from fossil fuels. Some countries such as Denmark, Belgium, and Australia, were successful in decreasing their reliance on fossil fuels by investing in renewable energies as well as increasing their electricity price which has successfully functioned as an intervention for households' electricity consumption behaviour. However, other countries such as Iran, Qatar and UAE had an increasing trend in electricity generated from fossil fuels. Moreover, due to lower electricity prices in those countries, the behaviour of households has been influenced and has encouraged their households to consume electricity inefficiently. It was concluded that although Iran has a decreasing trend in household size, their electricity usage per capita is constantly increasing due to energy subsidies and behavioural related consumption.

The study results contribute to a future understanding of the critical factors affecting different countries' domestic energy consumption and future solutions for the enhancement of energy efficiency in the domestic sector in oil-rich countries.

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THE EFFECT OF CLIMATE CHANGE ON RESIDENTIAL THERMAL COMFORT IN METROPOLITAN TROPICAL LOW AND HIGH ALTITUDE AREAS

Karl Wagner[1], Shaila Bantanur[2]

[1] Prof. Dr., Technische Hochschule Rosenheim, Germany, karl.wagner@th-rosenheim.de
[2] Director, Prof. Dr., BMS School of Architecture Bangalore, India, shailabunty@gmail.com

ABSTRACT

Principal researches on how to curb climate change in the face of the emerging huge populations in tropical countries are rare. Hence, the knowledge gap of how occupants can contribute practically by accepting higher temperatures in existing or upcoming Mass Custom Homes is obvious.

Looking for most energy-efficient ways, the authors wanted to find out the upper temperature space limit during the cooler night times. Its target is a temperature / relative humidity model that creates a customized night time thermal comfort, reducing carbon emission as well and hereby saving costs. To begin with, the authors showcase how by the influence of the three Karnataka tropical highland seasons can work by drawing up to the highest acceptable nighttime temperatures into the building compared to low altitude regions which are much more dependent on air conditioners. The authors compare the historical Bangalore meteorological 1990 and 2020 outside temperature data, to see whether it has already so dramatically increased that only the air con can help. In addition, the article's scope is to find out the advantages of outside night time temperature in tropical highlands compared to equator-near tropical coastal areas.

The main research outcome states that under the conditions of Karnataka harvesting the outside night temperatures mainly by mechanical ventilation present a high potential for saving carbon and creating more healthy indoor air than with split units of air conditions or opening the windows for natural air. By its findings, it further states that not one, but 3 ideal types of adaptive occupants with different acceptability of highest temperatures can be differentiated. It can be concluded that the air condition is almost jobless for 2 of the 3 customised types for those who operate and there id no need to purchase for those who so far live without.

INTRODUCTION

World leaders pledged tougher new carbon emission reduction targets at the virtual climate summit in April 2021. They stepped up the fight to limit the global temperature rise to 1.5°C above pre-industrial levels, instead of the 3 °C the planet is currently heading to. The 2020s are "the decade we must make decisions that will avoid the worst consequences of the climate crisis" (world leaders summit host Joe Biden)[1].

In the year since the meeting took place, IPCC (international Panel for Climate Change) detected that the planet will be on a runaway train toward drastic climatic catastrophes with a dead-end - if not the decisive steps for the three main CO2-contributors transport, industry and buildings are prepared and decided in 2021 and 2022[2]. Instead, among stagnating disappointments, lately a squadron of warmongers are spreading more CO2 then ever in East Europe – even pursued and endorsed by former

[1] https://www.gaebler.info/2019/10/email-to-greta-thunberg/
[2] Because the issue of climate change is real, we will not refer to the present bold discussion that climate change is just a typical cycle, which nature repeats in regular periods (Taylor, 2020).

"green" pacifist fundamentalists. They throw even more gasoline into the burning fire of overheating by answering military violence with equal violence[3].

Instead of frustratingly resigning, the novel approach presented here invites people from all political colours around the globe to think how climate catastrophe stopping plans could work on a larger scale for mass customized homes, without necessary thick arcane binders of official policy agreements. We, in charge of building R&D can take on some accountability for suggestions to reduce those 40% of global warming that building techniques are responsible for. Among other actions of swiftly developing affordable tools like RE for the masses, building science can play a vital role firstly looking at "*glocal*" warming. It is defined as tropical change of temperature at a certain city or area. It is locally produced, and still echoes in what is happening globally. This entails the question, what architects, developers, and the people in their residential communities in their own area can do to pull the right handle. It is all about our impact to shape a joint brain of building experts, not knowing whether policy makers will follow, but looking into the market potential and the potential buy-ins of industry players in a liberal society like India.

In this novel approach we will not only (1) create awareness of how bad global warming was and is over the past 30 years in comparison of two 8 million tropical megalopolises in India and Malaysia. Were the increases of *glocal* outdoor temperatures within the *global* Paris agreement limit or does one or another or both exceed? (2) Understanding differences between the two tropical cities will lead us to (3) how to select among renowned indoor thermal comfort standards under the circumstances of natural outdoor air supply. (5) In addition to the current problems on climate change, indoor air quality, overheating risk of buildings, thermal comfort are subjected at the same time.We know that if we can 'smartly' switch temperatures just slightly higher, which equates in "as high as possible", we can save millions of carbon in city homes and their communities. However, any higher temperature than the standards following ASHRAE ought to be in line with surveyed thermal comfort preferences of its occupants. Therefore, we will develop (6) a bottom-up adaptive tropical model of *TRTC (Tropical Residential Thermal Comfort)* where the so-called *USL (Upper Space Limit)* is the highest acceptable temperature benchmark for the occupants to pursue (5, Wagner (2017)). As humans have different necessities in terms of how high the maximum temperature should be, in a pilot night time study for sleeping rooms -as the easiest way to harvest cooler temperatures- we refer to *three* different research-based adaptive types of USLs that build upon each other.

The main question about higher temperature is about mechanical ventilation eventually in combination with air conditioners. It is a novel hybrid, easy, affordable and smart concept of natural night time ventilation in more insulated, shaded and a bit more airtight homes[4]. The concept even for cooler nights proved questionable for Kuala Lumpur in an earlier study between 2014-2019. But receiving and utilising outside supply air can be highly compatible under the climatic circumstances of the low night time temperature blessed Bangalore and the highlands of Karnataka. With very few compromises during the hot season (March to May), almost every night natural mainly "forced" ventilation can help to reduce the operation of air conditioners in standard homes almost towards "zero carbon", depending on the occupants' acceptability below (characterised by the following three types i, ii or iii).

GLOCAL WARMING COMPARISON BETWEEN TWO MEGALOPOLIS CITIES: KUALA LUMPUR (KL) AND BANGALORE (BGR).

Even though Global Warming is always global, as the CO2 and other gases emitted mingle and are not restricted to any air borderline once is has risen into the Planet's atmosphere, it is still interesting and motivating to see how "glocal" warming contributes to global overheating. We chose Kuala Lumpur (KL)

[3] Grüne Basis stimmt für Waffenlieferungen an die Ukraine (Green Party Base advocates Weapon Delivery to the Ukraine) – Süddeutsche Zeitung 20/4/2022.

[4] "Airtight" cannot yet appeal to the stronger standards of certified Passive houses of < 0.6/h (at 50 Pa), but described the attempt to remove at least detectible air leakages by thermal images e.g. with tapes and extra-insulation.

and Bengaluru/Bangalore (BGR), because both are situated in the tropical belt between 3.1390° N, 101.6869° E (KL) and 12.9716° N, 77.5946° E (BGR) latitude. However, the megalopolis of KL – typically for all cities around a country like Malaysia and also plenty of them in India –is located on a low altitude of 0-66m above the sea level. Bangalore in its moderate climate is located in an altitude of 972m with tremendous pleasing consequences especially in terms of annual night time coolness:

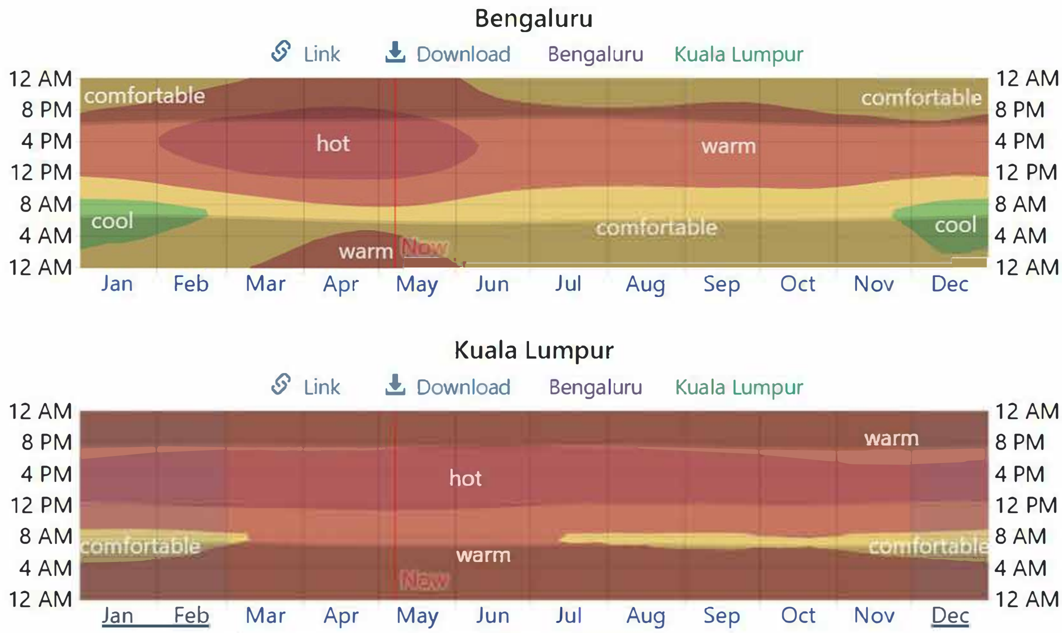

Figure 1: Annual rough classification of BGR and KL weather data clearly anticipating the cooling value between 12 am and 9 am[5]

In this overview, it can be seen at the lower leaps that during most seasons the climatic outdoor conditions in Bangalore over night are comfortable or even cool. In the Kuala Lumpur area, "comfortable" conditions appear to be very restricted. In addition, the most astonishing fact based on the "official" meteorological database that can be derived from the 12 months hourly taken data of both cities between 1990 and 2020 is the fact that *the temperature in KL rose by 1.8°C on average, whereas in Bangalore the increment was "just"* lenient with *0.3°C*[6] (1990: 23,5791895°C, 2020: 23,86733°C). The correlation of the hourly data comparing 1990-2020 is quite high (0.87) which for the whole year from January until December can be easily visualised by a daily time series plot (run chart):

This less worrisome result for the Indian metropolis coincided so far with the trend within the Paris agreement before it was even established. Assessing the ISHRAE-data with a minor statistical analysis, this

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[5] https://weatherspark.com/compare/y/108998~113829/Comparison-of-the-Average-Weather-in-Bengaluru-and-Kuala-Lumpur. Weatherspark is an overview visual comparison tool showing average temperature between selected cities over the year, but it is less useful for calculations where every degree C for set points and USLcalculation counts. Conclusions could be drawn for other equatorial cities and areas around the globe.

[6] For 2018-2020 we needed to rely on extrapolation, as the meteorological department in Malaysia / Petaling Jaya measurement station failed to deliver the full data. Kuala Lumpur's temperature. Extrapolated just linearly to 2050 would increase the temperature by another 1.8°C beyond the borderline of human acceptability, would make some regions inhabitable without air condition (Lesch, 2021). This again catalyses the carbon footprint further or trigger a major migration towards the cooler highlands like in Malaysia the Titiwangsa range (which is the mountainous spine of the country), the Ranau Area in Borneo or Karnataka Highlands in India, which already has become a well requested place for commercial and private entities (Standortportal Bangalore. In: https://en.wikipedia.org/wiki/Bangalore). For Bangalore, we used the official ISHRAE hourly weather data.

lenient result is *not* even counter-echoed by rampant standard deviations. These would have created an unassuming average score, alongside with heat waves and periods of very low temperatures which could not be verified in the pilot study.

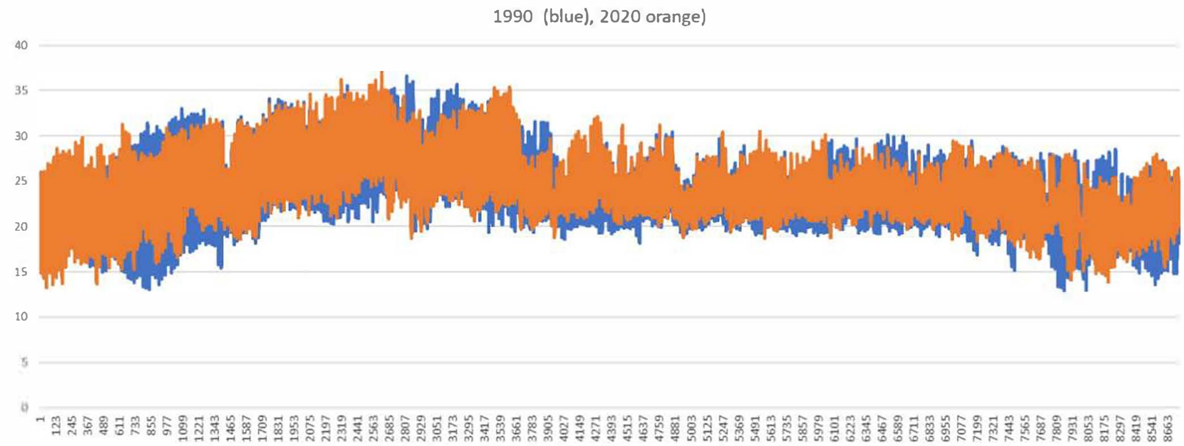


Figure 2: Bangalore's "dry bulb" ambient daily temperature 1990 (blue), overlapped with 2020 (orange)

Even though Bangalore still seems "green" in terms of temperatures (even quite unimpressed by the Indian heat wave in May 2022), as aforementioned, "glocal" warming does not presume that Global Warming is not everywhere. Hence, it would be a completely wrong sign in a traffic-and industry-ridden city like Bangalore to be complacent, and continue to build and refurbish the conventional way. Only raising the red flag, plus search for and implementation of less CO2 triggering strategies in standard buildings equating in ZE/ Zero Carbon for homes might help, especially to curb the usage of increased usage of compressor cooling[7]. This approach starts with a new definition of Tropical Residential Thermal Comfort (TRTC) to derive the highest USLs as still reasonable for occupants. An exemplifying application just on Bangalore follows, because -different from KL- like in many other tropical highlands the definition and the avoidance of compressor cooling seems feasible without too many compromises.

REDEFINITION OF USL FOR TROPICAL RESIDENTIAL THERMAL COMFORT (TRTC) IN THE WAKE OF CLIMATE CHANGE

Shortcutting the weary academic discussions on what temperatures humans desire to be exposed indoors, the generic term "thermal comfort" without thinking of climate change to switch temperatures as high as possible shaped up since the 1970s. But soon it turned out that the "right" temperature borderline can only be "adaptive" – probably different for you, her or him. In 1998, Brager & De Dears 3 elements of adaptation: a) *physiological* (acclimatization), b) *behavioural* (using operable windows, fans, doors, awnings, etc.), and c) *psychological* (adjusting comfort expectations toward climatic conditions prevailing indoors and outdoors)"[8]. These still measure the "Predicted Mean Vote - PMV" and the "neutral temperature", meaning how 80% of sampled occupants would feel comfortable and the remaining 20% probably not. Again, by devising bandings, the concepts including the adaptive scientists just dealt with humans, but not with the environmental issue which is clearly stating a borderline temperature and not more and not less.

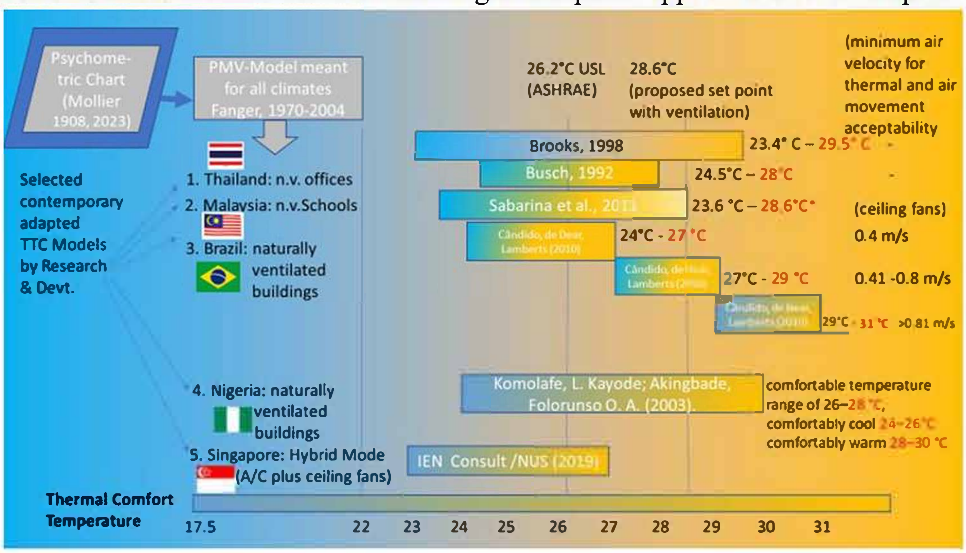
The first researcher who wrote about adaptation of non-tropical residents was Busch (e.g. 1992). He also wrote on different climatic standards for air conditioned closed vs. naturally plus mechanically ventilated open houses (offices). Applied 2022 in the highly temperate tropics, ASHRAE had conceded

[7] The Indian residential AC market has hit two records in 2020 and 2021 (https://www.business-standard.com/article/companies/sales-of-ac-other-cooling-products-again-hit-by-pandemic-in-peak-season-121051600301_1.html). It is estimated to be around 7 to 7.5 million units per annum.
[8] De Dear et al. (2013: 443) meant a pivotal enrichment of previous temperature bandings.

adaptation first in tropical Singapore by the SS554 (2009) standard reiterating Brager& De Dear. However, the already high temperature standards were much higher than most thermal comfort lines that had been created in the colder hemisphere. In tropical countries, the strongest cooling effect is either the "real" coldness of the air con in combination with a mechanical ventilation blower integrated in the device, or alone standing applications like stand-, table- or more comprising ceiling fans. These ventilators are in a way pretentious, as the power of the velocity blown on the critical parts of the skin presents just an air-blowing easing effect (cf. Shiel et al, 2017).

The next table beyond the conventional grey boxes presents a summary of current global adaptive researches that point out the resilience of people for the USL in red: is a "high" 20, 22, 24°C or a higher (CO2 reducing) temperature for adapted families in their homes the one to strive for at the age of climate change and its global warming? Or can even 28°C and higher be accepted with the application of the *velocity of the ventilation (Aynsley & Skoloday, 1999, 2003)?*

Table 1: Different thermal Comfort Levels according to Adaptive Approaches in the Tropics



APPLICATION OF 3 THERMAL COMFORT USL-IDEAL TYPES

Tolerated adaptive temperatures are not exactly individual, but with a few exceptions they seem to be *groupwise collectively similar*. And it needs to accommodate all occupants within a household which may lead to conflicts about the correct set point. The general 80% PMV-satisfaction rule with unsure standard deviations which was ever since widely practiced as overall standard, will not be of help. Far beyond, in line with the ASHRAE-commissioned adaptive style following De Dear & Brager (1998), we have devised not one, but at least 3 USL-borderline temperatures instead of any "banding". In a smart built environment they can be automated – in accordance with the occupants' shared preferences. Simultaneously, they can be produced by all three different (none, less or more CO2-triggering) technical sources: natural, mechanical and air con-induced ventilation[9].

The following paraphrased ***three group clusters*** bring *ideal typologies*[10] into the 2022 USL-playing field to reduce climate change in probably lots of ZEMCH-homes levels. Beyond setting a banding

[9] Chilled beams or cooling walls/ceilings which make sense still remain exceptional in very few tropical applications.
[10] Max Weber coined the ideal types as features that shape up at purity, but it is unlikely that they appear like this in real life. It is a "conception or a standard of something in its highest perfection. Ideal type is a model… a kind, class or group as distinguished by a particular character" (Webster Dictionary in:

temperature for all, occupants can then measure their customised precise upper temperature in their homes. Probably they can find themselves to define one, or depending on situations, 2 or 3 of the following upper borderlines of customisation:

Cold: these occupants feel they want to just accept set temperatures up to a USL of 24 ºC without fan or preferably A/C. It might be hard for this group to increase the temperature toward any proposed higher USL. Perhaps following the moderate climatic role model, especially younger people visiting private air conned schools might be used to climatic conditions at or even lower than 24°C. Whether they go shopping or to the movies, they are part of the often paraphrased "air condition society" which is artificial.

Cool: those occupants feel they can go for temperatures up to the ASHRAE / Singaporean adapted Green Mark's 26.2º C standard at any RH usually below 65% for new ad 70% for old buildings.26.2°C is still ok without fan or A/C (=Green Mark USL-Standard without ventilation). In addition, they feel they can stand temperatures up to 28.6 ºC with a tropically still moderate fan speed of <0.7- max.1.1 m /s which has the opposite (i.e. positive) cooling effect compared to annoying droughts in cold surroundings.

Hot: such people find the upper residential temperature borderline up to 28.6 ºC regardless of the RH without reasonable ventilation as still comfortable. They accept not only temperatures above 28.6°C as USL, but between 28.6°C and 30°C with an additional fan with the necessary velocity on the skin) will not yet cause discomfort with physical sweating. This is admittedly no longer in line with the tropical ASHRAE SS554 2009 or its related Singaporean Green Mark standard, which to date does not differentiate between cooling by ventilation and non-ventilation, with air conditioning or without[11].
After differentiating the three types in pilot studies, we looked into the viability to try out our approach in the cooler tropical highland city of Bangalore. Our target was to make use of outside night time ventilation just with the higher USL proposed by our model above for CO2-saving type ii and type iii, waiting for a survey in early 2023 to confirm or disprove the approach.

MODELLING AND RECOMMENDATIONS FOR THE DIFFICULT HOTTER EVENINGS

First of all, the charts of 1990 and 2020 as a shortcut longitudinal comparison in Bangalore look approximately similar with a high internal monthly correlation of almost 90%[12]. And they state that only in the months of March, April and May 1990 or 2020 the outside mechanical night time ventilation for sleeping rooms type ii and type iii will probably not work 100%, but "just" an estimated 98% (exact missing figures still to be confirmed week, KW):
In Bangalore, except for three days in the hottest month of March 2020, outside air supply would be sufficient to gain the USL for *Tropical Residential Thermal Comfort* in line with type ii. and iii. *all year long* – when we set the 28.6°C benchmark without additional ventilation. On two of the three hotter evenings in April 2020 ventilation or aircon from 11 pm-1 am would still be necessary – a small sacrifice compared with 363 days * 8h + 2 days *6 h.

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https://www.yourarticlelibrary.com/sociology/webers-ideal-types-definition-meaning-purpose-and-use/43758 An ideal type is a common mental construct in the social sciences derived from observable reality although not conforming to it in detail because of deliberate simplification and exaggeration. It is not ideal in the sense that it is excellent, nor is it an average; it is, rather, a constructed ideal used to approximate reality by selecting and accentuating certain elements. https://www.britannica.com/topic/ideal-type

[11] Scheatzle el al. (1989) found that at least 80% of the occupants could be comfortable at a temperature limit of 28°C and air velocities up to approximately 1 m/s.
[12] Prior to detailed studies, factoring in the aftermath of the Pandemic period in 2020, did not seem to have much impact on the data before (-April 2020) and after (until December 2020).

	Jan		Feb		Mar		Apr		May		June		July		Aug		Sep		Oct		Nov		Dec	
	1990	2020	1990	2020	1990	2020	1990	2020	1990	2020	1990	2020	1990	2020	1990	2020	1990	2020	1990	2020	1990	2020	1990	20
1 Average °C Day and Night	20.8	21,2	23.4	17,2	26.0	24,0	27.6	26,3	26.8	27.4	23.7	22.7	23.4	21,1	22.7	21.0	23.2	22.1	22.9	20.8	21.8	20,5	20.5	18.4
2 Average °C Nights (between 8 pm and 7 am only for critical nights months MAR, APR, MAY)					23.2	25.4	24.6 hottest month)	25,7	24.1	24.3													18.8 (coldest month)	
3 Night temp. Compliance level with USL28.6°C „w(arm)" 11pm onwards	100 %	100%	100 %	100 %	94%	100%	8%???	94% (2 nights > 28.6	77% (heated up)	100% (3 times > 26.1 but < 28.6	100 %		100 %		100 %		100 %		100 %		100%			
4. Daytime °C Days completely below USL „w"	31		0		2	2	0	0	1	0	1		17		26		17		20		28			
5.No. of Nights <28.6°C after 8 pm	31 (all)		28 (all)		29 (+2 nights after 9 pm)	22	26 (+4 only 1 hotnight USL only at 11	11	24 (+7, only 1 at 10 pm)	22	30		31		31		30		31		30			

Figure 3: 1990 and 2020 hourly Temperature Log Analysis for Bangalore, Average Temperatures and Compliance with USL Night Time Temperature Standards)[13]

Table 2: Analysis of the 3 hottest months in 2020 to meet the thermal comfort line

Hot Months (others pose no USL-temperature issue at all)	Max. Temp. at 11 pm (at hypothetical "bedtime")	Number of temperature 11pn evenings exceeding to reduce outside air precooling of sleeping room to USL 28.6°C	Average night temperature during hypothetical sleeping times between 11pm-7am	Overall Conclusion for necessary Ventilation to meet the USL
March 2020	28.1°C	Always below USL	23.4°C	0.4m/s 2h, ok for type ii
April 2020	31.1°C	4 evenings (29.1, 29.1, 28.8, 31.1°C)	24.8°C	<see text above>
May 2020	27.5°C	Always below USL	22.9°C	0.3m/s 2h

The operation of air conditioners would be restricted for only 4 h per year, useful perhaps in the 2040s - if global warming in Bangalore just linearly proceeds based on the 1990/2020 data. Accepting the elaborated USLs ii. and iii., air conditions could be dormant for more than 363 of all days over the year. Basically fresh natural air supply will do a better "fresher" and -equipped with filters- a "cleaner job" at costs of about 10% of a conventional air con[14]. The limitations and resulting questions that still need to be

[13] First column, last cell: "No. of Nights <28.6°C after 8 pm (completely below USL) „w"=> no precooling for bedtime 11pm".

[14] E.g. Based on latest filter technology "Generation and Monitoring of Thermal Comfort (TC) and Healthy Indoor Air Quality (HIAQ) (½ day Workshop by ASHRAE). Singapore 21/11/2015.

focussed on for further researches during the next months prior to an implementation stage of USL for climate protection in the built environment for ZEMCH-houses are:

How are we ***able to get the necessary outside air supply*** -preferably cross ventilation- just during the hottest month of April to precool the space of a standard sleeping room to 28.6°C until bedtime (here assumed around 11 pm)? Mechanical ventilation is still possible.

Is the ***outside air supply precooling time of estimated 4 h comparatively sufficient*** a) for closed, b) open c) at certain times of the day sunny and/ or properly shaded reference rooms?

For how many ***% of occupants*** in customisable standard closed buildings does model type ii. and iii. work (fresh air ventilation and air condition users)? How could people be convinced to accept higher automated USL-temperatures of both types in the sleeping rooms?

Is ***mould*** caused by Bangalore's typical higher early morning relative humidity *the* issue theoretically anticipated by numerous researches? (It is known that cross ventilation will decrease the chance of mouldering, it is even a weapon against summer mould in homes of the colder hemisphere).

CONCLUSIONS

After looking at the researches in open and closed "aireas", air conditioned and mechanically ventilated spaces, beyond the case study of Bangalore we can draw the following general conclusions:

All models in the tradition of Fanger (1970) connected with the psychrometric chart (Mollier, 1908), proposing 22.5°C as USL seem to be obsolete for the tropics. Especially in the age of climate change, to restrict artificial cooling to a minimum, is the commandment of not only the hour, but of all decades to come. The minimum USL as our target for mixed mode (air con plus fans) we detected is 27°C (NUS-studies and others since 2019), 4.5°C higher than Fanger and others devised based on Mollier's model.

The ASHRAE Standard SS554 (2009) echoes this fact in their 26.1°C, but it can be extended to a temperature of around 28.6°C for all modes, if velocity up to 0.7m/s or dislocated additional wall- or stand fans is accepted. This 28.6°C borderline that we chose is in accordance to mechanically ventilated independently run school experiments in Malaysia[15]. If, however, significantly higher temperatures up to 30 or 31°C can be or cannot be tolerated with a fan speed of 1.1m/s by tropical and adapted people, still needs to be verified in further studies outside South America and Africa (where research with this high temperature has been undertaken).

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[15] Two university researches, UITM's Abdul Rahman (1995) and UTM's Sabarina et al. (2007ff.), concluded independently the same upper figure of 28.6°C.

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THE CONTRIBUTION OF URBAN GREEN AREAS' ECOSYSTEM SERVICES IN DESERT CITIES. THE CASE OF THE FRANCISCO BOLOGNESI URBAN RESERVE IN AREQUIPA, PERU.

Carlos Zeballos-Velarde[1], Aline Ticona-Huaman[2], Carmen Morales-Pino [3]

[1] Professor, Department of Architecture, Universidad Nacional de San Agustin, Arequipa, Peru (czeballos@unsa.edu.pe)
[2] Architect, Universidad Nacional de San Agustin (aticonah@unsa.edu.pe)
[3] Independent environmental engineer (moralespinocarmen@gmail.com).

ABSTRACT

The ecosystem services of green areas provide numerous environmental, social, and cultural benefits to the inhabitants of cities. However, in many Latin American cities, neither the formal planning nor the informal occupation of the territory contemplate the creation of large green urban areas. Such is the case of Arequipa, a city located in the middle of an arid desert in southern Peru that urgently needs green areas. However, the last metropolitan park was implemented 80 years ago; the population has grown 10 times since then. Nonetheless, in the last 10 years, a private experience has made it possible to incorporate a 20-hectare urban reserve in a military school nearby the city center, becoming an important intervention in the city's ecosystem. This article analyzes the benefits of the ecosystem services of this experience from three aspects: a) the management experience for carrying out the park, despite many real estate appetites b) the impact of ecosystem services at an environmental level c) the social benefit that this reserve provides to the citizens.

Keywords: ecosystem services, urban reserve, desert cities, green urban areas

INTRODUCTION

Urban greenspaces, understood as areas of territory covered by some type of vegetation within an urban area (Taylor & Hochuli, 2017), offer different ecosystem services for the inhabitants of a city since they provide shade, produce oxygen, host biodiversity, give aesthetic quality and host important cultural activities among many other benefits. They also improve the quality of air, water, and soil resources, and in turn, help to capture pollutants, increase water capture and stabilize soils (Montesinos, 2012). Urban greenspaces are also fundamental agents for achieving the sustainable development goals, in particular, the goal N. 3 (ensure a healthy life and promote well-being for all at all ages), N. 11 (make cities and human settlements inclusive, safe, resilient, and sustainable), N. 13 (take urgent action to combat climate change and its effects) and N. 15 (protect, restore and promote sustainable use of terrestrial ecosystems, promote the sustainable management of forests, combat desertification, halt and reverse land degradation and halt biodiversity loss) (UN, s.f.; MINAM, 2016).

However, desert cities have many problems to develop large green areas due to water scarcity, which causes urban heat island problems and affects people's health. Additionally, the urbanization process suffered by many Latin American cities, characterized by expansive and often informal growth, does not foresee the creation of large urban parks, since these speculative processes are characterized by a short-term interest, mainly focused on obtaining economic benefits by occupying the largest possible amount of land without providing common areas, in particular greenspaces (Werthmann, 2022).

Population growth is added to territorial urban growth, given the attractive power that cities have for many people from rural areas. According to the Inter-American Development Bank (2022), "between 1950 and 2014, Latin America urbanized at an unprecedented rate, raising its urban population from 50 to 80 percent (as percent of total); a figure that is expected to climb to 86 percent by 2050." This population typically settles in peripheral, often unplanned areas, which lack green areas, and therefore these settlers do not receive benefits for their physical and mental health.

From the perspective of ownership, medium-size to large greenspaces are typically public and require maintenance, so they are often abandoned as local governments frequently lack the resources or interest to take care of them. As a result, these areas become residual spaces, often degraded by pollution and social deterioration (Zeballos-Velarde et al., 2022). On the other hand, some private initiatives (cemeteries, golf courses, schools, buildings with green roofs) can contribute to the supply of green areas in the city, providing some ecosystem services. However, given the investment involved in their installation and maintenance, these areas are often small or limited in scope.

Therefore, public-private initiatives can enable efficient solutions to the problem of creating large green areas in desert cities, since an important economic contribution and efficient economic management can be achieved at the same time. This is the case of the Francisco Bolognesi urban reserve, built by the Regional Government of Arequipa on a large 17.8-hectare barren area within the Francisco Bolognesi Military School property, thus incorporating around 20,000 trees, which in turn house important local fauna that has spontaneously settled in this urban forest.

Consequently, this research aims to determine what ecosystem services does a privately managed urban reserve of about 20 hectares provide to a desert city. The benefits of this models are highlighted so successful experiences like this can be replicated in other areas of the city or in other cities with similar characteristics to Arequipa.

LITERATURE REVIEW

Ecosystem services

Ecosystem services are defined as the benefits that people obtain from nature that are essential for human well-being (Millenium Ecosystem Assessment, 2005). Biodiversity is the diversity among living organisms, which is essential to ecosystems function and service delivery (FAO, s.f.). The Millennium Ecosystem Assessment and the Food and Agriculture Organization of the United Nations provide a classification of ecosystem services, distributing them into four types, depending on the benefit they provide to society, which are the following:

Support services: They are those that are necessary for the production of all other ecosystem services such as the water cycle, nutrient cycle, provision of habitat for species, and conservation of genetic diversity.
Provisioning or supply services: They refer to the products of each ecosystem that provide goods such as food, raw materials, fresh water, and medicinal resources.
Regulating services: They are those services that control or regulate ecosystem processes, such as pollination, biological control of pests, regulation of water flows, prevention of erosion and conservation of soil fertility, wastewater treatment, moderation of external phenomena, sequestration and storage of carbon, regulation of the local climate and improvement of air quality.
Cultural services: are intangible benefits that ecosystems provide to humans and have significant value for social, psychological and physical well-being, for example, aesthetic values, recreational values, spiritual experiences and a sense of belonging.

Cultural ecosystem services are the non-material benefits that people obtain from ecosystems, influencing quality of life (Cheng, Van Damme, & Uyttenhove, 2019), they can be considered direct (like walking across or seeing the landscape) or indirect, when obtaining social, psychological and physical well-being, (such as aesthetic values, recreational values, spiritual experiences and feeling of belonging, for example) (Ko & Son, 2018).

Seven categories of cultural services offered by urban greenspaces are (Holleland, Skrede, & Bech Holmgaard, 2017), including the MEA (2005) and the TEEB (2010), these being recreation, cultural heritage, aesthetics, education, spirit and religion, social relations and health (Ko & Son, 2018)

Studies on ecosystem services in urban green areas and their relationship with housing.

There are important benefits of linking people and nature, by providing various socio-ecological systems (Potschin & Haines-Young, 2017). Avendaño et al. (2020) carry out an extensive bibliographic review and an in-depth analysis about the importance of including the topic of ecosystem services in urban and territorial planning. These are fundamental to guarantee the quality of life of the population and the sustainability of the provision of these services when considering them in the planning processes, highlighting that the way to achieve it is still very complicated, but it is necessary in order to achieve the objectives of sustainable development. The authors also recognize that this goal is hampered by the politicization of land use planning processes that do not contemplate long-term development, thus affecting the implementation and protection of ecosystem services that urban green areas provide to society.

Nowak, D. J. (Hernández, 2014) mentions that urban green areas can mitigate many of the environmental impacts of urban development, since they regulate the climate, capture carbon dioxide and contribute to water storage, as well as improve air quality, reduce the rainwater runoff and flooding, reduce noise levels and provide habitat for fauna. Likewise, the author indicates that the presence of urban green areas reduces the amount of atmospheric CO^2 by storing it as part of its biomass, highlighting the contribution of urban trees, since trees larger than 77 cm in diameter, are capable of storing up to 3 m^3 of carbon, that is, 1000 times more carbon than that stored by small trees with less than 7 cm in diameter. Also, Woodruff & BenDo (2016) suggest that ecosystem services are a powerful tool for improving land use and for adequate territorial planning since they are vital in decision making.

Hernández indicates that "green areas and the presence of trees are factors that promote a high quality of life in cities, so that urban spaces become pleasant places to live, work or spend free time. At the same time, green areas increase urban aesthetics and property value, integrating constructions into the natural environment". Likewise, it highlights that citizen participation is essential in the management of urban green spaces since the current uncontrolled urban growth affects the conservation of these sites and that must be managed properly (Morales-Pino, 2021).

As it can be observed in this review, much of the scientific literature analyses the benefits of public green spaces, but very few of them focus on privately managed green areas, which can also provide important ecosystem services. As can be seen in the review, most of the scientific literature analyzes the benefits of public green spaces to provide ecosystem services, but very few of them emphasize the benefits of privately managed green areas that also provide important ecosystem services. Also, while a large majority of studies have been carried out in the Global North, very few of them are located in the Global South, which has a completely different sociocultural reality. These two aspects are emphasized in this research, analyzing the particular characteristics of a large green space inside a school surrounded by a residential area, located in a desert city in Latin America.

THE SITE

Arequipa, a city with a population of about one million inhabitants, is located in the southern Peruvian Andes, at an altitude between 2,300 and 3,000 meters. According to the Köppen climate classification, its climate is defined as BSw, that is, a cold semi-arid or steppe climate, with summer rainfall and an average temperature of 18°C. Meanwhile, according to the Thornthwaite climate classification, the city falls within a D (o i p) B'2 H2 climate, that is, semi-arid with dry autumn, winter and spring, temperate and dry (Zeballos-Velarde, 2020).

Arequipa has a density of 2759.8 inhabitants/km^2, occupying an area of more than 350 km^2, having grown 26% of its area in the last 20 years. However, the urban growth of Arequipa has not been accompanied by growth in green areas. In 1960 there were 102.2 ha. of parks available for 158,685 inhabitants (6.4 m^2/inhab), while in 2019 there were 287.0 ha. of parks for 852,807 inhabitants (3.3 m^2/inhab) (Zeballos-Velarde, 2020).

In this context, this research focuses in an artificial forest created from 2008 inside the Francisco Bolognesi Military School which is located in the Alto Selva Alegre district of the Province of Arequipa. The school, neighboring the central area of the city and close to the Chili River basin, has a total area of 36.15 ha, 21.30 ha of which are occupied by academic and sports facilities as well as gardens. Until 2008, the remaining 14.85 ha were vacant land without vegetation and used for the training practices of the cadets. Likewise, these areas were used to deposit solid waste both from the school and by the residents of the surrounding neighborhoods, who just throw their garbage from the other side of the long school fence.

In 2008, the project called "Afforestation of the Barren Lands of the Francisco Bolognesi Military School of the District of Alto Selva Alegre, Province of Arequipa - Arequipa" was launched, carried out by the Regional Government of Arequipa through the Agriculture Department, in collaboration with the direction of the Francisco Bolognesi Military School (Figure 1). With the support of Dr. Juan Manuel Guillén, at that time regional governor, the forest was developed, in compensation for the disaffection of 2.77 hectares that the school ceded for the construction of the access road to the Chilina Bridge (Zeballos-Velarde, 2020).

Figure 1: Aerial view of the Francisco Bolognesi Military School, containing de urban reserve
Source: Carlos Zeballos, Edwin Rios

To carry out this project, which from now own will be called “Francisco Bolognesi Urban Reserve” (FBUR), a drip irrigation system was installed, which is fed through two water reservoirs covered by a geomembrane, one with a capacity of 700 m3 and the second storing 810 m3, which take irrigation water directly from the Miraflores canal through a loading chamber, supplying water to the whole forested area.
In an initial stage, the FBUR occupied 14.85 ha that were planted with 19,624 forest tree seedlings. The selected species were molle serrano (*Schinus molle*), molle costeño (*Schinus terebinthifolius*), vilco (*Anadenanthera colubrina*), willow (*Salix humboldtiana*), jacaranda (*Jacaranda acutifolia*), huaranguay

(*Tecoma stans*) and other forest species such as pine (*Pinus radiata, Pinus patula*), casuarina (*Casuarina equisetifolia*), ash (*Fraxinus americana*), mimosa (*Acacia saligna*), poplar (*Populus nigra*), huarango (*Acacia macracantha*), and cypress (*Cupressus macrocarpa*). Currently, the forested border has been extended to complete 17.8 ha of forest in the facilities of the Military School, surpassing the 20,000 trees and including new local species, such as queñoa (*Polylepis rugulosa*) (Morales-Pino, 2021).

It is very eloquent to compare the satellite photograph of 2008 with that of 2022 and to verify the dramatic transformation of a vacant lot into a metropolitan forest in the span of 14 years (Figure 2). The impact of these trees on the environment is enormous, since it is estimated that they provide 500 tons of oxygen per day (Colegio Militar Francisco Bolognesi, 2018).

Figure 2: Transformation of the Francisco Bolognesi Urban Reserve from a barren land (2008) to an urban forest (2022)
Source: Google Earth / ESRI.

METHODOLOGY

Although there is a consensus that green areas provide different benefits to populations, there is no unified criteria to define how to measure these ecosystem services. Van Oudenhoven et al. (2018) state that these measurements should be credible (the information has to have scientific value), salient (it should be relevant), legitimate (considered fair by the users and not biased) and feasible (using available resources). For measuring the benefits of urban ecosystem services within the FBUR, two fundamental components are studied: regulation services and cultural services, as this area does not have production services. To measure them, a combination of three types of methods have been used a) asking about how people perceive cultural ecosystem services b) estimating the cooling effect that occurred in the study area, and c) measuring, that is collecting information about the biomass absorption of CO_2

Regulation services

These include the analysis of the CO_2 pollution and the study of the site temperature.

a) CO_2 pollution control

The regulation ecosystem service linked to the control of pollutants is calculated through the estimation of carbon dioxide assimilation, considered one of the main greenhouse gases. For this purpose, Morales-Pino (2021) in her study carried out inside the FBUR sampled areas according to criteria of uniformity in terms of the age of the forest species, which had 11 years old. This age was determined by the records of the donation of seedlings, which were given to the Francisco Bolognesi School 11 years prior to the measurement, all of them with an age of approximately 2 months. Also, the superficial and observable differences in the characteristics of the soil, as well as the data about uniformity, frequency, irrigation flow, water source and type of fertilizer, were obtained in the field through surveys to those in charge of the maintenance of the forest, as well as from official records and documents authorized by the Regional Department of Agriculture of Arequipa.

Subsequently, parcels were installed for the characterization of biophysical factors. For this purpose, 16 sampling parcels were distributed with an area of 75 m^2 each, making a total of 0.12 ha, covering the minimum sample size required by the Handbook of the Peruvian Ministry of the Environment (Morales-Pino, 2021). The plots were distributed in 8 zones and each zone contained 2 rectangular sub-plots of 5 m x 15 m; they were marked using 20 cm metal stakes and raffia, located randomly within each forest patch. For the characterization of biophysical factors, soil samples were extracted to determine their physical parameters in a laboratory, and solar incidence data were recorded using the portable photosynthesis equipment Li-6800 in an interval of two hours between each sampling. In addition, water samples obtained from the reservoirs used for irrigation were analyzed, determining their flow and physical characteristics. Finally, forest inventory data such as height, distance between trees, diameter of the trunk at 1.30 m and diameter of the frond were recorded.

Finally, an estimation of carbon dioxide assimilation was carried out. For this purpose, 6 individuals per each of four species: molle serrano (*Schinus molle*), Jacaranda (*Jacaranda acutifolia*), ash (*Fraxinus Americana)* and mimosa (*Acacia saligna*) and per sampling zone (Zone 1 and 2) were chosen, making a total of 48 sampling individuals (Morales-Pino, 2021). The selection criteria prioritized similar characteristics according to the average of their dimensions obtained in the forest inventory.

The daily evolution of CO_2 assimilation was determined using a Li-6800 portable photosynthesis equipment (Fig. 3). The measurements were made on three different days at intervals of two hours from 08:00 to 16:00 h, schedules that cover the diurnal course in which photosynthesis takes place (Sánchez, 2016 cited by Morales 2021). Also, they were measured in the months that make up the dry season due to the absence of rain, making a total of 18 repetitions per sampling area. In order to carry out the measurements, it was necessary that the analyzed leaves receive an adequate solar incidence, that is, away from the shade, in order to guarantee an optimal measurement of gas exchange. Likewise, mature leaves were chosen.

Figure 3: Measuring CO2 assimilation using a Li-6800 portable photosynthesis equipment
Source: Carmen Morales-Pino.

b) Temperature analysis

The cooling effect produced by vegetation on urban areas is one of the most important ecosystem services offered by green area, therefore we sought to know the benefit of the presence vegetation on the reserve in terms of generating more comfortable microclimates. One way to do this would be to measure the surface temperature of the land before and after the presence of vegetation. However, since there are no specific

thermal measurements of this plot before 2008, the alternative is to identify an area that currently has the same conditions as the barren land of 14 years ago and compare it with a nearby vegetated area.
For this purpose, a UAV equipped with a FLIR Duo thermal camera flew over the site, measuring its different temperatures. The resolution used was 0.6 m per pixel, which is much finer than that of Landsat (30 m per pixel) or Sentinel (15 m per pixel) thermal satellite imagery. The survey was carried out on May 2, 2022 (autumn, dry season, temperate climate) around 9:30 AM.
Four different types of land with clear characteristics were chosen (Fig. 2):

- ZONE A) mostly composed of barren land, similar to how the plot was in 2008
- ZONE B) a mixed area, with barren earth but contains spots of vegetation
- ZONE C) forested area, mostly covered with vegetation
- ZONE D) nearby residential area, o investigate how the forest affects the temperature of the surrounding houses.

Two thermal aero photos per each of the four types were selected accordingly. Since the thermal camera used was not radiometric, a surface thermometer measurement was carried out at four points in each of the four areas. Subsequently a calibration was carried out in ArcGIS using map algebra.
Next, the temperatures were classified in groups from 18 to 36 degrees Celsius, incrementing 2° C, per every group, a range that could accommodate the possible margin of error obtained in the measurement. Finally, the pixels of each of these ranges were counted using zonal statistics and then compared to establish the predominant thermal behavior of each zone.

Cultural services
The semi-structured interview was used as a research method, the methodological backbone of ecosystem service assessments (Gould, et al., 2014; Beiling & Plieninger, 2013), as cultural ecosystem services can be better understood when people's perceptions are studied (Thiagarajah, Wong, Richards, & Friess, 2015). This method is used with the purpose of gathering facts from a direct source, as perceived by the individual, which allows obtaining information for the understanding of the opinions of the people (Rowley, 2012). The application of the semi-structured interview method in this research aimed to identify the ideas, points of view and perceptions of the stakeholders directly or indirectly involved in the appreciation of the cultural ecosystem services of the urban reserve. By having a clear vision of their ideas, it was possible to understand how people perceive these ecosystems and the role they play in their environment.
For the data collection, the interviewees were divided into three groups: (i) residents living near the study area; (ii) teachers from the Francisco Bolognesi Military School and; (iii) specialists, or people with extensive knowledge of cultural ecosystem services. Their profiles were identified and classified according to direct and indirect beneficiaries (Altesor, et al., 2011). Conducting interviews with three groups will allow obtaining different levels of knowledge and different points of view on the problems addressed (Riechers, Barkmann, & Tscharntke, 2016). The interviews took place between the months of June and July. The approximate time of each interview varied between 10 and 50 minutes, the longest being those carried out with specialists.

For the formulation of questions, the report of the Millennium Ecosystem Assessment (MEA) was considered, where it mentions that the benefits that people receive are given through spiritual enrichment, reflection, recreation, cognitive development and aesthetics. of experiences. Gee & Burkhard (2010) Kumar & Kumar (2008) Polishchuk & Rauschmayer (2012) argue that cultural ecosystem services are region and person specific, as it depends on the personal benefits of each individual (Riechers, Barkmann, & Tscharntke, 2016).

In this sense, the interview guide addressed the following topics according to the Millennium Ecosystem Assessment (MEA, 2005) evaluating how nature favors human well-being, in addition to the fact that several studies have substantiated and improved this evaluation (Thiagarajah, Wong, Richards, & Friess, 2015): (i) Values for the conscience of nature; (ii) Values for the sense of place/identity; (iii)

Aesthetic values; (iv) Values for social relationships; (v) Spiritual values/sense of peace and; (vi) Values for artistic inspiration.

The specific type of sampling is called the multiplier effect (or snowballing) that was applied to select the neighbors in the semi-structured interview. The identification of participants was carried out according to their degree of relationship and interaction with the urban reserve, managing to contact specialists, educational authorities and residents near the study site.
Data analysis was done through a selective and open coding process (Kaplan & Maxwell, 2005). Selective coding involves combining data (interview transcripts) for mentions of predetermined topics. Microsoft Excel was used for data analysis through spreadsheets.

RESULTS

Regulation services

Analysis of the CO_2 pollution.
The study identified that within the Francisco Bolognesi Urban Reserve there are various types of soil with different physical characteristics such as texture, porosity, among others and different chemical characteristics such as the presence of phosphorus and other elements that intervene in the cation exchange, vital for the fixation of nutrients in the soil (Morales-Pino, 2021). Likewise, due to the forest inventory, differences in growth were identified between individuals of the same species but located in different areas of the forest.

Regarding the water quality parameters, normal values were found in terms of salinity, pH and water hardness, since they do not exceed any degree of restriction considered by the laboratory of the National Institute of Agrarian Innovation and the calculated irrigation flow. It ranges between 2.58 to 3.15 liters per hour in all plantation areas (Morales-Pino, 2021). Likewise, Figure 4 shows a notable variation in solar incidence throughout the day, which influences the assimilation of carbon dioxide, presenting the highest value at 12:00 h. and the lowest value at 16:00 h.

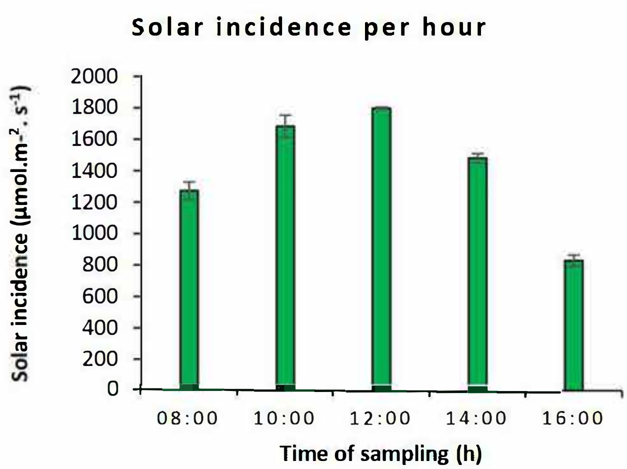


Figure 4: Solar incidence in the sampling areas at 5 time intervals
Source: Carmen Morales-Pino.

CO_2 in 4 species (2 introduced and 2 native)

The data recorded and shown in Table 1, represent the amount of carbon dioxide assimilated per hour in the 02 sampling areas of each of the four species analyzed. The data shows that, in a specific, the highest amount of assimilated CO_2 was recorded at 8:00 hours with 8.31 µmol CO_2/m^2. s, in trees located in zone 1 of molle serrano.

Table 1: Summa ry table of CO2 Assimilation
Source: Carmen Morales-Pino.

Species	**Type**	**Sampling Zone**	**Assimilation of CO_2 (µmol/m²/s) per sampled hour**				
			8:00 h	**10:00 h**	**12:00 h**	**14:00 h**	**16:00h**
Ash (*Fraxinus americana*)	Introduced	Zone 1	6.68 ± 2.41	7.89 ± 6.10	3.07 ± 1.40	1.92 ± 0.92	3.82 ± 2.55
		Zone 2	6.39 ± 4.04	2.88 ± 2.84	3.79 ± 1.61	2.59 ± 1.10	3.98 ± 2.50
Mimosa (*Acacia saligna)*	Introduced	Zone 1	3.19 ± 1.41	1.86 ± 0.75	3.22 ± 1.34	2.43 ± 1.07	4.00 ± 3.59
		Zone 2	6.05 ± 3.02	2.32 ± 1.07	2.99 ± 1.42	1.37 ± 0.33	4.34 ± 1.93
Molle serrano (*Schinus molle*)	Native	Zone 1	8.31 ± 4.21	3.03 ± 0.99	5.14 ± 2.81	4.22 ± 1.67	3.66 ± 1.68
		Zone 2	3.80 ± 2.69	0.69 ± 1.01	2.85 ± 1.36	1.95 ± 1.00	2.27 ± 1.00
Jacaranda (*Jacaranda acutifolia*).	Native	Zone 1	5.11 ± 3.99	3.99 ± 2.89	5.72 ± 4.25	3.13 ± 1.52	7.96 ± 5.28
		Zone 2	2.30 ± 0.81	1.53 ± 0.12	0.77 ± 0.43	3.16 ± 1.36	0.83 ± 0.46

Average Daily CO_2.Assimilation

The average CO_2 assimilation was carried out during the day, taking the values recorded in the five sampling moments. It should be taken into account that the Li-6800 portable photosynthesis equipment provides results at the level of a leaf surface of 2 cm², the values obtained are presented in Table 2 in decreasing order.

Table 2: Average Daily of CO_2 Assimilation
Source: Carmen Morales-Pino.

Species	**Sampling Zone**	**B) Average Daily Assimilation of CO2 (µmol.m-2. s-1)**
Jacaranda (*Jacaranda acutifolia*).	Zone 1	5.18
Molle serrano (*Schinus molle*).	Zone 1	4.87
Fresno (*Fraxinus americana*).	Zone 1	4.68
Fresno (*Fraxinus americana*).	Zone 2	3.93
Mimosa (*Acacia saligna*).	Zone 2	3.41
Mimosa (*Acacia saligna*).	Zone 1	2.94
Molle serrano (*Schinus molle*).	Zone 2	2.31
Jacaranda (*Jacaranda acutifolia*).	Zone 2	1.72

Analysis of the temperature.

Two sample photographs were selected for each of the zones. For reference an aerial photograph is included next to the thermal photograph

ZONE A: Barren land

The thermal analysis of the non-vegetated land, whose conditions are similar to the whole area before planting the trees, show higher temperatures, as the soil is basically formed by earth, sand and sedimentary rocks that become very hot during the day. Another area that, contrary to what it might seem, stores high surface temperatures is the synthetic grass soccer field (Fig. 5.b). While favors the development of sport activities and does not require water for its maintenance, on the other hand, it is an artificial material that does not produce a unity state. humidity and therefore accumulates heat. The hottest area is located on the cement sidewalk around de buildings on the lower left side of figure 5.a and 5.b. Cooler temperatures were registered in the shadowed areas and in spots where bushes were located. the classroom pavilions that are located relatively close to each other produce a shading effect and help to cool down the high surface temperatures (Fig. 5.a)

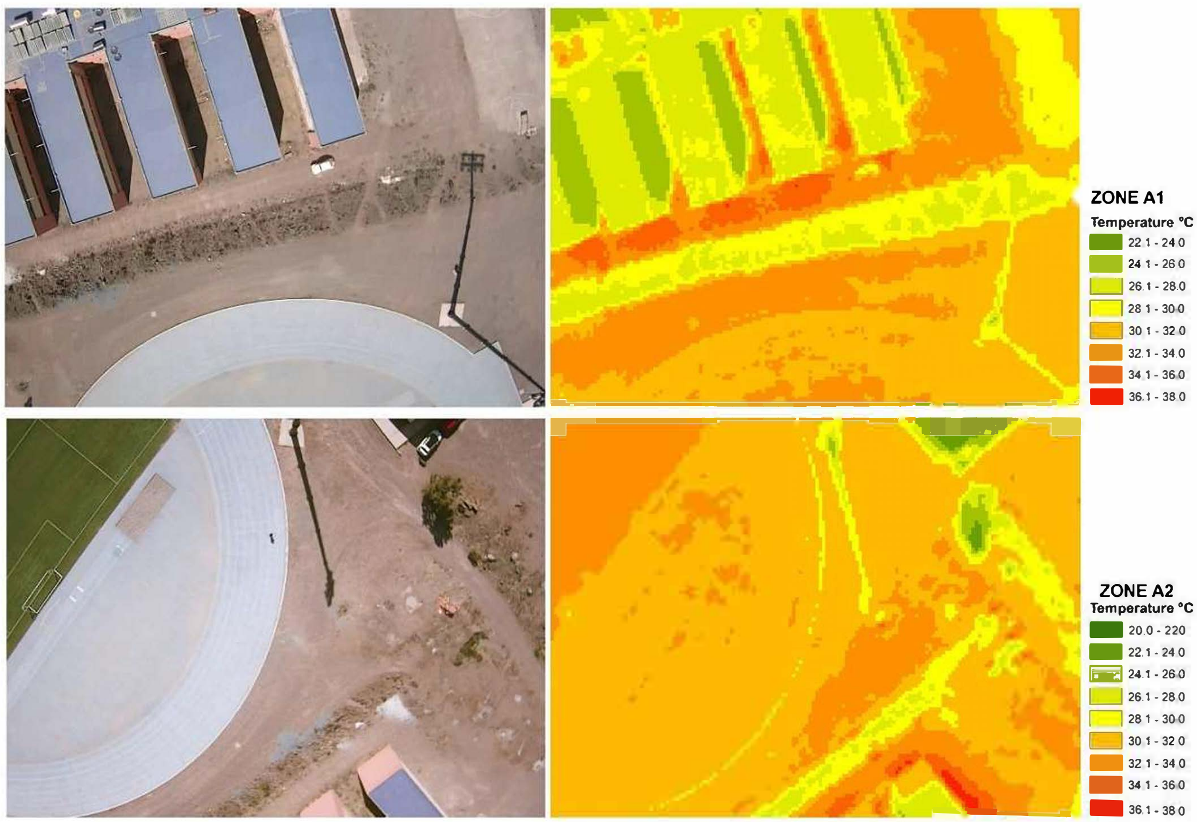


Figure 5.a, 5.b: Zone A1 and A2. Barren land
Source: Carlos Zeballos and Edwin Ríos.

ZONE B: Mixed barren/vegetated area

For this type, areas with scattered vegetation were selected. Figure 6.a shows an area with a water reservoir covered by geomembrane, placed here to diminish evaporation and also to prevent the drowning of some animals that used to come to this area to drink water, fell into the pond and could not get out. As the geomembrane is a polymeric sheet it concentrates heat up to 14 °C higher that neighbouring vegetated areas. Figure 6.b shows a concrete futsal court located next to a hill. However, due to the presence of some trees and shrubby vegetation, it is observed that the temperature is lower despite the use of this material.

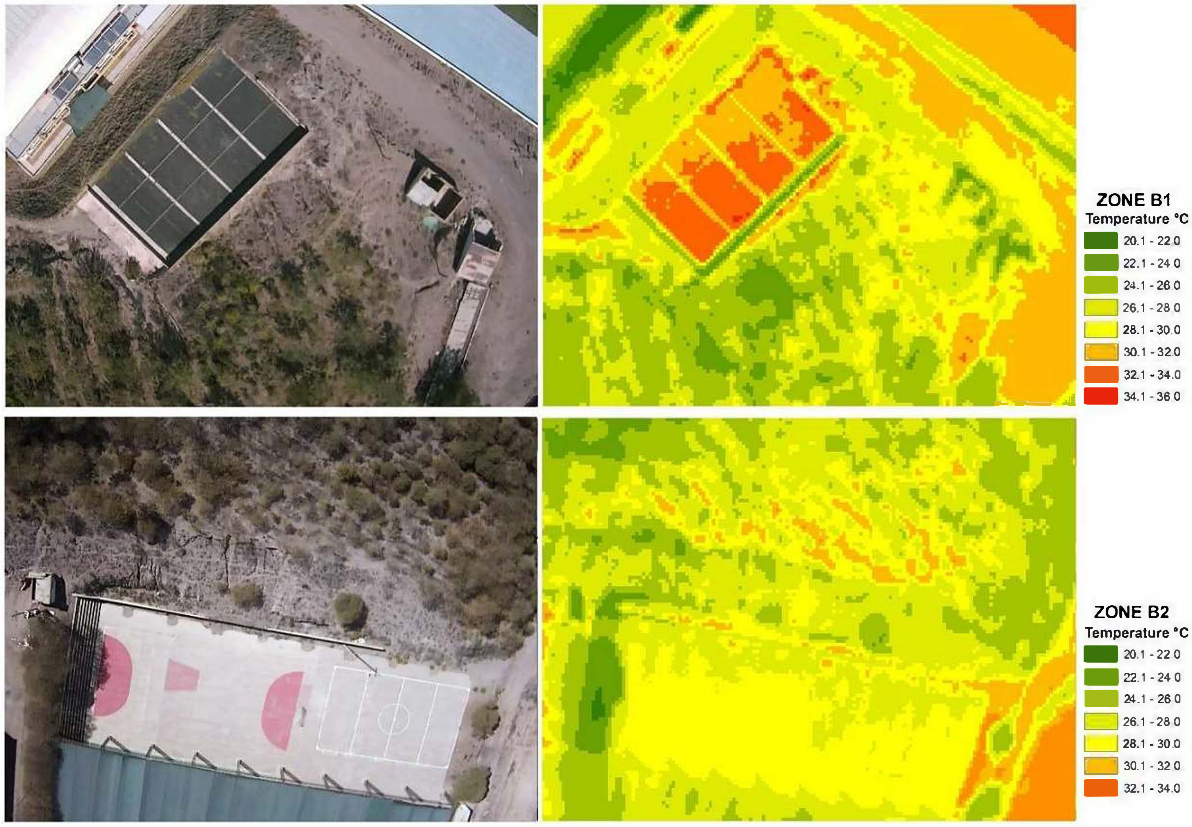
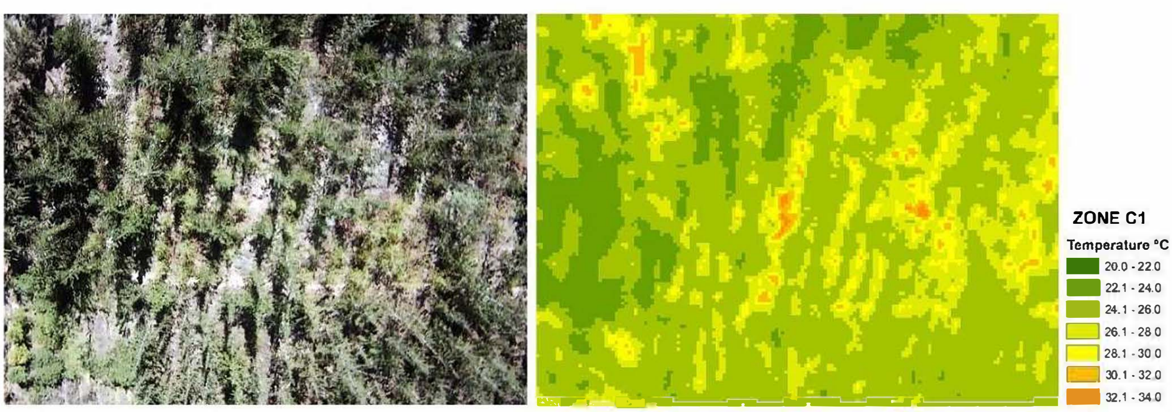


Figure 6.a, 6.b: Zone B1 and B2. Barren land
Source: Carlos Zeballos and Edwin Ríos.

ZONE C: Forested area

The forested area is considerably cooler due to the presence of vegetation. Figure 7.a shows basically pines and casuarinas (both introduced species) while figure 7.b. also contains *molles* (a native species). Both cases show low temperatures, although hotter areas are observed in the interstices between trees, due to the fact that the fronds are of medium size since the trees are still young.



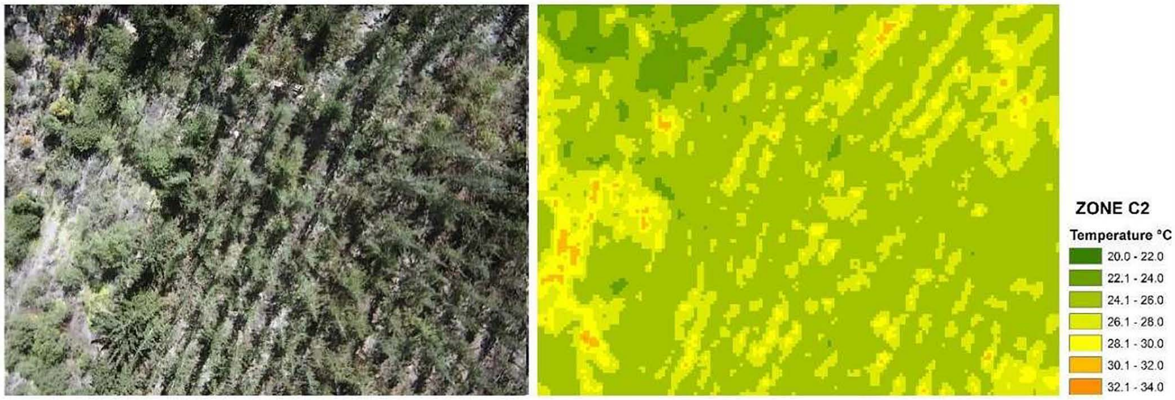


Figure 7.a, 7.b: Zone C1 and C2. Barren land
Source: Carlos Zeballos and Edwin Ríos.

ZONE D: Surrounding low-density residential areas

In the residential areas immediately neighboring the reserve (Fig. 8.a), cooler temperatures are observed than in those that are a little further away (Fig. 8.b). The highest temperatures are recorded in areas of bare earth and also on asphalt tracks. Since there is very low ground immediately adjacent to the forest, there does not seem to be a direct relationship between the decrease in surface temperature and the proximity to the reserve. It is possible, however, that the benefit is in the improvement of the environmental temperature due to the increase in humidity produced by green areas; however this parameter has not been measured.

Figure 8.a, 8.b: Zone D1 and D2. Barren land
Source: Carlos Zeballos and Edwin Ríos.

6.2 Cultural Services

There were a total of 23 interviewees,13 women (56.5%) and 10 men (43.5%), with an average age of 45 years, as it can be seen in Table 3.

Table 3: Participants of the semi-structured interviews
Source: Aline Ticona.

Type of participant	Form of de involvement	Number of interviews
Neighbors	Direct	15
Teachers of the Francisco Bolognesi Military School	Direct	6
Profesional experts	Indirect	2
Total		23

Table 4 shows a comparison of the results of the three types of stakeholders involved in the urban reserve.

Cultural Ecosystem service	Questions	Teachers	Neighbours	Experts
Aesthetic values	How would you describe the forest area?	Extensive and heavily populated with trees..	Spacious and extensive	Visual impact, innovative, extensive.
	In what aspects has the urban reserve changed from its creation to the present?	Significant increase in trees, appearance of fauna, change from being a desert area to being a green area.	Increase of fauna, wooded areas and reduction of dust	Change from exotic to native and endemic species.
Identity vaues	How do you perceive the sense of belonging generated by the presence of the urban reserve? (The sense of belonging can be understood as the relationship of the community and the place where it lives)	The fauna and reserve generate pleasant moments, generating a sense of belonging.	Lack of sense of belonging due to not knowing the urban reserve.	For people within the reserve, there is identity. For those who live nearby, it is of little relevance, since they are not part of it, it is not considered theirs.
	In what way do you consider that the presence of the urban reserve has improved the quality of life of the inhabitants?	Significant improvement in air quality.	Better oxygenation	Cleaner air, better physical and mental health.
	What actions would you recommend for a better management of the urban reserve?	Generate projects for the improvement and use of the reserve; In addition, coordinate with public and private entities for	Opening the reserve to public and generate incomes to facilitate its support and maintenance.	Increase environmental education; dissemination and opening to educational institutions.

		permanent support in maintenance.	Invite visiting specialists.	
Values for Artistic Inspiration	Could you mention how the urban reserve has provided you with ideas or images that could or do inspire art or some visual or creative form?	The urban reserve encourages taking students to make drawings or paintings.	Almost inexistent	Artistic expressions and paintings inspired by nature..
Values for the conscience of nature	How has your behavior or environmental awareness improved since the appearance of the urban reserve?	There is a greater commitment to take care of the urban reserve. On the other hand, encourage environmental awareness through science and technology and environment courses.	Increase of tree planting	Convey environmental awareness, commitment to dissemination, correct use of species.
Spiritual values/sense of peace	How has observing or being aware of the existence of the urban reserve generated a sense of peace and tranquility?	A space to find yourself in difficult times. Being a free area generates peace in recreational meetings.	There is very little sense of tranquility because the urban reserve is not observed.	The change from being in the city with traffic, stress and moving to the reserve area, there is a difference, feeling of calmness.
Values for social relations	To what degree has the presence of the urban reserve generated a sense of community among the neighbors?	There could be a sense of belonging, since the benefits offered by the urban reserve would generate interest in caring for it.	Lack of sense of community, because there is not much communication.	The lack of openness generates disinterest, while others see it as beneficial.
	How could you participate in the maintenance of the urban reserve?	In planting and caring for trees	Tree planting and cleaning.	Promoting research

As a result of the application of the interview guide, it was possible to obtain a detailed vision of the experiences, opinions and values of the interviewees. Next, the values of the cultural ecosystem services of the place of study will be described:

Aesthetic values: All the interviewees highlighted the magnitude of the urban reserve, only a few neighbors mentioned that it was small, arguing that they had not entered and were unaware of its extension.

Identity Values: One of the specialists expressed that "it is not given relevance, it is not perceived, [...], since people cannot enter, it is not considered part of them, when the reserve appeared, people threw solid

waste, evidencing lack of identity. This shows that the ignorance of some neighbors, lead them to carry out acts such as the aforementioned. For those who have visited the reserve, there is a commitment. For this reason, the need of opening of the urban reserve was mentioned by several interviwees.
Regarding the quality of life, all the interviewees mentioned the improvement of the air.

Values for artistic inspiration: Specialists and teachers, state that they have been inspired by the presence of the reserve, this did not happen to any of the neighbors.

Values for awareness of nature: Teachers and specialists stated that they had improved their environmental awareness and encouraged it, as did most of the neighbors.

Spiritual values/sense of peace: The neighbors indicate that just by observing the reservation of their homes, the sense of peace is almost null; on the contrary, teachers and specialists comment on the connection and tranquility that it evokes in them.

Values for social relations: Specialists confirmed that the lack of knowledge would not generate a sense of belonging among the neighbors. Regarding participation in maintaining the reserve, the interviewees mentioned contributing to the planting of trees and their knowledge in their specialty.

DISCUSSION AND CONCLUSIONS

Regulation services

The ecosystem services provided by trees are influenced by various factors, these are related to the type of forestry management, soil characteristics, nutrient supply, solar incidence, the location and distribution of forest individuals. These situations were identified within the FBUR since individuals of the same species show differences in growth as they are located in different areas, due to the existence of slopes that reduce the processing of nutrients by washing and runoff, generating microclimates.

The highest areas suffer from loss of nutrients because there is greater exposure to winds that erode the superficial layers of soil where humus is concentrated (Morales, 2021), factors that limit the assimilation of carbon dioxide by having a physiological influence on plants, since it weakens the leaves and decreases their turgor. Likewise, the assimilation of $CO2$ in the four species evaluated was negatively affected at 12:00 hours, when the solar incidence presented its highest level during the day with 1797.6 µmol/m2/s, thus demonstrating the influence of solar intensity on the assimilation of $CO2$, thus affecting the provision of ecosystem services, in this case, the pollutant regulation service.

Regarding the regulation ecosystem services, the carbon dioxide assimilation averages recorded throughout the day, it is concluded that Schinus molle L. located in zone 1, is the species with the highest $CO2$ assimilation rate, since it represents 46.16% of the total assimilated in the 8 sampling zones, corresponding to the 4 evaluated species. It is also the species that presents the highest record of assimilation during the day, with 8.31 µmol/m2/s at 8:00 a.m. This species is recommended to be planted in urban areas, in order to reduce the amount of $CO2$ present in the atmosphere,

In addition to analyzing the general average of assimilation during the day, it is concluded that the native species evaluated (*Schinus molle L.* and *Jacaranda acutifolia Bonpl*.) are the ones that present greater assimilation of pollutants than the introduced species, due to their high degree of adaptation to local conditions.

Also, vegetation is very efficient in cooling down high surface temperature accumulated in barren land. Table 3 compare the percentage of pixels counted in 10 ranges of temperature in the four zones, (two thermal photos per zone).

Table 3: Percentage of pixels per temperature range per zone
Source: Carlos Zeballos.

TEMP. °C	ZONE A1%	ZONE A2%	ZONE B1%	ZONE B2 %	ZONE C1 %	ZONE C2%	ZONE D1%	ZONE D2%
18 - 20	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06
20 - 22	0.03	0.00	1.39	0.15	0.00	0.02	0.95	0.79
22 -24	0.81	0.00	4.74	3.48	13.68	5.39	8.99	10.49
24 -26	0.89	6.12	20.90	21.96	59.52	64.74	17.28	19.17
26 -28	2.83	20.94	27.82	37.50	20.15	23.51	23.11	20.33
28 -30	7.01	15.69	17.93	29.11	5.30	5.56	39.36	23.49
30 -32	66.61	31.18	21.16	5.05	1.21	0.78	8.72	15.54
32 -34	20.46	23.31	6.02	2.75	0.14	0.01	1.31	8.84
34 -36	1.10	2.75	0.05	0.00	0.00	0.00	0.26	1.24
36 -38	0.26	0.01	0.00	0.00	0.00	0.00	0.00	0.03

Similarly, figure 9 illustrates the different microclimates generated by the presence of vegetation, their contrast with barren land and the cooling effect they produce in both mixed areas as well as residential areas.

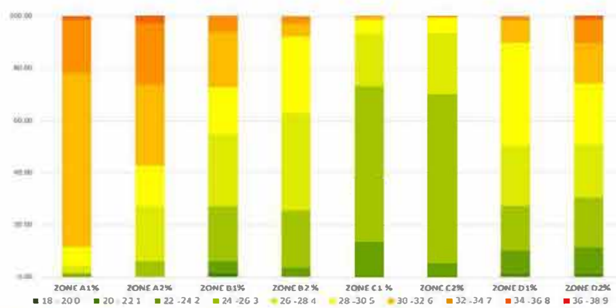


Figure 9: Percentage of pixels per temperature range per zone
Source: Carlos Zeballos.

Cultural services

The most relevant aspect recognized both by neighbors, school teaching staff and specialists, was the improvement in air quality; which is not only beneficial for those who live in the area but for the entire city. The perceptions of the Values for artistic inspiration and Spiritual Values/sense of peace are very different between people who have entered the reserve and those who observe it from afar. Walking among the trees, observing and listening to the fauna of the place, cause unique sensations for those who live it, being impossible when it is only observed. The same occurs for the values of identity and social relations, where those who have contact or have had it have a sense of commitment and identity, showing a sense of attachment (Manzo & Perkins , 2006). The connection with nature improves psychological well-being and pro-environmental behavior, in addition to pro-environmental behaviors, in everyday life. In contrast to other places that present cultural ecosystem services, where people can enter and enjoy in person the benefits they offer, the urban reserve presents this limitation. However, teachers and specialists argue that admission should only have an educational and research focus, but not a recreational one. This is due to the care that should be taken when touring the reserve, for example: the hoses that are exposed and could be easily damaged by visitors.

The lack of dissemination and knowledge caused that the neighbors do not see themselves as a part of the reserve, with this we refer to the term ecocentric approach, the sense of conformation of ecosystems is not being reinforced. A clear example is when at the beginning of the reserve, the designated land was in danger of being invaded, currently some have negative opinions for presenting certain inconveniences, such as the growth of trees very close to their homes. While others focus on the positive, this shows us that idiosyncrasies are particular to each individual and that in some of them it is evident the lack of knowledge of the benefits of an urban reserve. On the other hand, although the school is responsible for the management and maintenance of the reserve, the resources needs for this purpose are insufficient. For this reason, involving public authorities (local and regional government) and private companies would help to strengthen the reserve. Finally, environmental education is crucial to make better use of natural resources, helping the population to manage them sustainably and take permanent care of them for future generations. To this end, it is important to publicize the history, characteristics, and benefits of the reserve, disseminate the research that has been carried out, and promote new studies that will capture the interest of new stakeholders for its preservation and maintenance.

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CLIMATE RESPONSIVE ARCHITECTURE: ENERGY REDUCTION IN HOT AND HUMID CLIMATE THROUGH PASSIVE STRATEGIES

Esther Kiruba Jebakumar Clifford[1], Kotha Vineetha[2]

[1] Researcher, JBR Architecture College, Hyderabad, archiesther@gmail.com
[2] Intern, Affiliation, APSAB, Vijayawada, kvineetha96@gmail.com

ABSTRACT

Sustainable Architecture revolves around creating spaces that are climate-responsive and energy-efficient. This paper will help understand how through passive means, energy consumption can be reduced, with Nagercoil, a tropically hot and humid coastal town in India as context. The objective of this research is to compile and collect various passive strategies such as site-level orientation, massing, shading, material usage, fenestration design, redirecting natural wind patterns through the built-up environment, best daylight practices to enhance user experience and comfortable and efficient reading spaces, that help in energy reduction and thus create climate responsive architecture in a hot and humid climate. The way the built-up environment interacts with the existing surroundings and climate determines its efficiency and competence. With buildings accounting for nearly 40% of global energy consumption, architects have to find ways to reduce the overall consumption from planning to construction. Buildings, especially in hot and humid climates have problems arising in terms of energy, because they have to overcome the principal climatic issues of high humidity (and hence find ways of natural ventilation to push out heavy air and bring in fresh air) and solar heat gain (and hence find solutions that reduce the overall heat gain by keeping out the heat and cooling the interiors), while simultaneously taking care of thermal comfort and natural daylighting at the same time.

Keywords: Climate Responsive Architecture; Passive Design Strategies; Passive Architecture; Sustainable Design; Energy Efficient Architecture.

INTRODUCTION

The Built-Up Environment and its construction together account for 36% of global energy use and 39% of energy-related carbon dioxide emissions annually (United Nations Environment Program). Around the world, countries have come up with agreements and SDGs to help reduce carbon emissions and energy demand. The Paris Agreement is an example of how globally countries are trying to reduce the built environment's energy intensity. The goal is to reduce energy use by 30% by 2030. To assist in this a move has to be made from the planning to implementation stage even if the change is something small. This will help in creating a sustainable environment and reduce the carbon footprint while also reducing the costs involved. In Architecture, active and passive strategies can be employed to help in the reduction of energy consumption. Passive design strategies help in maintaining optimum thermal comfort in a building without the use of energy on heating or cooling. Passive design strategies are decided based on the climate of the site and temperature along with humidity are the main determinants of energy usage.

CLIMATE RESPONSIVE ARCHITECTURE

Climate responsive architecture is based on the way a building moderates the microclimate for energy reduction and enhanced thermal comfort. Richard Hyde explains climate-responsive architecture through its principles, *"The pragmatic and physical parameters associated with this aspect of architectural design are constants that transcend time and are regulated by the laws of science, in particular, the laws of thermodynamics"*. Climate responsive architecture works with the factors of

- Climate
- Sun Path / Orientation
- Existing Conditions
- Topography

These factors when considered at the site and surroundings level are then analysed to understand what kind of design or planning is required and this is translated into design strategies through the conceptual relations between planning, energy source, energy treatment and comfort demand. The contextual, architectural and technical incorporation of these principles into an actual design can be through

- Orientation & Alignment
- Massing
- Fenestration
- Shading
- Materials
- Wall, Floor, Roof Thickness
- Spatial Planning
- Innovative Strategies

PASSIVE STRATEGIES IN BUILT ENVIRONMENT

'The term "passive design" refers to a building whose architectural features are such that they take advantage of local climatic resources to provide an indoor environment which is as comfortable as possible, thus reducing energy consumption due to the need for mechanical heating or cooling.'(Butera et al., 2014)

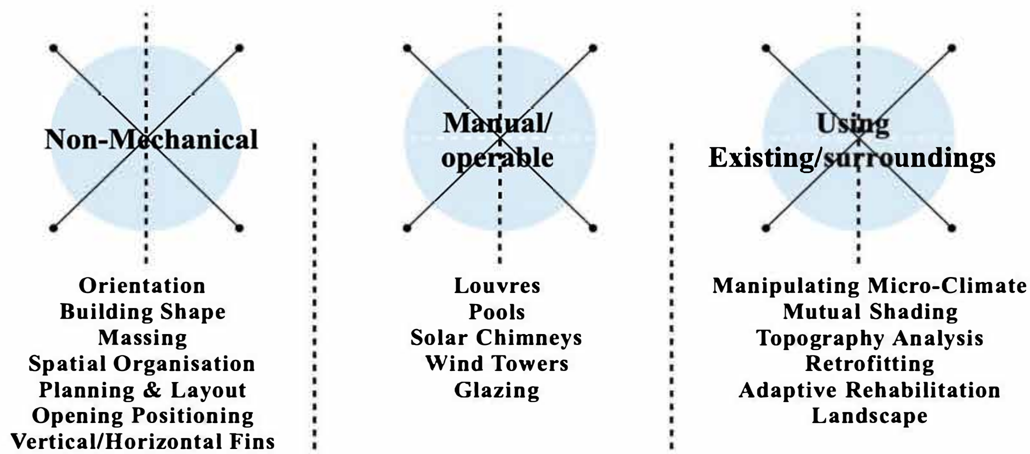

Figure 1. Types of Passive Strategies in Architecture

PASSIVE STRATEGIES IN HOT & CLIMATE

Easy to Work on Simulation software such as *Cove Tool, Climate Consultant, and Andrew Marsh Daylighting Simulation* can help in designing the shading devices and fenestration. Simple shadow analysis through *Trimble Sketch Up and Andrew Marsh Shadow Analysis* can help in massing the building keeping in mind mutual shading and volumetric design. Ventilation Analysis for the site during the site analysis and massing design stage and fenestration positioning can be done at a macro and micro-level with online tools such as *Windy*.

Wall thickness can be increased with sustainable materials such as

- Clay

- Lime Plaster
- Ventilation can be improved with
- Jaali Windows & Walls
- Larger Openings towards the Maximum Wind flow Direction.
- Cross ventilation throughout the spaces
- Daylighting strategies include
- Shading designed for specific windows and opening
- Vertical and Horizontal Shading Devices
- North Lighting for better visual quality

Reducing Openings in the South Western areas to reduce harsh lighting and minimising energy use due to solar heat gain.

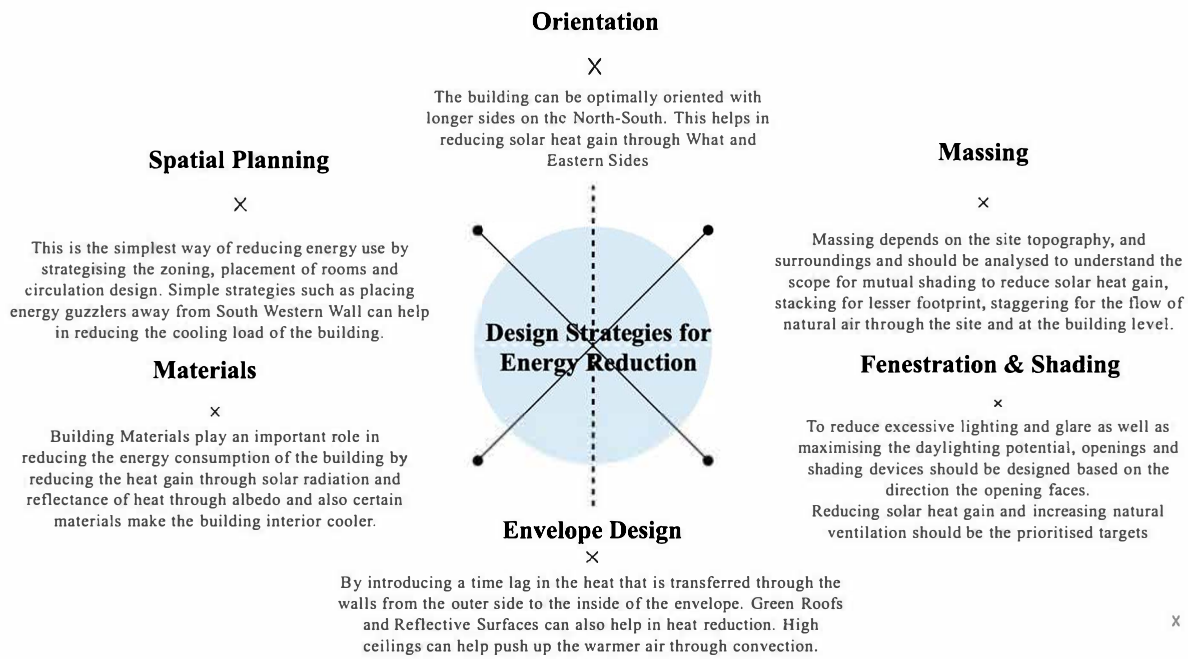

Figure 2. Passive Strategies used in Hot and Humid Climate

Rating Systems such as USGBC, LEED, IGBC, and GRIHA encourage the use of passive strategies while trying to score points for the certifications. 'Green buildings consume 40% to 60% (depending on the range of measures adopted) lesser electricity as compared to conventional buildings. This is primarily because they rely on passive architectural interventions in the building design, and high-efficiency materials and technologies in the engineering design of the building.'(Ministry and Energy and Resources Institute, 2010)

SUSTAINABLE BUILDING ILLUSTRATION:

The Design Project taken as an example is Learning Hub at Nagercoil, Tamil Nadu, India which was part of my Thesis "*Sustainable Learning Hub Design with focus on daylighting in Libraries*", while working on Master's in Architecture, Environmental Design.

For the initial design stage, *Climate Consultant* and *SketchUp* helped understand the shading potential for fenestration. A rough model of the site also helped with understanding the topography of the site and seeing how it affected sunlight. The orientation with sun path study analysis helped in placing the openings and deciding on the size of the openings. The WWR (Window to Wall Ratio) was set to an optimum 40% as per the *ECBC, Indian Standards*. *Cove Tool* helped to schedule usage tools and optimise the building for energy efficiency while also helping in the designing of the horizontal and vertical fins on the needed sides. *Daylighting Simulations by Andrew Marsh* helped in understanding the minimum and maximum depths of spaces inside the building. The passive strategies have been categorised at the site level and building level for easier comprehension.

At Site Level

The important aspect of incorporating passive strategies is first to commence with a detailed study collecting existing data on similar types of projects. Once the data collection is done and similar literature and case studies are conducted, the site (whether already selected or selected specifically for the project) is studied. The site analysis is the most basic and mandatory study of the predesign stage. The location & connectivity topography, existing conditions, surroundings, and views all play a role in coming up with a good design and plan while integrating energy-efficient strategies.

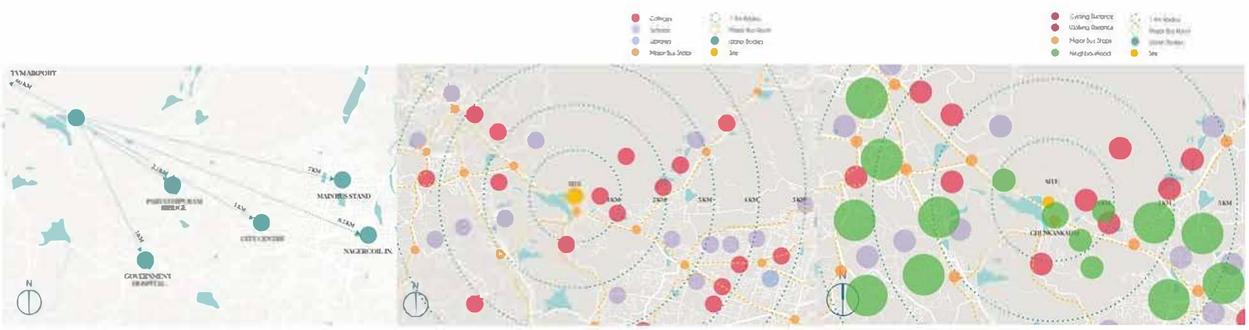

Figure 3: Site Analysis Process: Connectivity, Proximity, Major Hubs & Neighbourhoods

A SWOT analysis will help in routing out the best and worst features of the site while understanding the impact that each feature has on the site and environment. Environmental and social impacts are two ways of categorising the impacts while comprehending the various strengths, weaknesses, opportunities and threats of the site and the building on the site. As the data on passive design strategies suggests, the designs feature ideas that channel available natural resources to ensure thermal comfort and energy resources. The climate-specific approach based on sun, wind, light and micro-climatic considerations is what makes this stage of the predesign stage salient and paramount for a successful design culminating in a suitable built-up environment.

Zoning was done to plan parking, services, entrances, and ventilation without losing existing green cover to circulation. *Windy* Tool helped in analysing the natural wind patterns of the area (which at a micro-level was different from the macro-level in terms of a small hillock to the South blocking any possible breeze from the direction and a water body to the West that could be used in maximising the cool wind from there). It is interesting to note that a depression formed around 200 Km North of the Site in a place called *Courtallam* changed the wind direction around Monsoon time because of the depression formed there. This is a smaller-scale example of the '*Butterfly Effect*.

The contour analysis (that can be done manually or with *AutoCAD*) helped in efficiently placing the reading places so that good quality daylighting could be naturally utilised from the North. Contour analysis was done on the site to help understand ridges and valleys to mark out the best pathways to design passive features such as bio-swales and also take care of the storm water efficiently. The daylighting at site level was optimised with the help of massing, zoning and site plan. The massing was done keeping in mind both mutual shading to help reduce the direct solar heat gain with the harsh heat and sun and also in such a way so that the building is elevated toward the South coinciding with the natural contours existing. Shadow analysis was done with the help of *Andrew Marsh's Shadow Analysis Tool.* This way the hillock protected the Southern surface from overheating while providing an opportunity to raise the building and angle toward the Northern side (which helped in effective natural daylighting and also placing Solar Panels at the optimum angle and direction.)

Figure 4: SWOT Analysis, Contour Analysis and Site Conditions

Building form affects wind by altering its speed and flow patterns and can be used to create desirable wind conditions around the building. Wind, in turn, exerts a load on the building, which can be reduced with aerodynamic forms and resisted with structural systems (Fleming, 2015). Simply put the site when analysed for the wind direction, speed (Wind Rose) and potential blocks at micro and macro-level (*Windy*) can help in passively designing for the reduction of humidity. (Figure 5)

Once the site potential was analysed and listed out after being categorised according to the design components, the site boundary was overlaid with the all the potential design solutions and the site plan was formulated incorporating design solutions for services such as water management, stormwater management, service circulation, landscaping, massing at the site level, optimum orientation, zoning according to the wind direction, contours and the surrounding potter community. The issues such as potential waterlogging, solar heat gain, and humidity were taken care of at the site level by directing the winds through the site planning and channeling the wind potential and using natural contours without cutting and filling with the site and local species for vegetation in landscaping.

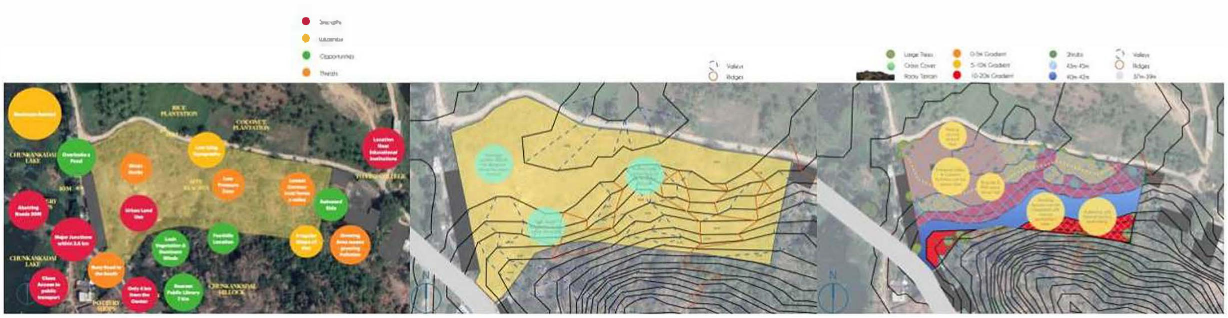

Figure 5: Site Potential and Utilising Views, Contours, Wind Patterns

At Building Level

The usage of sound passive design principles was the main aim of the project and at the building level, this helps to reduce energy use, and with the use of renewable energy systems, there was the added benefit of producing residual energy. The major decisions about building form, orientation, shading, and ventilation that were taken during the early design stage already had a strong impact on the energy use of the building. Next was the at the building level by reducing and trying to eliminate, the need for artificial lighting through filtered, indirect, glare-free daylight through careful positioning of fenestration and shading devices. This not only reduced the energy needed for lighting and reduced the cooling load but also helped in trying to improve the health and well-being of the users.

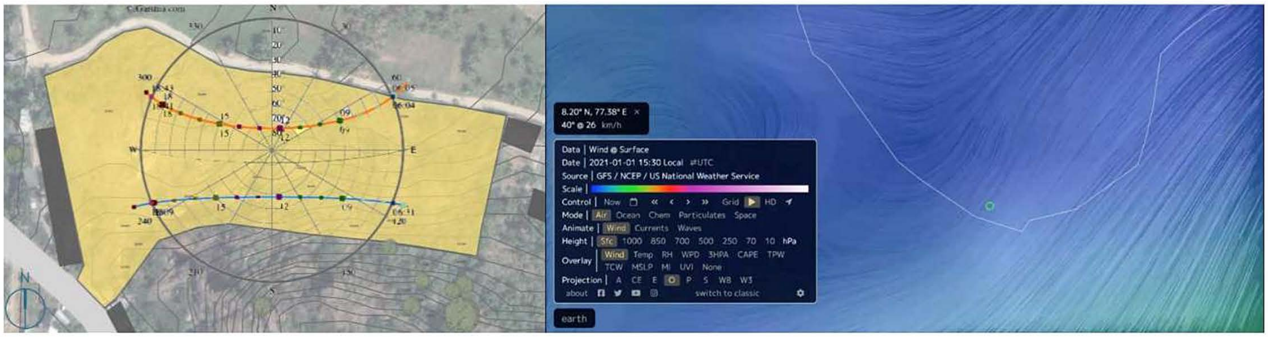

Figure 6: Wind Rose, *Windy* Analysis

It was imperative to design both conditioned and unconditioned spaces since the project involved designing a Library as a part of the Learning Hub. Hence the building needed air-conditioned spaces, but to allow daylighting glazing was used for an optimum reading environment. The skin of the building – walls, windows, and the roof was moderated with green roofs, specially placed *Jaali* for natural ventilation and vertical and horizontal shading devices designed specifically (With Climate consultant and Cove Tool) to reduce the solar heat gain, with optimum ventilation and time lag through double glazing. Selection of the materials for building envelope with appropriate thermal mass, insulation, and colour based on the hot and humid climate needs and functional requirements helped in reducing the number of hours when cooling was required to maintain comfort in the conditioned spaces

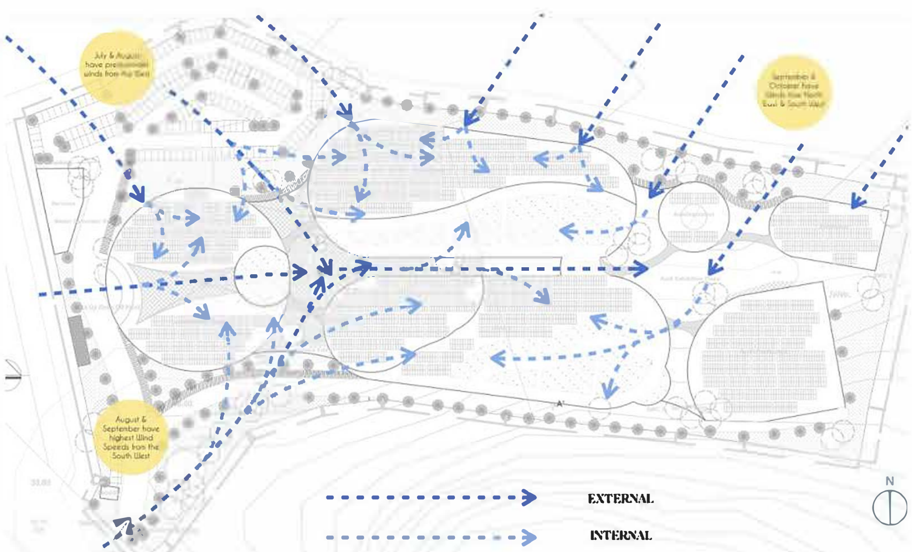

Figure 7: Placement of Openings around the Built-Up Area to optimise wind flow

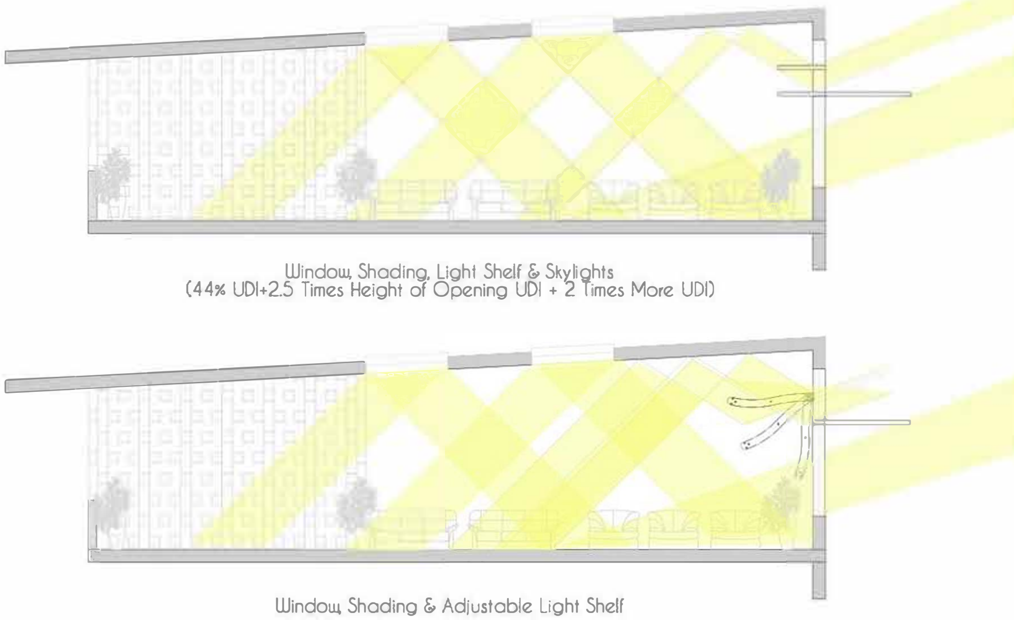

Figure 8: Daylighting Optimisation with Cove Tool and Climate Consultant

The daylighting design was worked on with the help of analysing the maximum and minimum depths of the spaces in the buildings according to the function of the space. This was optimised with the help of predicted lighting conditions and heating through *Andrew Marsh Daylighting Simulations*. The simulations were done specifically for openings in all the directions that the building envelope faced. This was then combined with the vertical and horizontal shading device requirements according to *Climate Consultant*. The final format of the shading devices was decided after *Cove Tool* optimisation. Cove tool helped in understanding the daylighting potential by using Occupancy Schedules, Horizontal and Vertical Shading Devices, Total Number of Occupants and when using Renewable Energy, the quantity of reserve energy the building can produce.

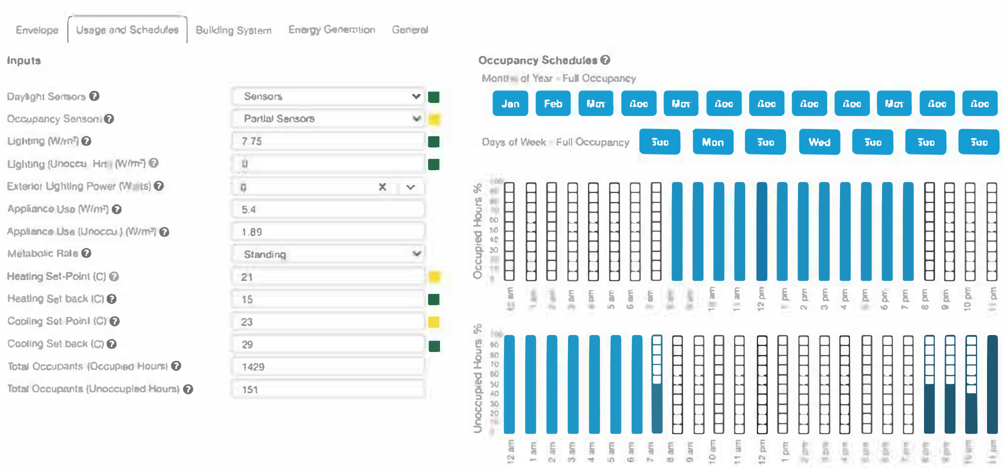

Figure 9: Daylighting Optimisation with *Cove Tool* (Occupancy Schedule)

The daylighting strategies used passively helped in reducing 19% of the energy that would have otherwise been used in artificial lighting. The overall passive strategies used in conjunction with renewable energy produced on-site helped in producing an excess of 26% energy which made the building be categorised as a Net Zero building.

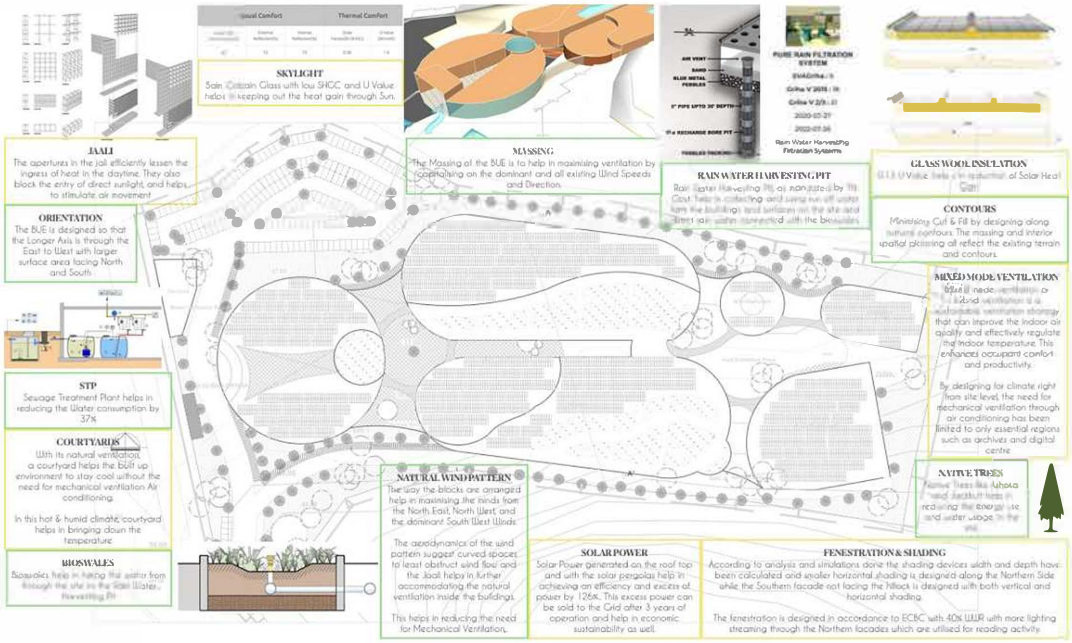

Figure 10: Final Design of Learning Hub showing all Passive Strategies

CONCLUSION

Every aspect of building design contributes to the impact on energy demand. One single fin on an opening can help reduce solar heat gain through solar radiation and lead to a reduction in cooling load, thereby dropping energy consumption. While it is difficult to achieve a very high impact with passive strategies, when used with renewable energy and smart solutions buildings can be designed to be net-zero buildings and carbon positive buildings giving back to the community. Site analysis studied along with the potential of the site and smart and passive strategies might present an organised way of selecting the best strategies during the design stage along with a continuous process rather than a one-time decision of planning. For example at every stage of the design from Predesign to the Final Design stage, daylighting is studied (Simple *Climate Consultant* tool in the Predesign, *Andrew Marsh Daylighting Simulation* in the Preliminary Design and Spatial Planning stage and finally *Cove Tool* for optimisation in the Final Design). This is called an integrative process by LEED. An integrative process is a comprehensive approach to building systems and equipment where project team members look for synergies among systems and components, the mutual advantages that can help achieve high levels of building performance, human comfort, and environmental benefits (U.S. Green Building Council, 2009). This process when incorporating passive design strategies can help in creating energy-efficient, cost-efficient and thermally comfortable spaces.

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REVIEWING THE EFFECTIVE UTILIZATION OF PASSIVE SOLAR STRATEGIES FOR DESIGNING A SOLAR OPTIMIZED NEIGHBORHOOD IN INDIA

Saurabh Ojha[1], Mahua Mukherjee[2]

[1] PhD Scholar, Department of Architecture, Indian Institute of Technology, Roorkee, India (skishoreojha@ar.iitr.ac.in)

[2] Professor, Department of Architecture, Indian Institute of Technology, Roorkee, India (mahuafap@iitr.ac.in.ac.in)

ABSTRACT

Considering the importance of reducing energy crisis in Indian building sector, energy savings policies are implemented with the goal of providing thermal comfort for individual buildings within an urban context that limits the actual energy saving potential of the buildings in a cluster or neighborhood. Indian Cooling Action Plan (ICAP), 2019, states that Solar-passive strategies will allow thermal comfort to be available for all while minimizing energy footprints of built structures. Liu, 2016 in his research mentioned about operational energy in buildings have maximum energy-saving potential. Majorly they fall into two categories: substituting fossil fuel for energy demand with clean alternatives, reducing the energy consumption from the source. It is therefore the need of the hour to have a balanced approach by encompassing both passive and active strategies.

Active strategies have the ability to substitute fossil fuel while passive strategies have ability to reduce the energy demand from source itself. A comprehensive understanding of the Urban morphology indicators gives the designer an opportunity to explore the importance of bioclimatic potential for implementing passive strategies. The aim of present study is to investigate the initiatives taken on implementing Solar-passive strategies as energy-efficient measures in India. Solar optimized neighborhood is a vision that enables us to address the energy, daylight and environmental concerns as an integrated procedure in a broader sense. Programs like Solar building and Solar city have successfully implemented Passive measures at local level. However, it is found that existing Solar passive design measures are not followed strictly at local level due to a lack of integration between urban form indicators and its response to immediate environment. The recommendations from this study will highlight the major Urban morphology indicators and performance indicators related to passive design potential that will be useful for similar climate conditions in India.

Keywords: Solar Passive Strategies, Urban Morphology indicators, Solar optimized neighborhood, Non-Renewable Energy

INTRODUCTION

Crisis arises when scarce resources (non-renewable) are subjected to meet the unprecedented energy demand. The energy crisis of 1970s coupled with the carbon emission made people aware about negative environmental impact of fossil fuel consumption. Nearly 80 percent of the energy demand throughout the world are supplied from these non-renewable resources. Almost half of the world total population (including India) reside in fossil deficient areas (Sixth Assessment Report, 2022). Regions where it is sufficiently available like in case of GCC countries cannot be exhausted due to carbon emission threshold. It is now accepted that the massive energy demand for constructing and operating building sector across India needs strategies to reduce their environmental footprints. It is estimated that the residential sector will come as the biggest electricity demand by 2030 (Energy, 2021). While energy savings policies are well recognized with the goal of providing thermal comfort for higher strata of society, the urban poor has yet to receive adequate attention.

Urban growth is increasingly occurring on the vertical scale, particularly in Asian countries where vertical growth is rapid. An action has to be considered before generating neighbourhood which consider solar and wind rights of buildings with the understanding of scientific (quantifiable) tools of dealing renewable energy coming to the site. The building in urban context has accountable impact on its attached neighbourhood, the concept of maximum developable building volume in our country is often recognized with a necessity to achieve maximum FAR, and buildings are designed with neglecting solar and natural wind accessibility. Indian Cooling Action Plan (Ministry of Environment, 2019), 2019, released by the Ministry of Environment, Forest and Climate Change (MoEF & CC), estimates that by 2038 a significant percentage of Indian low-income households will be residing in non-conditioned spaces which will have thermally uncomfortable indoors. A significant Proportion of the population will be dependent on only passive system to keep indoors comfortable. The idea is to integrate the design performance indicators in the development of mass housing sector while meeting the benchmark for visual and thermal comfort with the help of passive design strategies.

State of affairs of different Asian countries in renewable energy

Along with GCC countries and China, India accounts for more than half of the world's total increase in energy consumption over the 2015 to 2040 projected period. According to the recent report from IEO 2019, the major development of nuclear is concentrated in China and Japan (Energy, 2021). Nuclear offers low-cost electricity generation as compare to fossil fuel still the reason for decline of nuclear energy proposals in the Gulf region, clearly indicates the concern to de-carbonize the electricity generation process. This is also evident because of increasing pressure from international agencies to reduce the use of fossil fuel as an effort to encourage solar energy. Although the purpose behind unjustified utilization of the active solar energy is to attain global benchmark of zero carbon crown (Alnaser, 2011). It is to note that active solar energy helps in achieving the energy demand but does not help towards reducing the overall consumption. However, the ability of passive solar energy to reduce the energy demand at source has immense potential in conducive climatic conditions of India. BIPV is truly a convincing potential as passive strategies in building design and further can be developed as part of architectural elements in building design process (Alnaser, 2015).

Comparing the potential of renewable and non-renewable between three non-OECD countries, China registered more than half of the fuel supplies for catering energy demand are being Gas, Coal and Renewable, while Natural gas and oil in GCC countries (Alnaser, 2011). However, in India increasing energy demand was supplied by coal (for power generation) and oil (for transport) respectively. However, in 2018 coal as non-renewable resources contributed almost half (45%) of countries total energy consumption, along with petroleum and other liquids (26%), conventional biomass and waste (20%), while renewable resources such as solar, wind, and tidal make up a small portion of (1% to 2%) primary energy consumption (International Energy Agency, 2019) Figure 1.

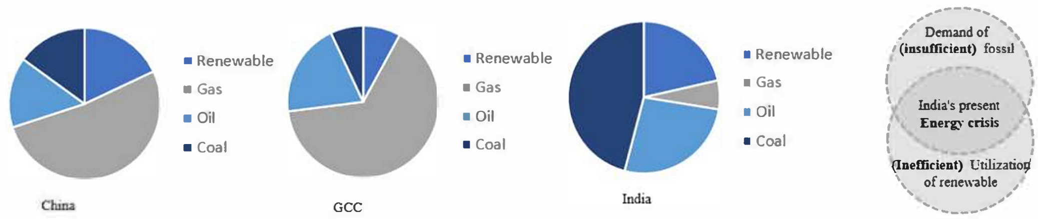


Figure 1: Potential of total primary energy consumption by all fuel in context to non-OECD countries
Source – IEA 2019, modified by author

Potential of Solar Energy utilization through passive strategies in India

India has tremendous potential of solar energy and day lighting having a sunshine hour of 2200 to 3600 hrs. Many researches have been done on building level to determine solar availability inside a building space. There is a research gap on an urban level daylight access analysis which would help to understand the parameters affecting pedestrian thermal comfort with building daylight levels and energy potential in urban context. With "Housing for all 2022" scheme from Government of India, it would be judicious to develop a framework for solar energy efficient neighborhood.

Meso-level initiatives: Government of India MNRE (India, 2014) has initiated Solar city program. In the context about 100 cities are considered to be provided by the infrastructure to develop as Solar Cities. However, the goal is to reduce the conventional energy demand by 10% by growing supply from Solar based renewable energy sources in the neighbourhood. The fundamental approach is to encourage the local authority to accommodate efficient uses of renewable energy techniques by using solar, wind, biomass, small hydro power project, and wastage to energy resources.

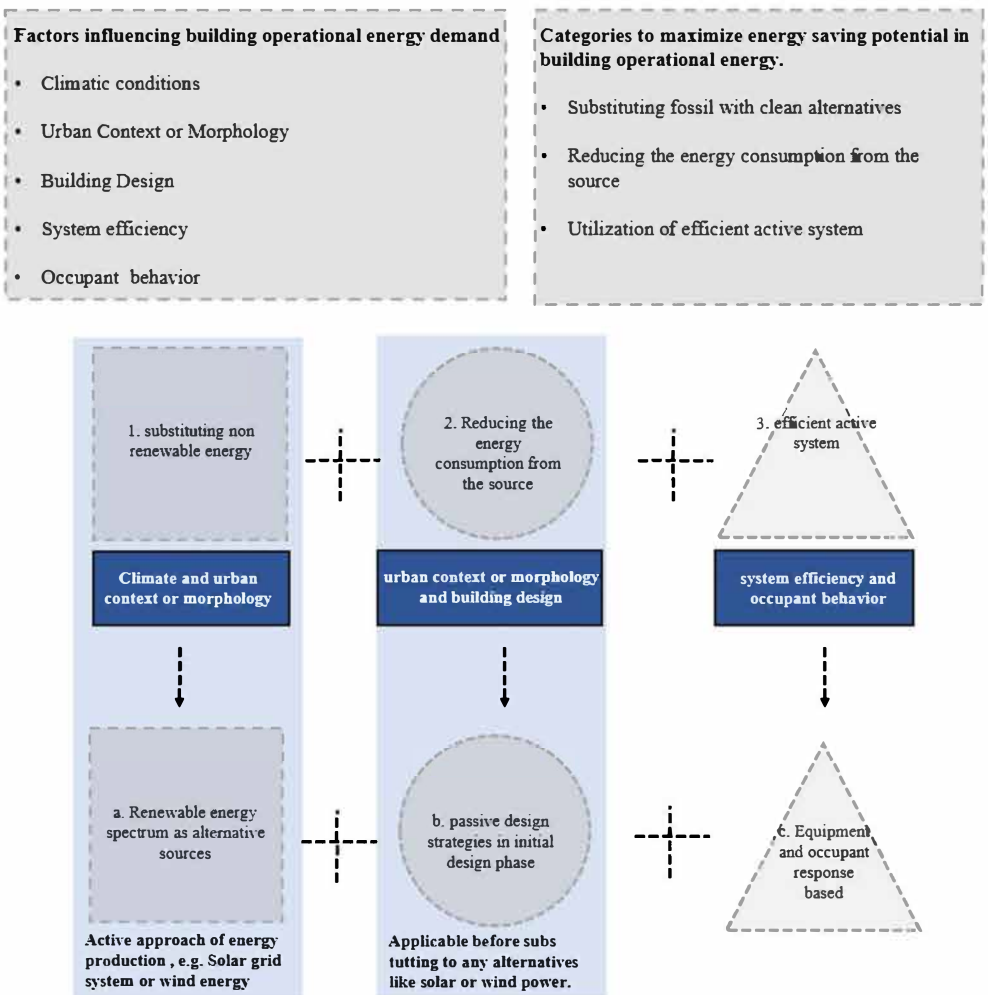
Micro level initiatives: These initiatives are implemented at street level where the interaction between street and clusters of buildings are considered. One of the major strategies in Solar House Action Plan for Himachal Pradesh (India, 2014), communicate that all government. and semi government building shall have passive solar features. While accepting solar energy as a nonlinear system one cannot expect a definite proportion of output from a known input (Bureau of Indian Standards, 2005).

SCOPE OF SOLAR PASSIVE STRATEGIES

Solar responsive neighbourhood is a vision that enables us to address the energy, daylight and environmental concerns as an integrated procedure at a broader sense. In traditional research architects have focused on building shell efficiency within an energy intensive urban context that limits the actual energy saving potential of the buildings. Though the understanding of this has arrived too late when global urban strata have started facing strong consequences from the climate change. The energy consumption of a building is largely dominated by the micro-environment it is surrounded with, whereas the micro-environment is dictated with urban morphology of the city. Therefore, Sustainable development is an integrated loop that has interdependency at each level of development, Figure .

Figure 3 Integrated loop of interdependency
Source – Author

It is observed that buildings industry represents a substantial fraction of world-wide energy consumption and demand. India witnessed the third-largest sharing of energy demand after China and GCC (International Energy Agency, 2019) due to building sector growth among all regions of the world. According to the Sixth Assessment Report by IPCC 2022, building sector is responsible for 32% of the global energy demand. Indian buildings sector is expected to increase by an annual average of 2.7 % per year (Sixth Assessment Report, 2022). As compared to other sector (transport, agriculture, forestry and waste) the building sector has highest energy demand and hence holds highest potential in energy saving and reducing carbon emission. However, significant aspects of energy demand in buildings includes climatic conditions, urban configuration or morphology, building form design, system installed inside the building and its annual efficiency and behaviour of the regular and occasional occupant (Baker Nick, 2000). These factors actually act as determinants to regulate the building operational energy**.** Liu, 2016 in his research mentioned about operational energy in buildings have maximum energy saving potential. They fall into three categories: [I]. substituting fossil fuel for energy demand with clean alternatives where possible, [ii]. Reducing the energy consumption from the source and [iii]. Utilization of efficient active system (Junjie



Liu, 2016) Figure 2.

Figure 2: Possibilities of maximizing energy saving potential in building sector, source: author

Category first has substantial link to the typology and availability of renewable resources. Insufficient availability of fossil fuels as resources are making stakeholders look towards carbon neutral and easily available resource spectrum like solar and wind power. Local climate and site context plays a major role in substitution of fossil fuel. Closer proximity to tropics makes Indian climate a Solar energy abundant country where most of the region gets substantial onsite solar radiation throughout the year (Bureau of Indian Standards, 2005). Sun as energy resource supplies almost equal part of energy to each stakeholder and further encourages to participate in generating their own energy and transferring extra energy back to grid. The second category aims towards reducing the energy consumption from, source can be achieved through passive strategies in initial design development process. A comprehensive understanding of the local climate gives the designer an opportunity to explore the importance of bioclimatic potential for implementing passive design strategies (Watson, 1976). The importance of passive design strategies for energy efficient applications cannot be undermined, particularly in the present context of growing energy crises. The third category about installing efficient active system refers to absolute value generated by the energy efficient building equipment and occupant load.

It is to observe that Substitution of fossil fuel with clean alternatives can be a best possible option for GCC countries where opting building passive design strategies is impossible because of harsh outside climatic conditions. While in Indian scenario where major energy demands are for upcoming housing proposals needs a significant approach of designing climate responsive buildings, where more of energy demand can be reduced from the source, so that rely on active system can be reduced. So, this itself open motivates to explore the possibilities of passive design strategies using sun as resources.

Background of Solar optimized neighborhood

As the world is increasingly becoming urban there is an immediate urge to give an attention on energy efficient measures at urban scale. The designing of a neighborhood involves numerous processes, procedures and analyses. Integrated action has a higher impact than any of the action taken in isolation. It is therefore the need of the hour to have a balanced approach by encompassing both passive and active strategies. For example, passive design strategies can reduce the overall heat gain, thereby significantly decreasing the energy demand as the need for an air conditioning system (Ministry of Environment, 2019). The consumption of the energy by the urban form is largely dominated by the micro-environment it is surrounded with, whereas the micro-environment is dictated with urban morphology of the city. Traditional research has focused on individual buildings efficiency within an urban context that limits the actual energy saving potential of the buildings in a cluster. Solar optimized neighbourhood is a vision that enables us to address the energy, daylight and environmental concerns as an integrated procedure at a broader sense (India, 2014). Another study concludes that form and orientation do not largely influences the energy consumption, especially in midsize and large size buildings (Straube, 2012). Infect, in Indian scenario Daylight and solar radiation plays a prime role in deciding energy utilization in a building and outdoor thermal comfort. Hence it is necessary to determine the relationship among urban morphology indicators, building physics and solar access and availability to minimize energy consumption in an urban scale neighborhood.

The first simplified urban archetypal urban forms performance was studied with respect to site coverage, height of the structure, depth of the structure from front road and occupant density present inside the building (Philip, 1971) studied first the energy implication with density and shape at large scale urban form. He coined high density linear growth was more efficient than centralized dense growth. However, Baker and Steamers further developed the scientific methodology based on light and thermal perception known as lighting and thermal (LT) method (2000) (Baker Nick, 2000). This method involves distinguishing passive zones (having access to passive lighting, heating, cooling and ventilation) and active zones (dedicated areas with active energy use to provide requirement of lighting, heating, cooling and ventilation). This method is vastly used in today's simulation tools to analyses larger urban context. It is often found that density equals efficiency (Holden Erling, 2004) but many researchers observed the anti-results of occupant density over the daylight conditions, and natural wind movement in the building as a trade of factor (Hui, 2001).

To understand this complexity of trade-off between co-variates researches developed methods to do analysis at urban scale. In 1974, Knowles develops a concept of solar envelop and solar volume using heliodon instrument and group of building models. A proposal based on solar access guidelines for urban blocks was formed. New structures do not affect the solar access onto immediate site and buildings. Building setbacks, orientation and form are significant factor in thermal performance. In the contemporary studies many case studies have been carried on urban level with energy and day lighting. One of the reports states the negative correlation between density of built form and available daylight with implications for buildings energy performance (J Strømann- Andersen, 2011) and outdoor thermal comfort conditions (Helmut Mayer, 2005). For urban sustainability it is been studied that high density is positive for urban planners at micro scale model. But when planning for temperate or cold climate high density zones create obstructions for day light ingress. It is studied that different sizes of site and building heights even with the same density, expect different level of solar irradiation (Lee et al., 2016). Despite the fact that the building envelope's thermal and energy potential and the ground's accessible solar potential were determined to benefit from lowering site coverage (Vicky Cheng, 2006). An analysis was performed by The European Institute for Energy Research on morphological aspects of London, Paris, Berlin Istanbul. Density is an accurate standard of heat energy demand with correlation 0.77. F.A.R above 4 was found out to have least heat energy demand. Surface to volume area ratio, building height are good indicator for energy demand. Ground coverage was found to have little correlation with energy demand. Other urban morphology indicator – Volume to site area ratio, gross surface index and sky factor shows strong correlation for daylight availability (Michele Morganti, 2017).

Solar panel production of renewable energy is influenced by day lighting. When solar PV panel potential is considered for entire building facades, the effect of site coverage is inverted because a larger building footprint means a larger roof area (Kyung Sun Lee, 2016). Higher solar potential on building envelopes and more daylight availability may result from an increase in horizontal and vertical randomization (Vicky Cheng, 2006).

Urban morphology indicators for developing Solar optimized neighborhood

Orientation

Orientation is one of the most important aspects in pre designing stage. It is proved that longer axis of building on east west axis consumes less radiation compared to other cardinal directions. As per Raphel Compagnon building façade orientation can lead to analysis of passive solar potential and active solar potential (PV cells) (Raphel Compagnon, 2004). He calculated each façade radiation value and compared it with threshold values to calculate solar performance parameters.

Different shapes of building when subjected to different orientation; there is change in energy levels, as it affects the amount of solar radiation falling on the various facades (Emmanuel, 2007). In a neighborhood surface temperature is a key parameter in boundary layers of neighborhood. Cities' three-dimensional architecture make it more difficult for the sun to heat urban surfaces evenly, which results in an effective anisotropy of surface thermal emission at the neighborhood level. This leads to increase in urban thermal comfort index of that vicinity. Orientation also decides the shading of streets. When compared to east-west oriented canyons, north-south canyons have more of an impact during the summer. Placement of open spaces and courtyards also help in optimizing UTCI of outer environment. Mutual shading of east and west wall can reduce heat gain considerably. Orientation also defines the daylight availability inside a built form. Northern façade and southern façade can be optimized with change in setbacks to maximize day lighting.

Site coverage / Gross space index

The concept of Site coverage and Gross space index is defined as the ratio of the building footprint area to the particular land parcel. Site coverage defines the complexity of an urban morphology. However, negative correlation is observed with ground surface coverage and heat energy demand as per research by LSE cities and EIFER (Energy, 2014). It has also a weak correlation of Pearson value of 0.1208. The increase of surface coverage control interaction of buildings with each other either because of shadow generated by neighbouring structure and consecutively reducing effective solar heat gains or through common wall sharing which further reducees building heat loss. As surface coverage decreases the vice versa will also be true till buildings are widely spaces such that shadows do not affect the interaction among built form. It is studied that ground coverage with less than 30%can have varied energy demand. Improved thermal performance can be observed in high rise apartment with low coverage ratio and a high coverage ratio in compact building block.

Floor Space Index / Floor Area Ratio

It is the ratio of gross floor area to urban site area. It is a good indicator of energy demand but not for day lighting on facades as it deals with floor areas rather than envelope surfaces. The high negative correlation and strong logarithmic association between the Floor space index and thermal energy consumption for European countries LSE and EIFER conclude that increasing density results in greater heat energy efficiency (Energy, 2014). A minimum density of less than 0.5 FAR results in a thermal energy demand of about 150 kWh/sqm/year. Greater than FAR 2 thermal energy requirement decreases to about 100 kWh/sqm/year at increasing densities. Additionally, it was discovered that FAR values between 1 and 4 performed similarly. The apartment complex with towering buildings shows good energy efficiency at FAR 1 density that are quite low. As a result, concentrations between FAR 1 and 1.5 are where the best energy efficiency is attained.

Building height / Building height to setback ratio

Building height in urban area is calculated by ratio of building volume to the built-up area. It shows strong negative correlation with energy demand. As per research by LSE and EIFER above a 4-storey height the variation in heat energy demand becomes considerably smaller concluding reduction of energy efficiency with increased built height beyond this point (Energy, 2014). Typology plays a great role along with height defining energy consumption. Detached housing up to 2 floors height shows greatest demand of 150kWh whereas high-rise apartments show an energy demand of around 70 kWh at a height of 10-storeys. As per Compagnon, only height of building is not enough to define daylight access. Building setbacks and street ratio defines the availability of daylight inside a building. The distance between two building blocks affects the radiation gain along with daylight accessibility. There has to be a trade-off between both the aspects, with decrease in street width energy saving percentage increases but the daylight decreases by 10 to 30 %. In office spaces (Nazanin Nasrollahi, 2016). if window to wall ratio and canyon width is kept constant, with increase in height of building results increase in daylight autonomy level inside the building.

Surface Geometry

Volume area ratio and Aspect ratio – It is termed as the amount of exposed envelope per unit volume. S/V ratio shows a strong positive correlation with energy demand. It describes the amount of surface exposed to radiation which in result defines the heating and cooling load. It is more of an energy indicator rather than daylight on façade indicator. As per LSE and EIFER research, with ratio below 0.2 ensures good thermal performance of less than 100 kWh (Energy, 2014). It was also concluded that worst type of housing was detached housing with highest surface to volume ratio

Volume to Plot area ratio / compactness

It is defined as ratio of building volume to site area ratio. This describes the compactness of a settlement. As it describes the outer organization of a site it is a better indicator for daylight availability at façade rather than energy. V/Pa ratio shows a negative correlation to daylight access with r value of 0.53.

Performance indicators for developing a Solar optimized neighborhood

Urban Daylight

Spatial Daylight autonomy & Continuous daylight autonomy – Spatial daylight autonomy (SDA) is defined as climate-based daylight metric that defines the percent of the floor area that exceeds a given threshold lux level for at least 50% of the given time (Illuminating Engineering Society of North America (IESNA), 2012). Continuous daylight autonomy (CDA) is the percent of the floor area that exceeds a given threshold lux level for at least 50% of the time giving a partial credit for time step below the threshold lux level (Illuminating Engineering Society of North America (IESNA), 2012). SDA makes more sense in understanding the daylight level as it is easily distinguishable the well-lit area and under lit area. To calculate the above metrics a tool "Urban daylight" developed by Reinhart and Michalatos in 2012 (Panagiotis Michalatos, 2012)is used. The utilization of Day-sim simulation, a Radiance engine-based program to evaluate the hourly radiations values on a grid of sensors that are placed across all building envelope in the simulation model (Oliver Walkenhorst, 2001). The results of exterior radiation values are transformed into a work plane grid with sensors that includes the participation of a particular façade segment to the generated interior luminance levels. These are converted through a two-dimensional light propagation algorithm that converts the data into daylight levels. While the above approach provides interior illuminance level at hourly duration for a urban form of any shape. The time required by Day-sim simulation analysis and at an adequate accuracy level for initial massing studies. It has been proved that overall daylight area simulated matches Day-sim simulation prediction within 10% that allows us to study urban designs in great detail easily.

Radiation level

Radiation is one of the most important performance indicators deciding the operational energy and urban heat island of a particular neighborhood. Radiation levels are measured on total global radiation falling on the surfaces and measured in kWh/sqm. In warm humid climate radiation level is to be minimized through spacing of built form optimization, soft scaping, mutual shading and tree cover. Radiation level is analyzed using Diva for grasshopper tool which considers latitude, surface materials, ray tracing parameters.

Discomfort hours

The discomfort hours are calculated using the same shoebox model for 8760 hours. It is considered discomfort if the internal temperature rises more than adaptive thermal comfort range. It considers the building physics, mutual shaded blocks and buildings sharing common walls. Umi is used to calculate the discomfort hours in following case area.

Universal thermal comfort index (UTCI)

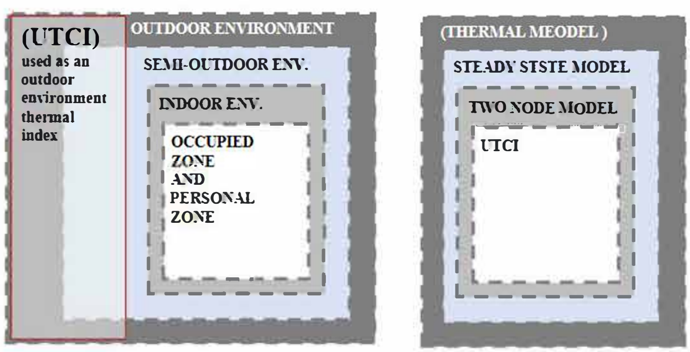


Figure 3: Universal thermal comfort index (UTCI) and its component, source: author

It delivers a bio meteorological assessment of the outdoor thermal environment based on the equivalent dynamic physiological reaction anticipated by a human thermo-regulation model linked with a cutting-edge clothing model. UTCI essentially measures the temperature that we experience and accounts for wind speed, relative humidity, radiant temperature, and occasionally sun radiation. While it makes use of variables in a human energy balance model to provide a temperature value representative of the outdoors' heat or cold stress, Figure 3. It ranges between 9 degree C to 26 degree C indicates no thermal stress 26 degree C to 28 degree C slight stresses (comfortable for short period) 28 degree C to 32 degree C moderate stresses (hot but not dangerous) 32 degree C to 38 degree C strong heat stresses (dangerous) More than 38 degree C extreme heat stress (very dangerous Radiation level - Radiation is one of the most important performance indicators deciding the operational energy and urban heat island of a particular neighborhood. Radiation levels are measured on total global radiation falling on the surfaces and measured in kWh/square mt. In warm humid climate radiation level is to be minimized through spacing of built form optimization, soft-scaping, mutual shading and tree cover. Radiation level is analyzed using Diva for grasshopper tool which considers latitude, surface materials, ray tracing parameters.

CONCLUSION

Households will quickly switch to active cooling retrofits, such as installing air conditioning, if thermal comfort through passive design is not incorporated. ICAP, the Indian Cooling Action Plan, asserts that it will be essential to maintain an increase in thermally efficient buildings with lower energy usage through passive design techniques including optimized building shape and improved natural ventilation. According to ICAP, passive techniques will make thermal comfort accessible to everybody while reducing buildings' energy footprints. The concept of reduction by using passive design is grossly neglected under the current mass housing regime. Design of building with efficient utilization of performance indicators daylight and thermal comfort can reduce cost of living.

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IMPACT ASSESSMENT OF BUILT ENVIRONMENT TOWARDS NET ZERO: CASE FOR TURKEY

Ayşe BAYAZIT SUBAŞI[1], Elçin Filiz TAŞ[2]

[1] PhD Candidate, Istanbul Technical University, Turkey, aa.bayazit@gmail.com, bayazita@itu.edu.tr
[2] Prof., Istanbul Technical University, Turkey, tase@itu.edu.tr

ABSTRACT

Buildings are responsible for approximately 30-40% of greenhouse gas (GHG) emissions. Throughout the life cycle of a building, namely, raw material extraction, manufacturing of construction materials, transportation to construction site, implementation, use phase, and end of life, there also have great negative impacts on environment. After United Nations Climate Change Conference, held in November 2021, Turkey committed a net zero target by 2053 and up to 21% reduction in GHG emissions from Business as Usual (BAU) level by 2030. To measure and to decide whether the reduction is made and the target of "net zero" is achieved, built environment and whole construction process should be considered and monitored. Life Cycle Impact Assessment (LCIA) approach provides tools and methods that can be applicable to Built-Environment. This paper aims to answer the questions: "Is Turkey ready to reach this net zero target?" and "What is situation of Turkey in the world in terms of impact assessment research of built environment?" To accomplish that paper covers a broad comparison of conference papers, articles and dissertations on environmental impact published in Turkey and the world. Besides comparing these, Environmental Product Declarations (EPDs), legislations and National Tools/ Applications introduced in Turkey are compared and evaluated. To collect the data both national databases for publications and dissertations is used together with ProQuest and Web of Science. National, Turkish tools such as YesTR (National Green Certificate System) and BepTR (Building Energy Performance) are also analyzed in terms of their contribution to net zero target. This paper shows that local and national contributions is very important to deal with a global problems like climate change and negative environmental impacts underlying the importance of Environmental Product Declarations, national methodologies, certifications, databases, and tools to measure and monitor the emissions and impacts of built environment and construction materials.

Keywords: Net Zero, Built Environment, Turkey, LCA, EPD

INTRODUCTION

Buildings are responsible for approximately 30-40% of greenhouse gas (GHG) emissions. Throughout the life cycle of a building, namely, raw material extraction, manufacturing of construction materials, transportation to construction site, implementation, use phase, and end of life, there also have great negative impacts on environment. As shown in the Figure 1, in United Nations Environment Programme (UNEP) report, 2020 Global Status Report for Buildings and Construction, buildings and construction take 35% of energy and 38% of emissions as of 2019. As seen from the Figure.1, residential buildings are responsible of 17% of direct and indirect emissions, while non-residential buildings are responsible for 11% of direct and indirect emissions (UNEP, 2020). To diminish these negative impacts, all over the world, so many precautions are being taken in local level, regional level and globally. United Nations (UN), for instance, have organized many events to raise the awareness among nations, conventions to fight with climate change such as United Nations Framework Convention on Climate Change (UNFCCC), protocols to limit and reduce GHGs. Recently, United Nations Climate Change Conference, known as COP26, was held in Glasgow on 31 October - 13 November 2021 with the participations from 197 countries. After the COP26 summit, Turkey committed a net zero target by 2053 and up to 21% reduction in GHG emissions from

Business as Usual (BAU) level by 2030.It is significant that governments make commitments since they are expected to regulate their sectors parallel to their commitments. Moreover, academic studies are of importance that they lead and assist governments and sectors to committed targets. To measure and to decide whether the reduction is made and the target of "net zero" is achieved, built environment and whole construction process should be considered and monitored. Life Cycle Impact Assessment (LCIA) approach provides tools and methods that can be applicable to Built-Environment.

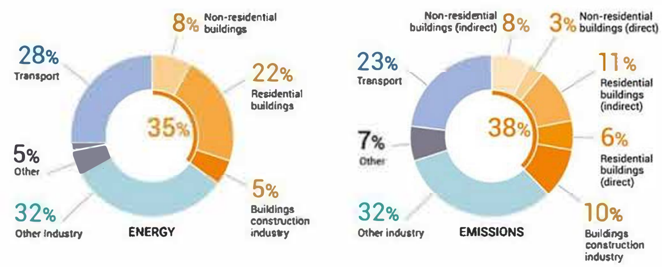


Figure 1: Global share of buildings and construction final energy and emissions, 2019
Source: UNEP, 2020

METHODOLOGY

Data and Method

This paper aims to understand the position of Turkey in terms of net zero target and in terms of the studies related with the life cycle impact assessment (LCIA) carried out by academic world to reach that target. Another aim of this paper is to identify the gaps in built environment and constructions sectors in terms of net zero roadmap. To state that, we search and compare conference papers, articles and dissertations on environmental impacts published in Turkey and the world. Secondly, we search and compare the EPDs for construction materials in Turkey and in the world. Moreover, the commitments of Turkey are collected and compared to the actions taken and to be taken. Finally, for Built-Environment, applications and certifications that are used for assessing the performance in terms of energy and environment are analyzed. For buildings and construction sector, this paper presents a wide literature review on impact assessment in Turkey especially in these days when Turkey made the commitment towards net zero. In the conclusion section we provide an overall country review of Turkey. Data sources are defined as (i) Web of Science (WOS) and Turkish National Article Database for the papers, (ii) ProQuest and Turkey's National Thesis Center for dissertations, (iii) EPD International website and IBU website for EPD, (iv) Ministry of Environment Urbanization and Climate Change, TÜİK (Turkish Statistical Institute), green rating tools, and LEED and BREEAM directories for applications.

RESULTS

Articles

In this paper, first we searched for with the key words "life cycle assessment" and "net zero" in web of science collection (WOS) the years between 2002-2022. Then results were analyzed in terms of paper type and the discipline that paper belongs to both for Turkey and the rest of the world. As seen in Table 1, Turkey has 481 articles on Life Cycle Assessment (LCA), whereas the rest of the world have 35.172. For the review articles, Turkey has 51 out of 4.134. In terms of proceedings papers, Turkey has 47, while other countries contributed with 7.564 papers. Turkey's performance is compared in terms of the share of the country among others in Table 2. Turkey has a share of % 1.35, %1,23 and %0.62 for articles, review articles and proceeding papers respectively. The lowest performance belongs to proceedings on Life Cycle Assessment.

Table 1: Academic papers on "Life Cycle Assessment"
Source: Compiled from WOS, 2022a

	Life Cycle Assessment			**Net Zero**		
	Turkey	**Other Countries**	**Total**	**Turkey**	**Other Countries**	**Total**
Articles	481	35.172	35.653	85	10.145	10.230
Review Articles	51	4.083	4.134	2	344	346
Proceedings Papers	47	7.564	7.611	20	2.009	2.029
Total	**579**	**46.819**	**47.398**	**107**	**12.498**	**12.605**

Table 2: Share of Turkey in terms of Academic papers on "Life Cycle Assessment" and "Net Zero"
Source: Author's calculation from WOS, 2022a and 2022b

	Turkey's Share in LCA	**Turkey's Share in Net Zero**
Articles	0,0135	0,0083
Review Articles	0,0123	0,0058
Proceedings Papers	0,0062	0,0099
Total	**0,0122**	**0,0085**

When the key word "net zero" is concerned, Turkey has only 85 articles, 2 review articles and 20 proceeding papers, whereas other countries have 10.145, 344 and 2.009 respectively as seen in the Table 1. The number of articles in LCA is much higher than the articles on "Net Zero" in building and construction sector in the world having 47.398 and 12.605 papers in total respectively. Turkey is also having a similar tendency with 579 papers on LCA and 107 on net zero in total. On the contrary, interestingly, as seen in Table 2, proceedings papers on "Net Zero" have a higher percentage than the proceeding papers on LCA. It can be driven that LCA has been studied in Turkey more than Net Zero in general. It can be concluded that, to lead the sector and regulations, more studies should be carried out on net zero to close the gap in this field in Turkey. We assume that after COP26 and commitment to net zero by 2053, scientist will study net zero in upcoming years. When the disciplines are concerned, we have chosen five Web of Science categories related with the Built-Environment, that are Architecture, Engineering Civil, Construction Building Technology, Regional Urban Planning, Urban Studies. As the Figure 2 shows, the articles on Life Cycle Assessment in Turkey and the world respectively are 6 and 106 for Architecture, 53 and 2.353 for Engineering Civil, 47 and 1.874 for Construction Building Technology, 8 and 247 for Regional Urban Planning, and finally 3 and 16 for Urban Studies. The other disciplines have 364 and 30.573 respectively. For Turkey, the lowest numbers of papers belong to Urban Studies with 3 papers, followed by Architecture with 6, Regional Urban Planning with 8 papers. Turkey's Civil Engineering and Construction Building Technology disciplines have the highest research papers on net zero as of WOS. Even though architects design the built environment, the research on LCA are 1/10 of Civil Engineering research.

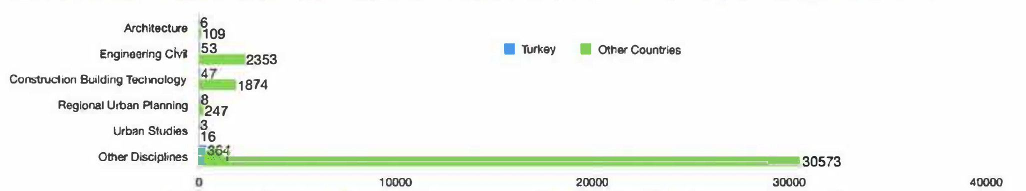


Figure 2: Academic Papers on "Life Cycle Assessments"
Source: Compiled from WOS,2022a

For the key word “Net Zero”, the results for same five selected categories in Turkey and the world respectively are, 1 and 99 for Architecture, 3 and 446 for Engineering Civil, 7 and 663 for Construction Building Technology, 0 and 33 for Regional Urban Planning, 0 and 49 for Urban Studies, 74 and 8.855 for other disciplines respectively as seen from the Figure3. On net zero, in Turkey there are no research in Urban Studies and Regional Urban Planning disciplines. Construction Building Technology takes the lead but with 7 papers, very low, almost half of the share when compared to LCA.

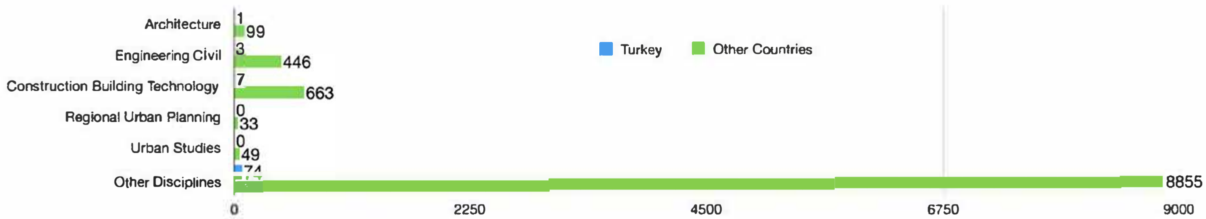


Figure 3: Academic Papers on “Net Zero”
Source: Compiled from WOS, 2022b

In Turkey, for research papers, there is also a national database; DergiPark, in which 590.971 articles stored as of the day of access. 1.575 articles are about Architecture and 1.227 articles are about civil engineering having a total 2802 papers for built environment. We also search for the same keywords in Turkish National Database as searched in WoS. In DergiPark, when the keywords “net zero”, “LCA”, “Life cycle assessment” and “embodied energy” and “operational energy” are searched, then the results were 9, 92, 42, 8 and 5 respectively in Table 3.

Table 3: DergiPark Database results between years 2004 - 2022
Source: Compiled from DergiPark

Key words→ Discipline ↓	**Net Zero**	**LCA**	**Life Cycle Assessment**	**Embodied Energy**	**Operationa l Energy**
Others	2	80	22	1	3
Buildings / Architecture	7	12	20	7	2
Total	**9**	**92**	**42**	**8**	**5**
Percentage in the field	*%78*	*%13*	*%48*	*%88*	*%40*

For the results for “Net Zero”, total of 9 papers are found in Turkish database, 8 of them were published in the last 10 years, starting from 2014 (DergiPark, 2022a). 7 of the paper are related to buildings and architecture. When the keyword “LCA” is concerned, total of 92 articles are found in Turkish database, but only 12 of them are related to building and construction sector. The first publication among these 12 is dating back to 2011(DergiPark, 2022b). For the results for “Life cycle assessment”, publications start from the year 2005, 22 of them are in Turkish, 20 of them are in English, 39 of them were research article, while 2 of them were review article (DergiPark, 2022c). Unfortunately, only 20 of them related to building and construction sector of which the oldest one dated 2011. We have also searched for other keywords that are important to reach net zero targets which are “embodied energy” and “operational energy”. When the keyword “embodied energy” is concerned, only 8 papers are found in DergiPark, 7 of them were related to building and construction materials (DergiPark, 2022d). Publications starts from the year 2004. For the keyword search “operational energy” in DergiPark, only 5 papers are found, with publication years starting from 2004, 2 of the which are related to architecture and buildings (DergiPark, 2022e). It shows that research on “net zero”, “embodied energy” in building and construction sectors are quite dominating the research fields in Turkey with the percentages %78 and %88 respectively. Unfortunately, the total number of papers are so low; 9 and 8 respectively. Built environment has a share of %13 for LCA studies, out of total 92 papers. In DergiPark, there are total 2802 papers published under Architecture and Civil Engineering disciplines. In Table 4, the percentages of built environment research are calculated. Net zero has a share of %0.25, LCA has %0.43, Life Cycle Assessment %0.71, Embodied energy has % 0.25 and Operational energy has %0.07. It can be driven that embodied energy and operational energy are the new subjects to Turkish researchers who is dealing with Net Zero Energy Buildings when compared to total number of papers published. Operational energy having a general share of 0,0007 with 2 articles in the field considered to be new subjects for researchers in Built Environment in Turkey.

Table 4: DergiPark Database results between years 2004 - 2022
Source: Compiled from DergiPark

Key words⟶ **Discipline** ↓	**Net Zero**	**LCA**	**Life Cycle Assessment**	**Embodied Energy**	**Operational Energy**
Buildings / Architecture	7	12	20	7	2
Share in Total Built Environment	***0,0025***	***0,0043***	***0,0071***	***0,0025***	***0,0007***

Dissertations

Using Turkish National Thesis Database of Council of Higher Education, we searched for "life cycle" and "environmental impact" keyword to understand the trends in academic world in Turkey. For the Life Cycle Assessment keyword, we have found 126 dissertations varying in 14 disciplines as shown in Figure 4. The highest dissertations are from Environmental Engineering discipline with 65 dissertations and the second in ranking is Architecture with 19 dissertations. Civil Engineering has only 1 dissertation, as mechanical engineering has also 1 dissertation too.

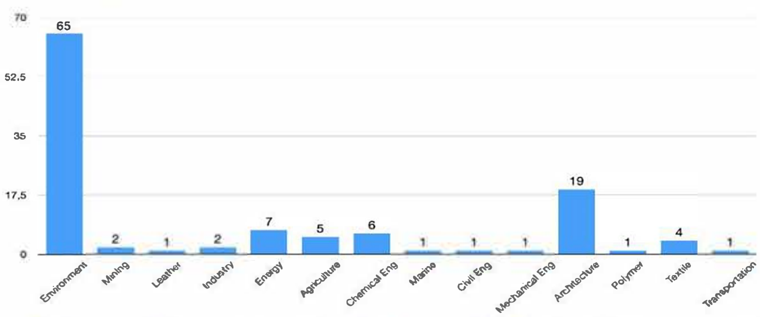
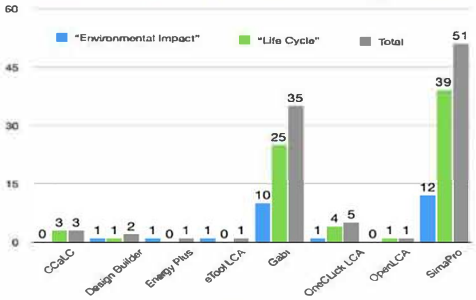


Figure 4: Master and Doctoral dissertations in Turkey on "Life Cycle" in terms of related disciplines
Source: Compiled from Turkish Thesis Center Database, Council of Higher Education

After general comparison on disciplines, we also examine their summaries and the table of contents to get deeper information on what they study and how they study the topic with the research key words "life cycle" and "environmental impact". To achieve this, we look the databases, and the tools they used for the study. In Turkey, for the LCA studies, Simapro is used in 51 dissertation and Gabi in 35 as shown in Figure5a and in Figure5b, the databases they used together with the programs are CML in 52, Eco invent in 18, Eco-Indicator in 15, ReCiPe in 10, and Impact in 9 dissertations. Unfortunately, no Life Cycle Impact Assessment methodology was found specific to Turkey or developed in Turkey. Only one dissertation was found in Architecture, in which a Panel approached was applied to Turkish experts to obtain the Turkey-specific weighting factor for impact categories for Midpoint impact categories (Karaman Oztas, 2017).

When we search in ProQuest, the results were 27.679 dissertations on Life Cycle and 27.951 on Net Zero (ProQuest 2022a and 2022b). Although the percentage of Turkey in dissertations is lower, 0,0045 when compared the share of Turkey in terms of articles which is 0,0122, a remarkable rise in the LCA topic in dissertation is observed in Figure 6. As from the year 2010 an awareness in LCA is rising in Turkey.



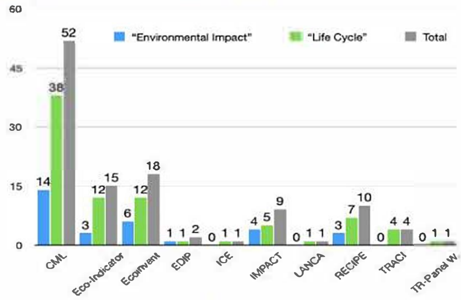


Figure 5a(left): Programs used in LCA study **Figure 5b(right):** Databases used in LCA study
Source: compiled from Turkish National Thesis Databases

Figure 6: Master and Doctoral dissertations on "Life Cycle" in Turkey
Source: Compiled from Turkish Thesis Center Database, Council of Higher Education

Environmental Product Declarations (EPDs)

Environmental Product Declarations (EPDs) is mandatory in LCA studies. It gives thirds party validated information about products and systems in align with ISO 14025 Environmental Labels and Declarations – Type III: Environmental Declarations – Principles and Procedures. In EPDs, life cycle stage information, service life and the environmental impacts that are studied are declared and used for LCA calculations (ISO 14025, 2006). To have sustainable buildings we should first know the impacts in material level, in building level and in district or urban level. In databases of two third-party bodies for creation of EPD, EPD International and IBU (Institut Bauen und Umwelt), that are disclosed to public via their websites, we search for construction products and refined the search to Turkey. The results are shown in Figure 7. Turkey constructions firms prefer EPD International as a third-party verifier than IBU as the numbers of published EPDs are 19 and 9 respectively.

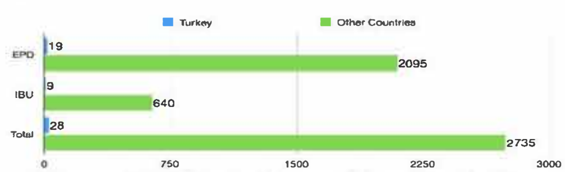


Figure 7: EPDs in the world and in Turkey
Source: EPD, 2022 and IBU,2022

The numbers of construction product EPDs are so low in the world and in Turkey since a simple building has at least more than hundred items. Moreover, in construction catalogues, in Turkey there are more than 4050 construction materials in 26 categories (Bayazit, 2016). Having only28 EPDs are extremely low when compared to number of construction materials in the catalogue.

Legislations and Applications in Built-Environment

Energy Efficiency efforts for buildings in Turkey first began in 2008 by launching and implementing "Regulation on Energy Performance of Buildings" in 2008 (Legal Gazette, 2008). Later, the ministry announced an application, called BepTR, national and mandatory application, that enables designers and engineers to calculate the energy performance of the building and to create a Building Energy Identity Card as shown in Figure 8. In the first page of the Energy ID card, performance of the buildings in terms of Annual Energy Use, GHG emission and share of renewables can be seen and compared. When the regulation and application was launched all new buildings should have had at least D-level energy performance. But now, in 2022, all new buildings shall have energy performance at least C-label. It has been stated in ministry website that more than one million buildings have energy performance C-level and above (ÇSB, 2022a). Unfortunately, this ID card only focus on buildings use phase performance, namely operational energy of the building.

Figure 8: Building Energy Performance Identity Card created by BepTR
Source: BepTR Manual

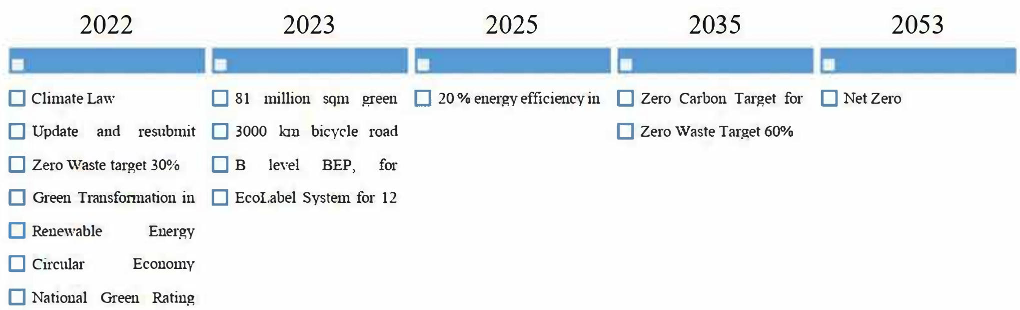


Figure 9: Green Development Roadmap of Turkey.
Source: Author's consolidation from TUCA (2022)

Recently, in COP26, Turkey declared and committed the Net Zero Target in 2053. After the conference, in Turkey, the name of the Ministry of Environment and Urbanization changed to Ministry of Environment and Urbanization. According to Turkey Environment Agency (TUCA), a meeting held with the name of "Turkey on the Road to Green Development" and a Final Declaration revealed. As seen Figure 9, the actions planned for the target are compiled and picturized (TUCA, 2022). According to declaration, from now on, new buildings having 500 sqm or bigger, shall have at least B-level energy performance instead of C-level. According to Turkish Statistical Institute (TUIK), in general in Turkey, 96.001 new building construction permits have created in 2020, while in 2021 136.474 permits were assigned (TUIK, 2022). When the potential of new constructions in every year in Turkey is concerned, having B-level energy performance requirement makes significant improvements in terms of carbon emissions. Ministry has announced the "Nearly Net Zero Building Regulation" and is expecting %25 decrease in energy usage in buildings and 5 billion Turkish Liras in total savings in energy bills (ÇSB, 2022b).

Moreover, in 2022, beside BepTR a national green building certification system called YesTR has been launched. The grading is similar to Leadership in Energy and Environmental Design (LEED), but it differs in percentages in terms of the importance of subcategories. The aim of the YesTR is to lower the costs of owners in Turkey, to widen the usage of green rating systems and to have sustainable built environments. Unfortunately, the statistics or information about the numbers of the buildings certified by YesTR up to the time this paper prepared could not be found, since that the YesTR certification system was just launched recently.

In YesTR, however, the certification can be applied to new and existing buildings; residential, office, education, hotels, healthcare buildings, commercial and other types of buildings. As seen in Figure 10, YesTR has 6 modules: BBT (Integrated Building Design), YMD (Construction materials and LCA), IOK (Internal Air/Space Quality), EKV (Energy Usage and Efficiency), SAY (Water and Waste Management), INO (Innovation). In YesTR, buildings can gain 15 credits out 100 in BBT module, and 16 in YMD module. In BBT module, if LCA analysis performed for the project, 3 credits are available for residentials and 2 credits for the other types of buildings. In YMD module for new constructions, preferring construction materials with lower environmental impacts based on EPD data has 5.76 credits available, preferring local materials transported in boundary of 200 km has 1,44 credits available, preferring reused, recovered, or recycled materials for the projects has 4,16 credits out of 100. All these credits, 14.36 credits out of 100, are related to construction materials used in construction phase aiming to lower embodied energy of the buildings.

	YENİ BİNA - B1													
	KONUT		OFİS		EĞİTİM		OTEL		SAĞLIK		AVM		DİĞER	
MODÜL	KATSAYI	AĞIRLIKLI KREDİSİ	KATSAYI	AĞIRLIKLI KREDİSİ	KATSAYI	AĞIRLIKLI KREDİSİ	KATSAYI	AĞIRLIKLI KREDİSİ	KATSAYI	AĞIRLIKLI KREDİSİ	KATSAYI	AĞIRLIKLI KREDİSİ	KATSAYI	AĞIRLIKLI KREDİSİ
BBT	0.15	15	0.14	14	0.14	14	0.13	13	0.13	13	0.14	14	0.14	14
YMD	0.16	16	0.16	16	0.16	16	0.16	16	0.16	16	0.16	16	0.16	16
İOK	0.20	20	0.20	20	0.20	20	0.20	20	0.20	20	0.20	20	0.20	20
EKV	0.25	25	0.30	30	0.30	30	0.30	30	0.30	30	0.30	30	0.30	30
SAY	0.24	24	0.20	20	0.20	20	0.21	21	0.21	21	0.20	20	0.20	20
TOPLAM		100		100		100		100		100		100		100
İNO		+ 10		+ 10		+ 10		+ 10		+ 10		+ 10		+ 10

Figure 10: Modules ans Credits in YesTR **Source:** TUCA (2022)

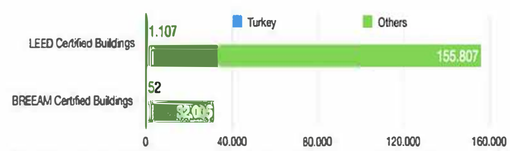


Figure 11: LEED and BREEAM Certified Building Numbers (LEED & BREEAM)

Since YesTR newly introduced, the number of the projects in Turkey having LEED and BREEAM certifications are searched for a comparison. The data is taken from LEED and BREEAM websites. In all over the world LEED Certifications were 156.914 and the Turkey refined search results was 1.107 (LEED, 2022), whereas BREEAM certified building number is 52 in Turkey. As in Figure 11, Construction sector prefers LEED as a green rating system, as the ratio between LEED/BREEAM is 22,28. Moreover, in the declaration, for 2023, the target of 81 million sqm green area set, 3.00 km bicycle road will be constructed, B level for BepTR will be mandatory, and Ecolabel system for 12 industry sectors will be launched. The sectors for ecolabels are not declared yet, therefore, it is not certain whether the construction sector or construction materials sector is included or not. For the 2025, 20% energy efficiency is targeted for public buildings. For 2035, in transportation and cities, zero carbon for cars is declared. For 2053, net zero target is declared. It has been stated that United Nations Development Program (UNDP) and Turkey are working to achieve these goals no details found in ministry website. In the future, with the climate law, there will be more to discuss in built environment. (UNDP, 2021)

CONCLUSION

To provide an overall evaluation the share of Turkey in terms of each topic mentioned in this study is listed in Table 5. The share of Turkey is %1.22 for publications on LCA (WoS, 2022a), %0.85 for publications on Net Zero (WoS, 2022b), %1.18 for publications on Embodied Energy (WoS 2022c), %1.18 for publications on Operational Energy (WoS 2022d), %0.45 for dissertations, %1.02 for construction products having EPDs, %0.70 for buildings having LEED Certification, and %0,16 for BREEAM certification. Since the number of papers in Embodied and operational energy are so low, their percentages regarded as out of ranking. Papers on LCA is leading the field with highest number of studies and highest ranking. Net zero follows LCA as second in order. When national Database and WoS are compared, there are 481 articles for LCA and 85 for net zero from Turkey, while in national database, there are 92 and 9 respectively. It states that the scientists in Turkey prefer to publish in WoS since the ratio of WoS/DergiPark is 5,22 for LCA and 9,44 for net zero.

Table 5: Turkey overall performance
Source: Author's consolidation from WOS, LEED, EPD, Global Data.

Topic	**Turkey**
Construction Market Size	**$114 billion**
Scientific Papers: LCA	0,0122
Scientific Papers: Net Zero	0,0085
Scientific Papers: Embodied Energy	0,0118
Scientific Papers: Operational Energy	0,0118
Dissertations	0,0045
EPD	0,0102
LEED certified buildings	0,0070
BREEAM certified buildings	0,0016

For the further studies we recommend that researchers would fill the gap in these topics via: (i) research on built environment, especially in measuring and monitoring the environmental impacts, embodied and operational energy, (ii) increasing the number of national Life cycle inventory studies to publish more EPD for local construction materials, (iii) developments on LCA methodologies, such as national and worldwide weightings, new impact categories, (iv) developing national databases and Turkey-specific values for LCA and LCIA studies, instead of using other countries' databases or generic data.

For the built environment in Turkey, we suggest decision makers and policy makers: (a) designing buildings with construction materials with less environmental impacts, (b) supporting the research on net zero buildings and built environment, (c) launching and implementing regulations for built environment such as climate law, (d) increasing the number and usage of national databases, methods, certification systems, (e) giving incentives on publishing new EPDs, (f) giving incentives to buildings which prefer construction materials with EPD, (g) giving incentive on green buildings, near net zero buildings and net zero buildings, (h) increasing the number of green and (nearly) net zero buildings, (i) building only green and net zero buildings for the public sector. This papers stated the current research environment and applications in Turkey. To conclude, in Turkey, there is an increased awareness of these subject and this increase in Life Cycle thinking in built environment seems to be consistent in the future.

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STRATEGIES FOR THE MITIGATION OF URBAN HEAT ISLANDS IN RESIDENTIAL AREAS OF DESERT CITIES. THE CASE OF AREQUIPA – PERU

Carlos Zeballos-Velarde[1]

[1] Professor, Department of Architecture and Construction Engineering, Universidad Católica San Pablo, Arequipa, Peru (crzeballos@ucsp.edu.pe)

ABSTRACT

The effect of urban heat islands (UHI) affects the comfort conditions of residential areas and the health of their inhabitants. In cities located in desert areas, the particular physical conditions of the territory differently affect the generation and intensity of the urban heat islands effect Understanding the different microclimatic characteristics is important to propose suitable architectural solutions for each case, in order to mitigate high urban temperatures. This research is carried out in Arequipa, Peru, a city with a desert climate that has one of the highest solar radiations in the world and where studies of UHI and residential areas have not been previously conducted. The paper has three objectives: the first is the location of the urban heat islands. For this purpose, satellite remote sensing is employed to identify hotspots in the metropolitan area that suffer this effect. Subsequently, airborne temperature measurements and high-resolution thermographic imagery were collected using an unmanned aerial vehicle (UAV) in four typical areas where housing of different density interacts with vegetated and non-vegetated environments, in order to identify particular physical, thermal and spectral information for a more accurate microclimatic analysis of a variety of residential areas in Arequipa. The third objective is to identify specific situations at an architectural level and to propose concrete heat mitigation strategies and green infrastructure that can be carried out to benefit microclimate conditions in residential areas. It is expected that the methodological framework and results of this research can be equally replicated in other cities of Peru and South America that suffer from the negative effects of climate change and urban heat islands.

Keywords: urban heat island, urban climate, desert cities, heat mitigation, planning tools

INTRODUCTION

Urbanization transforms the territory into a complex cityscape, characterized by forms, materials and activities that differ sharply from the forms of the natural landscape. Thus, the flow of energy in an urban area is different than in a natural greenspace. While the reflectance of sunlight is lower, the sensible heat generation at ground level is higher in cities compared to rural areas. the way the city interacts with its territory, the type and frequency of activities carried out in this urban area and the number of people living in the same place causes changes in the microclimate, modifying the thermal balance urban union increasing anthropogenic heat.

The phenomenon of temperature distribution that occurs in the city, called the "urban heat island" (UHI), creates a situation of thermal inversion, when a dome of hot air is trapped under a layer of colder air and, therefore, heat and dusty air act near the population (Zeballos-Velarde, 2020; Santamouris, Regulating the damaged thermostat of the cities—Status, impacts and mitigation challenges., 2015; Voogt & Oke, 2003). Therefore, heat islands are associated with urban development. Among the causes that generate heat islands are the high construction density, the thermal behavior of construction materials and the design of open spaces and green areas. In particular, surface urban heat islands (SUHI) can be affected by several aspects that have to do with the properties of natural and artificial materials, with the layout of the urban fabric and with the capacity of conductivity, emissivity and sensible heat accumulation capacity (Santamouris, et al., 2017) This increase in temperatures in the city has a direct effect on the increase in energy consumption and the thermal comfort of citizens related to their health and well-being, also generating an increase in environmental pollution, promoting the greenhouse effect and acid rain. The city works as a heat accumulator generated by itself as well as the activities that take place in its territory (vehicles, engines, industry, heating, etc.), which are directly proportional to the size its population, as Oke (1973) proposed.

The spatial distribution of these temperatures is often concentrated around the city center, forming a "heat island" in the landscape. The intensity dimension of an urban heat island depends on the size of the city (based on its population) and on the climatic conditions of the region.
Firstly, the thermal conductivity of the materials used in construction is several times higher than that of the area in its natural state, so they absorb radiant heat more easily. Secondly, the spread of more or less shiny smooth surfaces turns the urban landscape into a labyrinth of mirrors that favor multiple reflections of the energy emitted by the Sun. Thirdly, the dome of suspended particles characteristic of the "thermal inversion" and the height of buildings that affect the wind make it difficult to dissipate pollutants due to aeration. Finally, the discharge of rainwater through the sewer system and the pavement of the streets reduces evapotranspiration, thus maintaining a higher ambient temperature than that which would occur in natural conditions (Zeballos-Velarde, 2020). People feel uncomfortable outside, which is why they prefer to spend more time inside a building, however, these are not properly designed to be comfortable either.

LITERATURE REVIEW

The thermal effect of the heat island has different effects at urban and residential levels.

Urban level

The urban heat island phenomenon is concentrated mainly in city centers, where the population density is higher, there is less exposure to the winds and also less presence of vegetation; these phenomena are caused by the accelerated urban growth (Soto-Estrada, 2019). It is known that vegetation can mitigate urban heating, however, the effect of mitigation depends of the plant species used and the spatial and landscape design of the greenspace (Feyisa, Dons, & Meilby, 2014; Gunawardena, Wells, & Kershaw, 2017).
The green and blue infrastructure (vegetation and bodies of water) offer a possibility of urban cooling. Studies carried out at the microscale level determine that, by means of a correct channeling of winds, these spaces can improve their comfort as well as the health of their inhabitants. (Gunawardena, Wells, & Kershaw, 2017). The evaporation process of water bodies also influences the behavior of heat islands, the movement and cooling of water during the day relieves heat stress, however, due to its heat capacity, water causes the temperature to remain high overnight (Steeneveld, Koopmans, & Heusinkveld, 2014).
Understanding the most common materials used in cities and their thermal-environmental behavior is important to determine the characteristics and scope of heat islands. It has been noted that the temperatures recorded inside and on the surface of the pavement are always higher than those measured on the outside (Correa, Flores Larsen, & Lesino, 2003). In addition, waterproof materials play an important role since they contribute to increasing heat in urban areas (Romero Aravena & Molina; Qin, 2015)

Residential level

The design and use of buildings have a direct effect on the increase of surrounding temperature. Thus, a green building is defined under the three pillars of sustainability and understands the direct relationship between construction and urban heat flows. To achieve this goal, this type of architecture must take into account the configuration of the environment, the design of the shape of the building, the architectural surrounding, the facilities, accessories, and especially the understanding of the users behavior (He, 2019).
The shape and orientation of the building are important because they can take advantage of wind circulation and solar radiation, particularly considering the facades that receive the most radiation during the day

(Farhadi, Faizi, & Sanaieian, 2019), since generating shaded surfaces reduces and stabilizes the temperature, and therefore has a direct effect on the surfaces thermal conditions (Zhou , Yan, Ge, & Hu, 2022).
In addition, strategies such as the adaptation of green and cold roofs, considering their albedo (or "reflection coefficient"), mass, and insulation (Kolokotsa, Santamouris, & Zerefos, 2013), can help mitigate the effect in urban areas. These roofs have benefits such as reducing energy consumption due to their thermal inertia, they favor acoustic insulation by means of permeable surfaces that hold rainwater, and therefore reduce the heat island effect. However, it is necessary to know what type of green roof is suitable depending on its construction system, the climate it endures, and also the investment in construction and maintenance (Jamaludin, Hashim, Zakaria, Ahzahar , & Ridzuan, 2022).

Several types of resources, known as cold materials, have the ability to maintain low surface temperatures, which can be used in buildings or in urban areas characterized by high values of solar reflectance and infrared emittance, as both values contribute to lower surface temperatures. Light materials in tiles, marble, mosaics, concrete, and asphalt with white aggregate, can effectively reduce the impact of urban heat islands (Farhadi, Faizi, & Sanaieian, 2019; Synnefa, Dandou, Santamouris, Tombrou, & Soulakellis, 2008). Cold materials are mainly used on horizontal surfaces, such as ceilings and reflective concrete floors, incorporating reflective color pigments into the paved surface (Qin, 2015). Finally, the energy consumption of buildings and its direct relationship to the effects of urban heat islands must be considered, by increasing the number and effect of cooling strategies, especially in downtown areas, as well as reducing the need for heating (Li, et. al., 2019).

THE SITE

Arequipa, the second city of Peru, is located around a valley that cuts through an arid desert, located on a plain at an altitude between 3,000 and 2,300 meters, flanked between hills to the south and a volcanic range from north to east (Figure 1). Since Arequipa is located in a depression between two mountain ranges, it presents an average daytime temperature between 15 to 18°C; that can rise on warm days up to 28°C, although for short periods of time (Figure 2). The nights are cold, with temperatures that drop to 10° C. The relative humidity is highly variable, ranging between 30% and 40% at noon to 80 - 90% in summer (the rainy season), increasing at night. Relatively intense winds occur in a Northwest-Southeast direction. In addition, the climate of Arequipa is conditioned by the Pacific Ocean, which proximity is less than 80 km, given its nature as a thermal regulator and producer of water vapor (Zeballos-Velarde, 2020).

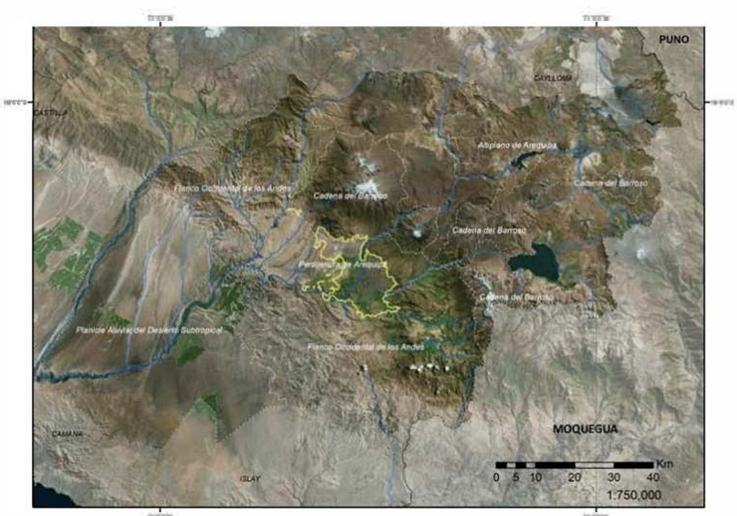


Figure 1: Geography of Arequipa Province
Source: Carlos Zeballos.

Therefore, Arequipa has a “Temperate Climate of Continental Type”, that is, it is a semi-desert with little rainfall, which creates dry atmospheric conditions with a great daily difference in temperature, but a very little annual variation. In addition, Arequipa receives a large amount of solar energy due to its low latitude, its height, and has an arid climate without cloud cover. According to the Köppen climate classification Arequipa belongs to a BSw type: a Cold Steppe or Semi-arid climate, with summer rainfall and climate with an average temperature of 18°C. Also, according to the Thornthwaite climate classification, the city is located in the D (o i p) B´2 H2 zone, with semi-arid, temperate climate, dry autumns, winters and springs (Zeballos-Velarde, 2020)

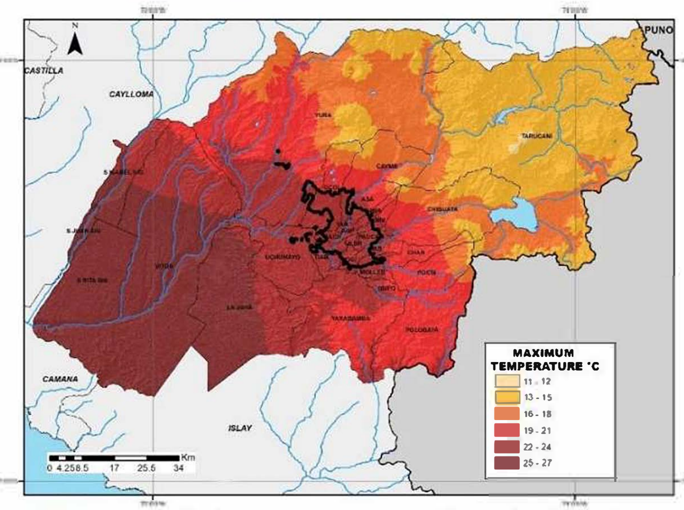


Figure 2: Maximum temperature Arequipa Province

Summer is long and hot when it doesn't rain. From December to March, air circulation between (0.5 and 1.0 m/s) is needed to stay in the comfort zone. Summer nights are usually pleasant, and sometimes require ventilation, which is normally provided by the prevailing breeze regime in the area.

METHODOLOGY

For the proposal of architectural solutions that allow efficient thermal comfort, a comprehensive methodology is proposed that considers an understanding of the microclimatic conditions in the territory of a desert city like Arequipa. The present study is based on two levels of analysis, the first using multi-spectral satellite images, and the second using measurements made with a drone-mounted thermal camera.

The first phase of this study seeks to determine the occurrence of urban heat islands in the city through remote sensing. For this purpose, the analysis of land surface temperature (LST) has been carried out, based on a Landsat image taken on August 5, 2018, at 09:46 (winter time). Also, a NDVI analysis was conducted to understand the presence of natural and planted vegetation. This imagery has a pixel resolution of 30 m. Subsequently, a map algebra correction, a radiometric correction and an atmospheric correction by the FLAASH method were made. Finally, a conversion from Kelvin to Celsius degrees was carried out. The urban heat island map allows us to identify four scenarios with different thermal conditions that influence residential areas: a) the urban-rural interface, the city-river interface, low-density residential areas, and high-density residential buildings in dry areas. Subsequently, a UAV (drone) equipped with a Flir Duo thermal camera captured imagery in each of these areas. However, since this camera is not radiometric, it was necessary to perform surface temperature measurements in situ using a thermometer to recalibrate the image values accordingly. This imagery has a pixel resolution of 50 cm.

The second phase consisted of analyzing the relationships between the buildings and the surrounding land, in order to identify mechanisms of interaction of the architecture with the climate, both of energy input and output. Finally, architectural alternatives are proposed to mitigate the urban heat island effect in residential areas.

RESULTS

The NDVI analysis (Figure 3) shows that the majority of vegetation in the city corresponds to agricultural fields located towards the south and south west of the city. The urban area, located mostly in the foothills of the volcanoes to the north and northeast, is notoriously lacking in vegetation, which favors the creation of urban heat islands.

As for the surface temperature, it tends to be concentrated in the uncultivated hills that surround the city, but it begins to drop as the volcanoes gain height, reaching freezing temperatures above 5,000 meters of altitude (Figure 4). Typically, the city tends to be warmer in the south where the altitude is lower than in the north or in the foothills of the surrounding mountains. For example, the ambient temperature in the quarter known as Tingo is normally milder than in the city center, and for that reason it used to be a popular spa in the last century (Zeballos-Velarde, 2022). This is because Tingo is located at an altitude of 2215 m, while the Arequipa's main square in the central area has an altitude of 2328 m. (MPA, 2019). In contrast, in the case of the so-called "Parque de las Rocas" ("Rock Park"), located at an altitude of around 2650 m, the ambient temperature is lower, hosting wild flora which is typical from the highlands.

Figure 3: NDVI analysis in Arequipa city
Source: Carlos Zeballos.

However, the urban heat island analysis (Figure 5) shows a different surface temperature pattern than that of the ambient temperature. The Tingo area mentioned above has a moderate surface temperature due to the presence of water and riparian vegetation, while the soil of the Parque de las Rocas is much hotter due to the absence of vegetation. In general, the areas with the highest temperatures are the arid hills surrounding the city, as well as some spots within the urban fabric, such as the airport, whose urban heat island is up to 20 degrees Celsius higher than that of the immediate residential areas. In contrast, agricultural areas have a lower surface temperature, regardless of the altitude at which they are located. Therefore, some of the most important issues that increase the urban heat island effect are: large surfaces of materials with low albedo and high admittance; scarce vegetation, and permeable surfaces, which do not generate shade and evapotranspiration (Wang, Berardi, & Hashem Akbari, 2016).

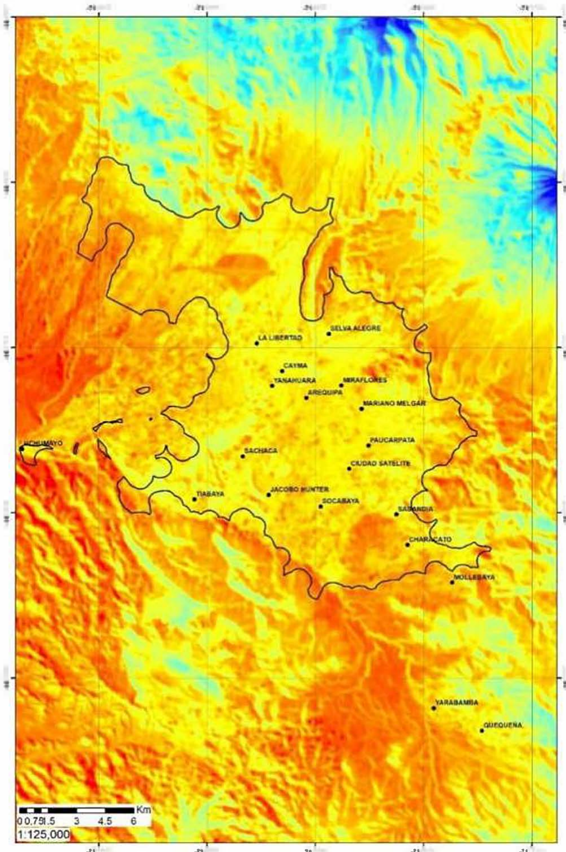


Figure 4: Land surface temperature of Arequipa city
Source: Carlos Zeballos.

Additionally, in order to carry out more detailed studies of surface temperature and its relationship with housing, four sectors of typical characteristics have been identified, over which UAV flights equipped with a thermal camera have been carried out.

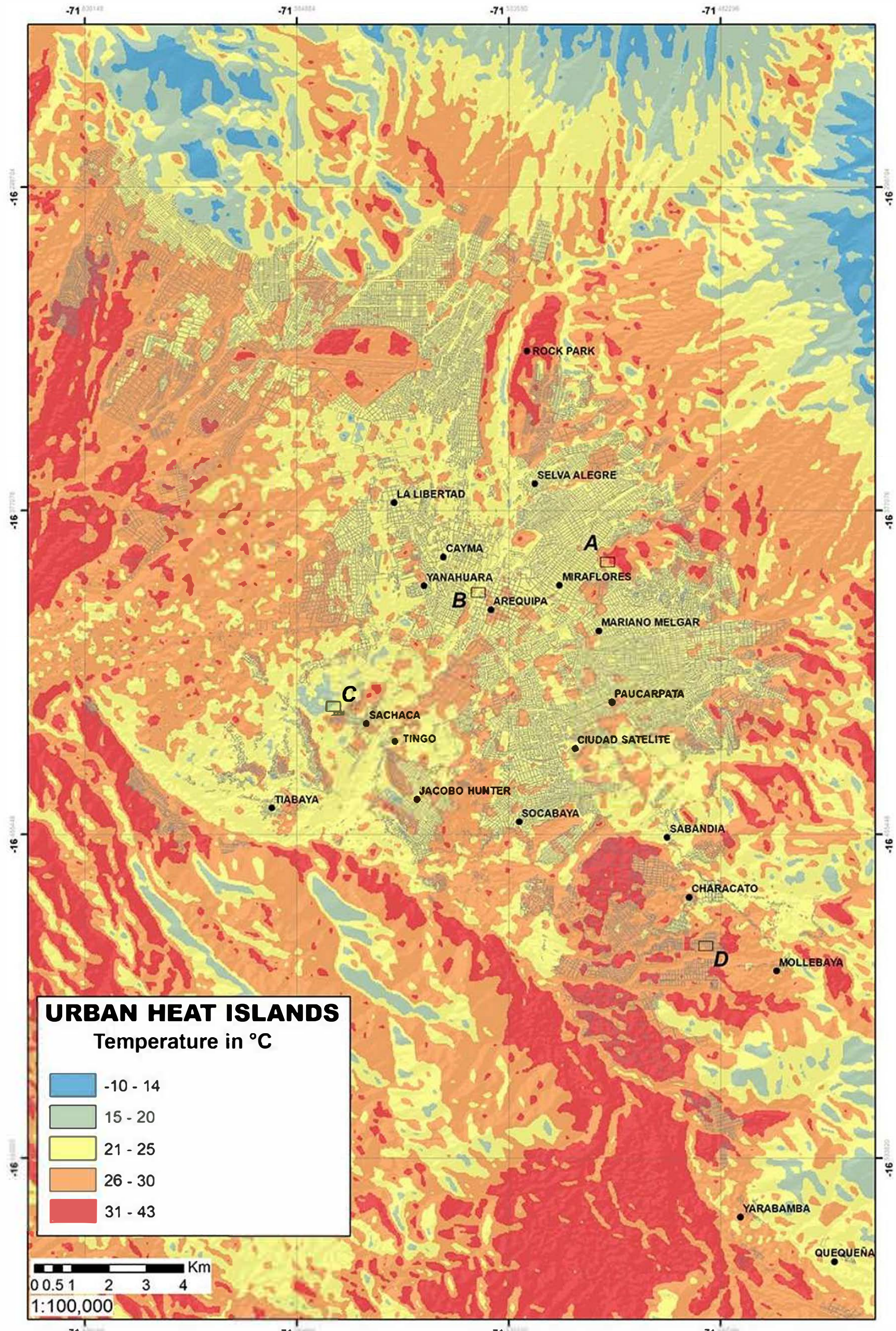
High-density residential areas next to barren land

The study sector is located in Miraflores district, next to a barren hill that contains little wild vegetation (Figure 6). This is a high-density residential area inhabited by many middle-class families and these high buildings and narrow alleys modify overall wind speeds, thus creating urban canyons. In front of these high-rise buildings there is a seasonal ravine that is activated during the rainy season (the summer months) but hosts scarce vegetation during the rest of the year. This ravine crosses a park that is also barren, without vegetation. These factors contribute to increasing the urban heat island effect and reducing thermal comfort, which affects many families.

Mid-density residential areas next to riverfront

The Chili River basin has a low surface temperature, not only because of the cold water that runs through it, but also because of the surrounding vegetation. However, La Marina avenue, located in the next to the river bordering the city center, has a high land temperature due to the surface covered with asphalt. This phenomenon is also observed in a large empty lot that affects the surrounding housing areas, which could have better thermal conditions thanks to their proximity to the river, but are affected by the presence of large dry surfaces (Figure 7).

Figure 5: Urban heat island map



Source: Carlos Zeballos.

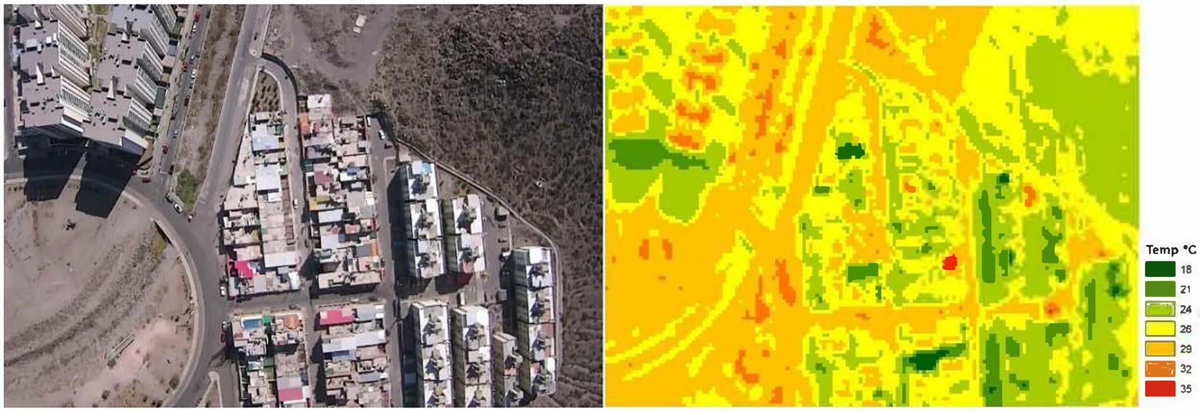


Figure 6: Miraflores, A) Aerial photo B) Land surface temperature
Source: Carlos Zeballos.

Figure 7: Riverfront in downtown, A) Aerial photo B) Land surface temperature
Source: Carlos Zeballos.

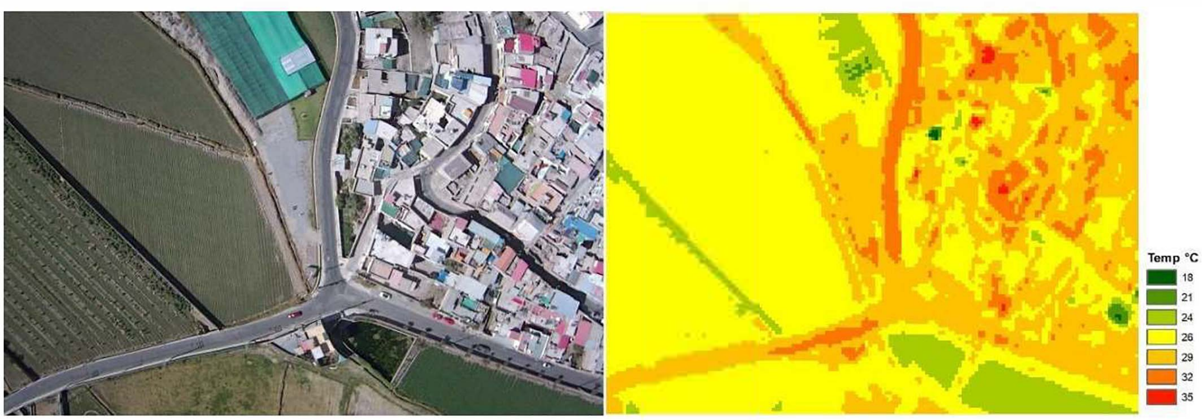


Figure 8: Sachaca, A) Aerial photo B) Land surface temperature
Source: Carlos Zeballos.

Mid-density residential areas next to agricultural fields

This settlement, called Sachaca, is located next to an agricultural area, so the surface temperature is mostly moderate. The thermal analysis also allows us to appreciate that there are differences in the surface temperature according to the types of crops. For example, onions will have a higher surface temperature than alfalfa or corn, due to the amount of foliage on the cultivated plants. However, as the houses move away from the farm, their surface temperature increases due to the absence of street vegetation and the materials used in the roofs (Figure 8).

Low-density residential areas on barren land

The Characato area is located to the south of the city and is characterized by its low-density housing development. The scarce vegetation, the building materials used in the houses, as well as the high ambient temperature and radiation have a direct effect in the high temperatures, affect the outdoor thermal comfort of the residents.

Figure 9: Characato, A) Aerial photo B) Land surface temperature
Source: Carlos Zeballos.

DISCUSSION

The effect of urban heat islands increases with the density of buildings, therefore buildings should be considered as an opportunity to reduce the greenhouse effect by understanding the interaction of the building with its environment. The creation of healthy and comfortable buildings for human beings is important, reducing their energy consumption and carbon emissions through urban heat island mitigation strategies to achieve zero heat impact in buildings (He, 2019). We must consider that the analyzed sites are residential areas, which typically have a larger occupation during night hours (outside working hours), where the outside temperature has decreased. This has not been the case, however during the COVID-19 pandemic, because many people have occupied their homes to carry out remote work. In a desert city like Arequipa, where the amount of water is limited to provide large areas of vegetation, it is necessary to have alternative strategies that allow an efficient mitigation of the effect of this heat. The following table summarizes the strategies that can be considered in residential areas in desert cities; Its use in each of the selected typological sectors is subsequently explained.

Table 1: Central area, UHI mitigation strategies
Source: Paredes

SOLUTION NUMBER	STRATEGY	OBJECTIVE	USE
1	Vegetation	To promote the use of vegetation to increase the shadow area in open surfaces.	Open spaces
2	Open areas	To maintain a percentage of free area in housing areas, so that buildings could generate more shadows on unbuilt spaces and on themselves.	

3	Building orientation	To design and accommodate new spaces for an optimal use of solar energy to generate thermal comfort within them.	Wrappings
4	Albedo	Application of light-colored materials, especially on horizontal surfaces, in order to increase solar reflection.	
5	Energy efficiency	Replacement or optimization of incandescent light bulbs that generate heat inside homes.	Closed spaces
6	Natural ventilation	To adequately design and condition spaces to generate natural cross-ventilation, as a measure of cooling and air renewal.	

High-density residential areas next to barren land

These tall buildings tend to accumulate heat on surfaces such as ceilings and walls. Likewise, the lack of vegetation in the surrounding uncultivated areas causes the development of high temperatures (Fig 8 a). Because of the high-density housing buildings, strategies it is recommended to improve the albedo in surfaces and also to develop green roofs, since the cast shadows cast by the edifices dramatically reduce temperature, due to the dry climate conditions of the city; in addition, the design and orientation facilitate natural ventilation of houses. As for the warm areas located around the seasonal stream and its surroundings, forestation with native vegetation can be used, as plats with low consumption of water can be useful to mitigate the heat, with afforestation programs that include native species which need little water to survive and are not currently used for aesthetic reasons (Zeballos, et. al, 2021) (Fig 8 b).

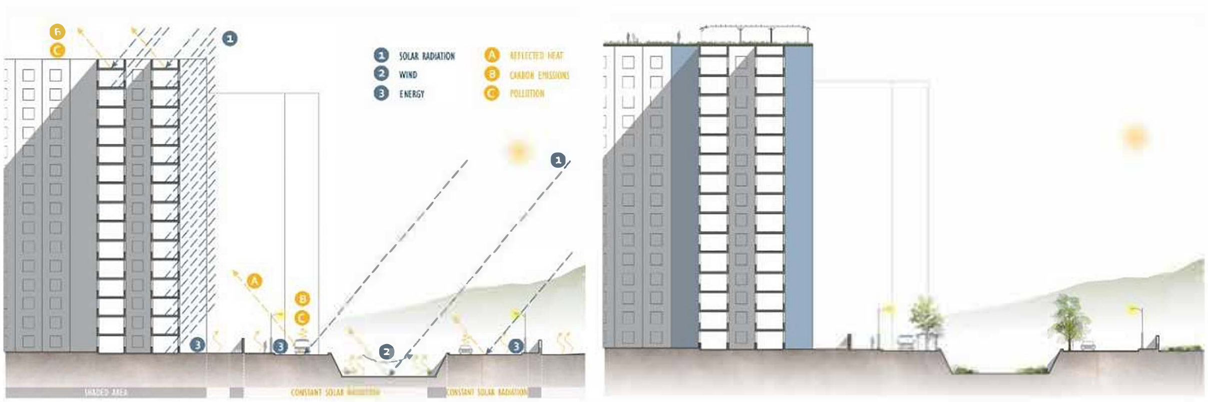


Figure 8: *Miraflores. A) Current conditions. B)* UHI mitigation strategies.
Source*: C. Zeballos based on Paredes*

Mid-density residential areas next to riverfront

As for the riverfront type, heat is accumulated in the roads next to the river and also in areas with scarce natural vegetation (Fig 9 a). Therefore, it is important to restore flora in the river basin, since the adjoining houses belong to the historic center of Arequipa, generally have inefficient cooling systems. In addition, albedo can be improved, due to the materiality of the ashlar (ignimbrite), a volcanic rock traditionally used as construction material, which produces a high solar reflection index due to its white color. Additionally, some parts of the road can be constructed underground, to reduce the heat produced by the asphalt and, mainly, to bring the city closer to its river (Fig 9 b).

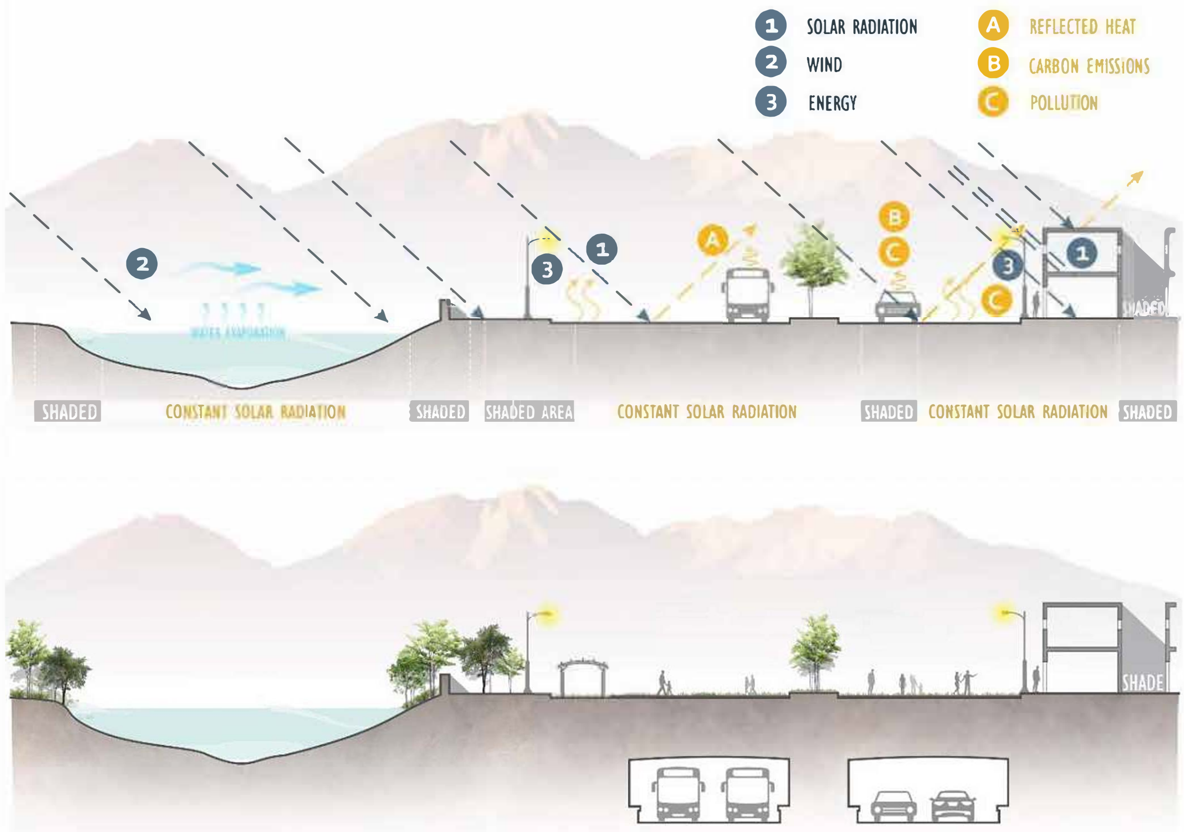
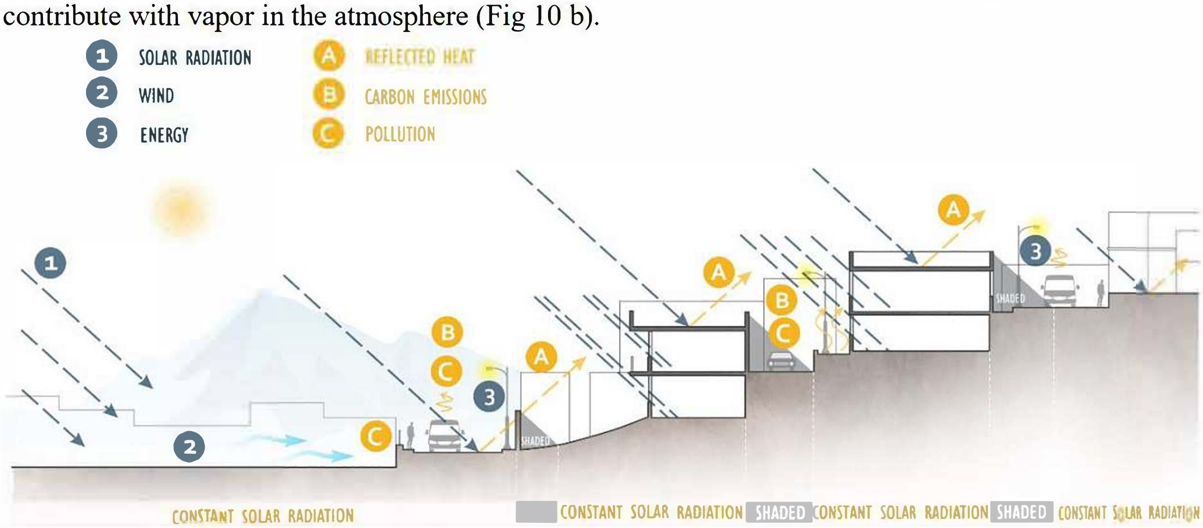


Figure 9: Central area. A) Current conditions. ***Graph***: C. Zeballos based on Paredes. B) UHI mitigation strategies. ***Graph***: C. Zeballos

Mid-density residential areas next to agricultural fields

In the case of Sachaca, in addition to the countryside and cultivable areas close to housing, the topography in the sector is more rugged than in the other case studies (Fig 10 a). This sector can accommodate urban furniture and vegetation, as shadows can be generated to avoid the heat island. In addition, since they are houses more peripheral to the city, strategies 1 and 2 should be used in the farms, as trees with foliage contribute with vapor in the atmosphere (Fig 10 b).



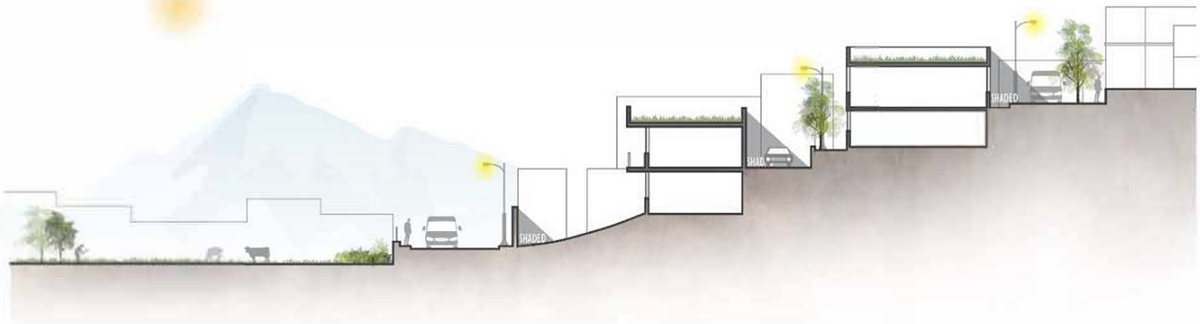


Figure 10: Sachaca area. A) Current conditions. ***Graph***: C. Zeballos based on Paredes. B) UHI mitigation strategies. ***Graph***: C. Zeballos

Low-density residential areas on barren land

The area of Characato is currently very little urbanized, as there are only some precarious dwellings of one or two levels, far apart from each other, leaving a large amount of land exposed to radiation. solar, which shows a greater concentration of the heat island (Fig 11 a). This case is the one that requires improving the albedo in the surfaces of buildings as well as pavements. Also, native desert vegetation, which does not need a lot of water throughout the year, can be used (Fig 11 b).

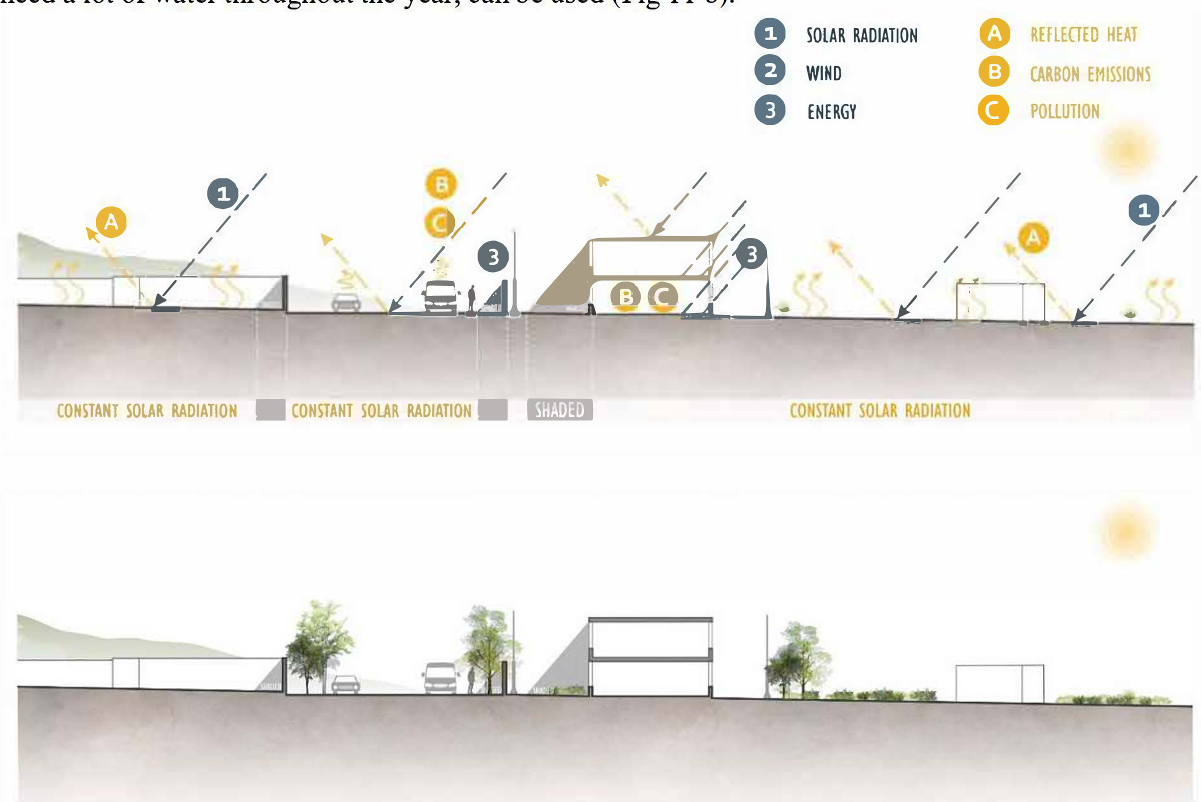


Figure 11: Characato area. A) Current conditions. ***Graph***: C. Zeballos based on Paredes. B) UHI mitigation strategies. ***Graph***: C. Zeballos

CONCLUSION

An urban heat island map for the city of Arequipa was produced using multispectral satellite imagery from the Landsat, which allowed determining that urban areas close to barren land with little vegetation accumulate surface temperature while agricultural areas tend to have milder land temperatures, regardless of altitude or ambient temperature.

The heat island map of the city also allowed to give an overview of the problem and also to identify four specific types where the territory interacts with residential areas. These types are a) high-density residential areas next to barren land b) mid-density residential areas next to riverfront c) mid-density residential areas next to agricultural fields d) low-density residential areas on barren land. Subsequently, airborne flights equipped with a thermal camera were carried out over and later calibrated with temperatures taken on-site with a thermometer, which allowed identifying in more detail the ways in which the surface of the territory affects external thermal comfort in residential areas.

Finally, six strategies were proposed to mitigate the urban heat island effect in residential areas, in terms of vegetation, open areas, building orientation, albedo, energy efficiency and natural ventilation. Further research on each topic will be carried out at an architectural level to propose specific solutions for a desert city such Arequipa.

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REDEFINING THE LIVABLE NEIGHBORHOODS IN BANGALORE PERIPHERIES- A CASE OF DOMMASANDRA AREA, BENGALURU

Harshita D [1]

[1] Assistant professor, School of Architecture, Ramaiah Institute of Technology, M S Ramaiah Nagar, Bangalore, harshitadk25@gmail.com

ABSTRACT

Large metropolitan areas include urban and rural periphery areas. Between there areas are the links that cannot be examined separately(UNESCO, 2014). The pressure of rapid growth has resulted in a rapid transformation in the fringes of city to accommodate the growth. These areas are the transition zones-transition characterized by diverse range of land use, communities, physical infrastructures (environments)(Narain and Nischal, 2007).

Sarjapur-Dommasandra which is under the jurisdiction of BDA and Anekal is located towards south and east of Bangalore witnessing rapid growth transformations and new developments. The area under BDA is zoned as agricultural planning district and zoned under industrial and residential district in Anekal planning authority. It is found that there has been increasing demand for housing in the area due to the increased influx of people mainly due to migration from other parts of the country. For this reason, private developers are converting the land from agricultural to residential to accommodate the population's demand. Hence these areas have transformed their socio-economical fabrics through interactions with the city.

The research paper proposes a methodological assessment to study regional and precinct level scale that emphasizes the analysis on trends in transformation mainly focusing on land use proposal, development type, real estate price, infrastructural facilities, demography, population, transformations, shift in occupation, ecological factors, typology and character of built forms considered to develop the strategies which will redefine the neighborhood in these peripheral areas for a better quality of living.

The paper attempts to integrate and guide the developmental trends in the best possible method under the framework of affordability, land cost, and density factors for housing and commercial developments which is the major factors driving the type of growth pattern in the Dommasandra area. It also studies the real estate development trend, zoning regulations, and byelaws across the area. It considers the impact of new developments across the area and notes to protect the natural and cultural resources which are the key assets and these are getting engulfed by urban areas. It also illustrates the scenarios of development based on the current market trend growth, the 2031 master plan scenario across the area and the envisioned alternative future for the area combining both.

Keywords: Peri-urban areas, Transformations, development trends, natural and cultural resources.

INTRODUCTION

Many villages gradually get included in cities and people migrate to villages transforming them into towns. The rapid growth and transformation of land use from rural to urban has impacted on agriculture and livelihoods in the rural-urban fringe.(Narain Vishal, 2010)

Sarjapur-Dommasandra is located in the Anekal taluk of Bangalore Urban district in Karnataka. The area is under the jurisdiction of BDA and Anekal is located towards the south and east of Bangalore. It was found that there has been increasing demand for housing due to the increasing population caused mainly by the migration of people due to surrounding IT hubs.

Sarjapur-Dommasandra started experiencing intensive physical development after 2005. Most of the people other than the original inhabitants are relocated settlers from different parts of India and from Bangalore. The real estate housing type with different facilities provided within built by private owners. Most of the original inhabitants about 87.74 % engaged in work or business activities.(Census of India-Anekal, 2001)

Problem Statement

Deprived of their cultivable land, people of these areas have switched to different occupations and activities. Most of these areas have shops catering to the basic needs of the inhabitants and specific needs of the city. The study area gives an overlook on the increased Population of the village (Dommasandra, TC Halli and Chambenahalli) has by 60% in last 10 years (Village panchayat Records).

The project also analyses the current scenario of development off stretch along the Dommasandra area shows:

- Ribbon development along the main Sarjapur –Dommasandra corridor.
- Development in all directions leading to low density.
- The gross density of this mainly agricultural area is only 5 person/ha which is very low compared with the average gross density of BBMP area (42persons/ha). (Srinivasan and Shankar, 2016)

Hence the project is aimed at minimizing the unplanned growth and enhancing some sense of order in the area by re-organizing and redeveloping the residential neighborhood through strategies that will Integrate and guide the development trend in the peripheral areas to facilitate a development type in a residential neighborhood. This will be achieved through applying the right planning standards and guidelines and also looking at other peri-urban areas that have been planned successfully in order.

Understanding existing surrounding of Dommasandra

Less than a radius of about 16 kms from Chandapur circle, as many as 70 IT companies and OEMs are located. Sarjapura Attibele Road, Infosys has acquired a 300-acre land for their next IT expansion. Attibele (which is the border and last part of Bangalore), which is another 14 kms away from Dommasandra Circle - has a project by Shriram Properties with upcoming 1300 apartments in one single project location. With these developments, in another 3 to 5 years, this area too will become a hot spot like Sarjapur, Marathalli, Whitefield, HSR Layout, Hosur road, Electronic city, Jayanagar, Koramangala, etc. and will be unaffordable then, prohibitively expensive perhaps at 2800 or 3200 per sq. ft just for the land alone then.

The following are the growth activities in Sarjapur belt, currently announced: Under construction are 275 acres of 1100 villas, 200-row houses,500 apartments, an 18-hole golf course,4 screen multiplex, 5-star hotel with 150 rooms. Shopping mall on Anekal jiganu road, phase ii of Bangalore metro to be done from 2015-2020 has already got Chandapur circle included in the rail network proposed and is expected that Anekal will be included in phase iii. Sarjapur connectivity to IT clusters located along the ORR, Whitefield and Electronics City has turned it into a sought-after destination for residential developments. This micro-market has recently witnessed a surge in commercial activity (office space leasing) with a large tech park under construction and smaller standalone projects meeting spill over demand from the ORR. (RAVIKANTH, 2017) *"According to research by Cushman and Wakefield, it is considered an attractive investment option for migrant employees in the IT/ITeS sector. The capital values currently range between Rs 4,500-6,500 per sq ft. The rental values range between Rs 20,000-35,000 per month for a two-bedroom configuration and Rs 30,000-45,000 for a three-bedroom configuration"*(Kanika Arora, 2016)

Material and data:

Dommasandra- location and socio-economic data

Dommasandra is a village located in Bangalore East. The total geographical area of village is 100 hectares with total population of 12610 peoples. Figure 1 shows the Statistical data on social class and sex ratio. Almost about 295 houses present in Dommasandra village. Bbmp is nearest town to Dommasandra with a proximity of 6km. New developments have resulted in employment opportunities to the local communities. Villages depend on industries such as Garment factories, marble/granite crushing, and brick kiln industry for their livelihood. Others are into construction labors, maid/cook, and security guards. (*INDIAN VILLAGE DIRECTORY*, no date)

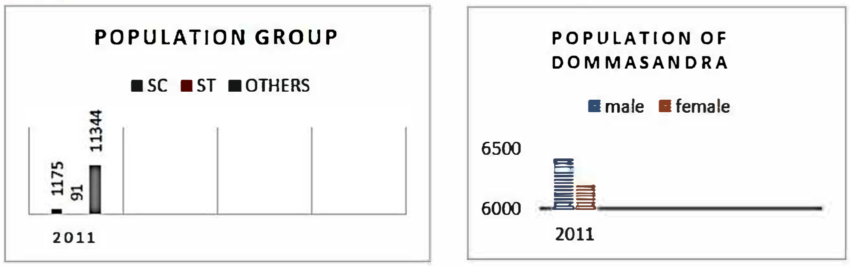
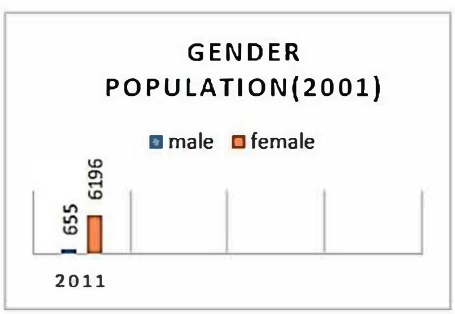


Figure 1: Population statistics data based on stratum numbers.
Source: Author, 2017

Chambenahalli Village - location and socio-economic data

Chambenahalli Village with population of 1271, located in Anekal sub district of Bangalore district. Total geographical area of Chambenahalli population of 1271. Population density of the village is 527 persons per km^2. Almost 1271 people dwell in the village, among them 655 (52%) are male and 616 (48%) are female. There are 266 households in the village and an average 5 persons live in every family. In 2011, literacy rate of Chambenahalli village was 77.75 % compared to 75.36 % of Karnataka.98.28 % of workers describe their work as Main Work (Employment or Earning more than 6 Months) while 1.72 % were involved in Marginal activity providing a livelihood for less than 6 months. Of 523 workers engaged in Main Work, 100 were cultivators (owner or co-owner) while 88 were Agricultural laborers.(*INDIAN VILLAGE DIRECTORY*, no date)



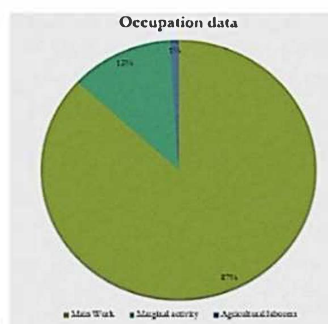


Figure 2a: Statistics data on sex ratio.
Figure 2b: Occupation Statistics data,
Source: TC halli village panchayat

Thigala Chowdadenahalli village location and socio-economic data

Thigala Chowdadenahalli village located in Anekal of Bangalore district, with a total of 938 families residing. The village has a population of 3532 of which 1855 are males while 1677 are females as per

Population Census 2011.as shown in fig 3, 87.70 % of workers describe their work as Main Work (Employment or Earning more than 6 Months) while 12.30 % were involved in Marginal activity providing livelihood for less than 6 months. Of 1593 workers engaged in Main Work, 109 were cultivators (owner or co-owner) while 13 were Agricultural laborers.(india@glance, 2022)

RESEARCH METHOD:

The framework was worked out by reviewing the relevant case studies on peri-urban residential growth - replanning, and reorganization of the same. The study also refers to guidelines regarding peri-urban growth observed in other countries. The Methodological assessment to study was carried out on 2 broad levels- Regional and Precinct level that emphasizes the analysis on trends in transformation mainly focusing on land use proposal, development type, real estate price, infrastructural facilities, demography, population, transformations, shift in occupation, ecological factors, typology and character of built forms that will be considered to develop the strategies which will redefine the neighborhood in these peripheral areas for a better quality of living.

ANALYSIS:

Regional Jurisdiction Boundary, Byelaws of BMR And Anekal Planning Authority

This helps to understand development pressure on land due to jurisdictional boundary, change in land use, proposed land use of BDA and Anekal, proposed development projects, and land parcel divisions.

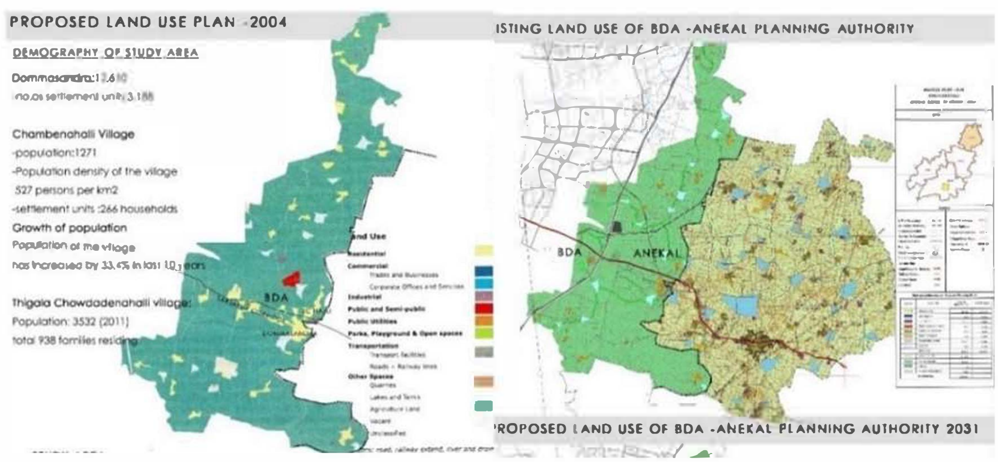


Figure 3: Bangalore master plan 2004, 2015.
Source: RMP -BANGALORE 2015,2031

As shown in fig 3, The master plans designate this area as land reserved for future urbanization while protecting natural features while maintaining the same agricultural land. Land use proposals protect the agricultural land including the valley and lakes. Maintaining mainly agricultural use of this area through land use to promote agricultural activities.(Bangalore Development Authority, 2007)

The location is also included in major infrastructure development projects. Development of Sarjapur road to a four-lane road is in the pipeline. The proposed Peripheral Ring Road (PRR) and Satellite Town Ring Road (STRR) are passing very close to the project location and would provide a major economic boost to the locality. The proposed development of NH 207 also passes very close to the project location.(Bangalore Development Authority, 2007) . The 2031 master plan map does not take into consideration of village area quality spaces. The whole of agricultural land is converted into industrial zone i.e., there is no intention of safeguarding or managing resources.

Pattern-Factors Influencing the Type of Development Along the Sarjapur Corridor

Table 1: Timeline series of Sarjapur Dommasandra region showing the type of development.

2004-time series:	Villages had mud road trails for connectivity. There existed 1 international school and a few small-scale brick industries. There were not much of many notable developments seen in this area.
2008-time series:	Sarjapur corridor was introduced in 2005 causing rapid development along the same. 2 international school and 1 academy was proposed. Major of development happened linearly. The pressure on resources is high because of the increase in urban activities towards these corridors. Green belt encroachment –illegal layouts coming up in the green belt area.
2012-time series:	Housing developments were the major trend of development that was seen. 2 international schools were constructed between 2008-2012. New connectivities were introduced to other villages. Many agricultural lands were converted to residential base. Drop in agriculture production.
2016-time series:	Major developments along the Sarjapur spline. Industries such as garment, brick kiln factories, granite cutting, and other commercial retails emerged along the Sarjapur corridor. the development was seen majorly towards Sarjapur hobli, Anekal district. plotted developments, row houses, villas, apartments and residential layouts were major development types that were seen here.

Real Estate Developments:

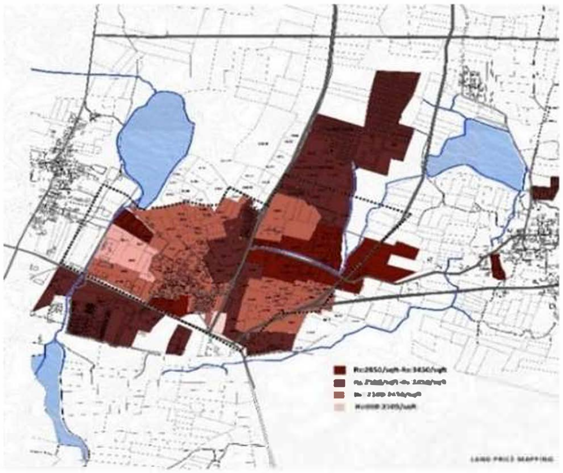
Rural area land conversion from agriculture to others (residential, industries, commercial), FAR, zoning regulation, byelaws of the same, Cost of land, built-up cost. As shown in Figure 4a, The land price around the main transit corridor of Sarjapur- Varthur routes was found to be in demand for construction. Low densities along connecting village main roads show commercialization. The absence of dense housing units and good accessibility factors along the village route owns to high land prices by developers. The plot size ranges from 0.06acres to 0.14 acres with far of 1.5-1.75. The plots falling within 250m radius from gramathans, FAR consumption is 1 and maximum floor G+1.

Existing Land Use

Land use of the area is predominantly residential, commercial land use such as tire showrooms, car repair, welding, furniture making, bakeries, luxurious three-star hotels, markets, warehouses, and small-scale industries exist along the different hierarchy of main roads. The public use amenities that are meant to serve the residential population are religious and educational institutes along the main transit corridor connecting Sarjapur and Varthur as shown in figure 4b.

Ecological Mapping

Analysis on scenarios of lakes and Nala systems of site surrounding. The implication of new developments resulted in depletion of water system. (Change in occupation and livelihood). Most of the catchment areas of lakes and tanks are filled with landfills, Natural canal systems have been polluted by the weaving industry, harmful chemicals from dying factories are led out to water systems, these waterbodies were used for domestic purposes previously. There is a need to redefine the lake edges.



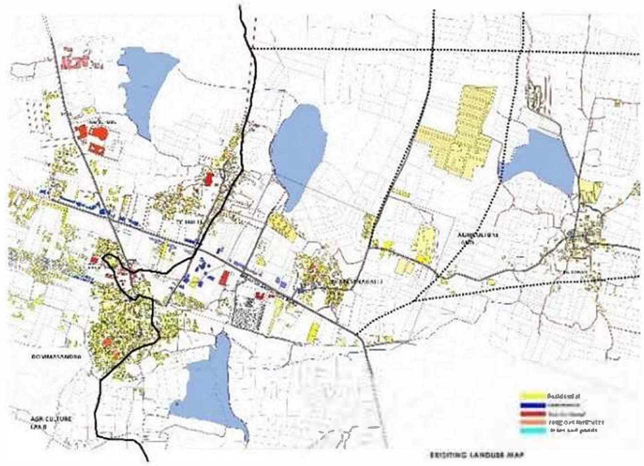


Figure 4a: The land price around the main transit corridor of Sarjapur-Varthur road.
Source: Author, Clear value price of BDA.2017
Figure 4b: Existing land use plan
Source: Author, survey maps Anekal,BDA

***Infrastructure**:*
The villages distributed throughout the planning district have a diverse population that ranges from 300-2500 persons. Some of the villages have traditional fabrics. Dommasandra with a population 12610 shows a mixed activity. Since the international school, multi-specialty hospitals, a development authorized by BDA and located near Whitefield Road and Sarjapur crossing.

Roadways: The main existing roads are part of the rural framework. They serve the villages and some of them are used by the bus routes even if its physical condition is very poor as shown in fig 5. Two major roads running through the area are the Sarjapur road, major district road, primary urban road, Whitefield Road, state highway (SH35), and a major urban road.

Figure 5: Network access to surrounding villages, upcoming new constructions, and waterbodies.
Source: Author .2017

Religious Mapping
Dommasandra and surrounding villages has a rich cultural network. karaga festival, yellama procession, ooru habba are evidently seen these regions. The ooru habba & Jatra happens every year in summer and autumn. These festivals connect all three village communities via the procession route to temples, Ashwath kattas, and Kalyani's.

Social Space and Occupation Mapping

The existing occupation predominantly found are looming, farming, business, daily wage labors, vendors, and other small-scale activities. The present scenario of people doing farming is seasonal and they depend on other small-scale daily wage activities and on looming for their livelihood. The daily wage labors range working for construction site and factories such as brick kiln, marble, stone cutting, Carpenter, cement, garment, etc. Social activities such as annual fairs, weekly markets, and procession connecting surrounding villages happen every year.

Figure Ground Map

The pattern shows an organic type of development over a period of time. The neighborhood streets has transformed as new development started to emerge along the main Sarjapur spine. The residential zoning in the Anekal planning authority has developed pressure on the existing areas due to the privatization of large lands.

Typology and Built Form

New developments have resulted in a change of the typology and infrastructure of the area. New plotted developments, high-rise apartments, gated communities have been evidently seen in these regions.

The analyses of various typologies is done through understanding the hierarchy of street networks and community spaces for public realm, the different types of structures of the weaving community, gated community, and large-scale apartment housing types in different village peripheries, can be seen in shown in figure 6b. In the dynamic setting these areas display, many societal interests are met. The in-migration of population and the emergence of new income-generating activities leads to a major transformation of the place. This is visible in the form of increasing population densities, changes in land use and occupational patterns, reduced farm activities, and growth of houses, commercial and industrial establishments. The growing demand for work and residential spaces also leading to new constructions.

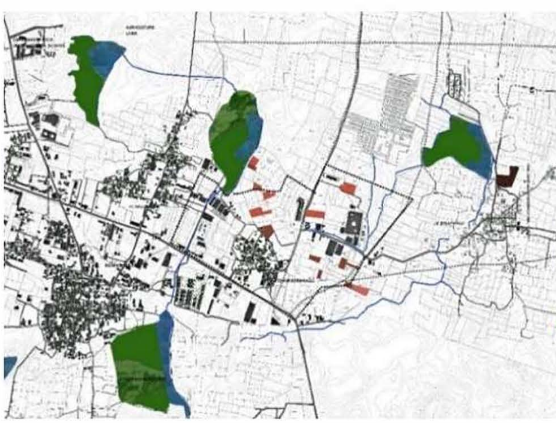


Figure 6a: Figure-ground map-Shows an organic pattern of development.
Figure 6b: Analysis on emerging housing typologies in different village peripheries.
Source: Author.2017

STRATEGIES FOR ADDRESSING THE ISSUE

As shown in fig 7, New developments are blocking the water systems and drying up of the existing ponds. The pressure on resources is high because of the increase in urban activities towards these corridors. Green belt encroachment –illegal layouts coming up in the green belt area. Lack of infrastructure-traffic congestion – Increase in land price -roads not able to serve the prevailing traffic, water, solid waste management, and necessary connectivity. Drop-in agriculture production. Change in built form because of growth nodes. These peripheral areas need to be planned for the growing population to live a better quality of life.

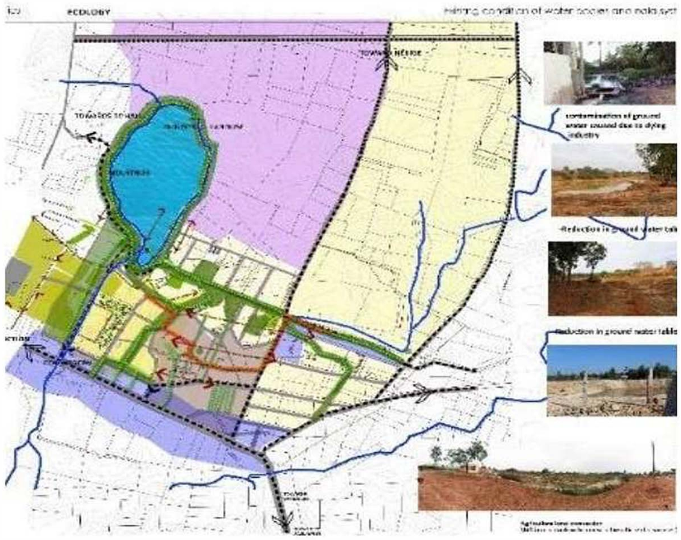


Figure 7: Ground issues mapping.
Source: Author.2017

Strategies Vision

Design Strategies were adopted based on the surrounding area analysis:
To create a network of protected areas, ecologically and culturally, More open spaces to be introduced, Reviving lakes, natural nala systems, Connecting open spaces, Promoting multi-functional uses of open spaces, Encouraging pedestrian connectivity, improving accessibility to rural areas, new settlements, and markets, New developments and built forms must reinforce the character to the place, residential and commercial developments should be of the form and scale compactable to these areas, Provision of housing near to employment cluster, service, and public transportation.

DESIGN DEMONSTRATION

Scenario Plan of Current Market Trend Development- Case 1

As shown in figure 8a, the market trend scenario is worked out considering the bylaws, various plot sizes, proposed road width, FAR, built-up area, and land price value for increasing population due to location of the cluster which has a major attraction from Varthur, electronic city, and Sarjapur, access facilities to these areas. The area is under the jurisdiction of BDA and Anekal planning authority having a green belt and yellow zone respectively, resulting in the new development mainly towards Anekal jurisdiction.
The development scenario considers the market forces, the access facilities of Sarjapur spine lying along SH bypass.

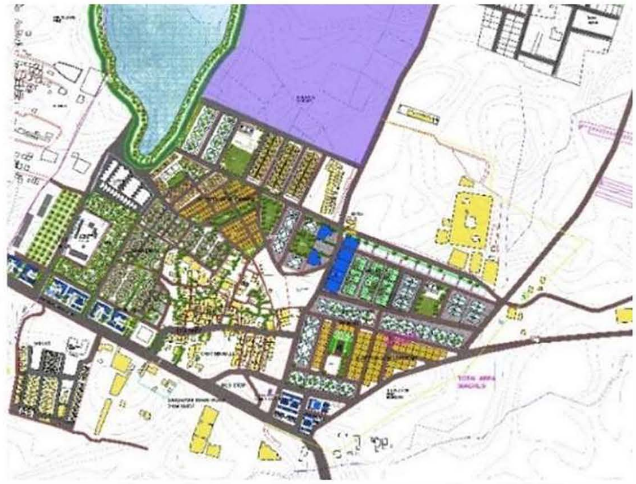
 

Figure 8a: Master plan worked out w.r.t current market trend . Source: Author. 2017.
Figure 8 b: Master plan: Current Market Trend And Master Plan Development
Source: Author. 2017

Scenario Plan of Current Market Trend and Master Plan Development-Case 2

As shown in Fig 8b, the area is developed as a response to the ecology and geography of the site. The main spine runs along the villages and connects most of the newly developed residential neighbourhoods. The community-level open spaces such as local shopping and recreational areas are provided towards the lake edges. Commercial areas such as retails, large-scale provisional stores, and other activities are provided to cater to the need for a residential neighbourhood. Development type is a response to the land use, master plan proposal and surrounding site context data's. Streetside parking can be used as parking for residences, pedestrian walkway is provided continuously without breaks. The setback from the lake edge to its surrounding development shall be 30m. Proposed land use in the project area:
Residential- 55%, Commercial-6%, Small scale industries -2%, Open spaces -8%, Civic amenities -11%, Roads -18%. Floor area ratio (FAR) shall not exceed more than 2 Setbacks - Minimum 12% in front and 10% in sides and rear. Road width shall not be less than 9.0m. Details of each block are worked out based on the scenario plan of current market trends and master plan development(Bangalore Development Authority, 2007b).

CONCLUSIONS

This paper has put forth the transformations happening in urban-rural peripheral areas in terms of transition characterized by a diverse range of land use (change in agrarian to urban practices), communities, physical infrastructure with adverse environmental impacts involved (Narain and Nischal, 2007).It also focuses on the critical link that connects urban centers with the villages and the pressure mounting on these rural areas to accommodate the growing population needs. Due to rapid urbanization, there is a growing demand of infrastructure by the relatively higher income group people, while there is a lack of even basic services for the people who are dwelling in the area(Manasi and Raju, 2022). There is a need to strengthen rural areas from a livelihood's perspective due to changes in socio-economical fabrics through interactions with the city (Maina and Karimi, 2010). The absence of development control and lack of enforcement of rules have transformed these areas into mixed land use in a haphazard manner. Hence, the first case: Scenario plan of current market trend development considers the growing population, new developments, and access facilities to the rural areas, this will provide a compact neighborhood that is sufficient in all ways where people can interact and socialize with others freely. However, the plan does not consider other factors such as natural resources, environmental amenities, and rural activities which form the basis of the region's identity and will be lost with important social and economic consequences. The second case: Scenario plan of current market trend and master plan development considers the strategies vision and design consideration based on the thorough analysis of area. Planning according to ecology and geography of the site, community-level interaction spaces, cultural resource- practices and development type in response to the land use, master plan proposal, and surrounding site context are considered.

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FROM VISION TO REALITY: DATA GOVERNANCE AND TECHNOLOGY OF INDIAN SMART CITIES DURING COVID – 19

Shanu Raina[1], Shaila Bantanur[2]

[1] Associate Professor, BMS School of Architecture, shanu.raina@bmssa.ac.in)
[2] Director, BMS School of Architecture, director@bmssa.ac.in)

ABSTRACT

Cities contribute 80% of the total global GDP and host about half of the global population (The World Bank, 2019). Cities became transmission hubs as a result of rapid urbanisation and the growth of high-density, populous cities, combined with easy and quick transit infrastructure. The recent pandemic not only paralleled cities' economies and social lives, but it also served as a wake-up call for all city stakeholders. It has given us an opportunity to think about and analyse the future course of our city planning. COVID–19 emphasised the need to reimagine sustainable, adaptive, resilient, and people centric cities. People-centric COVID-19 pandemic, novelties related to the best practices of a number of smart cities will become an imperative study to shape and design approaches for future cities.

The research was conducted in four Indian smart cities using Agra, Varanasi, Surat, and Bangalore as case studies, these cities were touted as having the best practises for Indian practices during COVID-19 using information and communication technology. ICT-based applications for data management were adopted as a common intervention under the smart city mission. The COVID-19 pandemic has accelerated the smart city concept in spatial planning. The criteria identified for evaluating each case study are based on an extensive literature review. Each case study was evaluated on five parameters, which are information dissemination, setting up public health facilities, managing lockdown—ensuring food and shelter for the economically weaker section and contact tracing-—de,livery of essentials. The results of the study validate that the implementation of smart the city initiatives can augment planning and preparation capacity. Smart solutions that incorporate smart technologies can help predict pandemic patterns in cities, reduce or delay virus propagation, reduce supply chain disruption, make basic services available to all, facilitate timely and synchronised responses, from overstressed sectors, and optimise city operation optimization and safety, the right to open-source data, the reach of technology and its affordability, legal barriers, misinformation propagation, and inclusivity are few of the concerns and challenges associated with the adoption of ICT-based applications of the smart city initiative. Despite this, this research shows that further development of smart city initiatives can provide exceptional prospects for boosting resilience to the pandemic and similar future events.

Keyword: COVID - 19, Smart Cities, Smart Technology, Resilience

INTRODUCTION

Urban centres now cater to more than fifty percent of the world's population, and this share is projected to increase to almost seventy percent by 2050. India is diverse nation in which cities have become larger and more assorted than before. According to various projections, India will have 600 million urban residents living in over 10,000 towns and cities by 2030. From 1967 in 1901 to 7933 in 2011, the number of cities increased fourfold, while the population increased 15fold, from 25 million in 1901 to 377.10 million in 2011.The progression of urbanisation has gained significant momentum over the last 50 years.

With rapid urbanisation comes multiple challenges, such as the fact that Indian cities are at the vanguard of climate-generated risks and vulnerabilities. According to several future climate scenarios such as RCP 4.5, major Indian cities are projected to have amplified multi-hazard and compound risks due to climatic variabilities and change, and that too under the average climate situation during 2009–2039. The start of the COVID-19 pandemic not only completely disrupted city life, but it also highlighted the gaps in city resilience. The impetus of the local governments at present is to rethink the delivery and functioning of physical and social infrastructure. It was digital processing that kept the economy operational.

SPREAD AND IMPACT OF PANDEMIC

COVID-19, or coronavirus, was classified as a pandemic that impacted most of the global population and continues to do so. The spread of the virus globally through travel, trade, and mobility meant that a large number of the first detected infections appeared in urban areas, prompting many to question their future (UNHabitat, 2021). The on - going pandemic has taken an equal toll on highly developed urban centres and on vulnerable communities and areas. Densely populated, overcrowded urban areas are vulnerable and prone to infection risk in the current health crisis (Chang, 2020; UNHabitat, 2021).

Governmental nodal agencies, urban local bodies, etc. had to make sure that essential services such as food supply, electricity, water, healthcare, transport, and education were least disrupted or affected. 68.55 percent of total cases in the first wave of the pandemic were shared by fifty-three million plus Indian cities. India's situation became much more difficult due to its large population, high density, more vulnerable communities, and limited health care capacity (Deloitte, 2021). Furthermore, migrant exodus and frail social security nets exposed us to grim realities (Shahidi, 2021). Even with humongous challenges, the pandemic transformed India's urban development strategy as a country. It prioritised sustainable urbanization, which has been critical to COVID-19 recovery (Chakraborty, 2021). Table No. 1 below discusses various parameters that made COVID-19 more challenging for Indian cities.

Table 1: Parameters which made COVID – 19 more challenging for Indian cities
Source: (Census, 2011), (Sharma, 2017), (Priyakaraj, 2020)

1	Large, density populated cities:	In 53 urban agglomerations (Census, 2011) with a population of more than 1 million people, or around 43% of the world's 377 million urban dwellers, or 31.2% of all people, live in high-density.
2	Limited healthcare capacity	The health infrastructure in Indian cities is insufficient, with 8.5 hospital beds per 10,000 residents, 1 doctor for every 1,445 residents (the WHO recommends 1 doctor for every 1,000 residents), and 1.7 nurses per 1,000 residents (43% fewer than the recommended minimum of three, following WHO guidelines).
3	Vulnerability of population to economic shock	The population working in the unorganized sector and those living in slums are the most vulnerable to economic shock in the city, which disrupts business operations and causes rapid job losses. The 139 million (Sharma, 2017) urban migrants living in cities around the nation are included in these parts, as are informal workers and their families who reside in the city and frequently reside in slums.

The need for communities to reconsider how they plan their cities with regard to health has grown over the past few decades. No city can be considered fully resilient or sustainable without having its municipal plans developed, examined, and approved from a healthcare standpoint.

SMART CITY MISSION IN INDIAN

India launched Smart City Mission (SCM) in 2014, which focused more brownfield development rather than building one hundred new smart cities. The aim of the Indian government is to develop hundred smart cities by 2024. The mission must be employed with help of funds emancipated by both central and state governments at already set interval of time from 2017-2022 (Aishwarya N, 2021). SCM brought with its innovative ideas and make an exemplar shift in its method about how the national missions were ideated earlier.

Table 2: Models of area- based Smart City Development
Source: Smart city Mission, GoI

S. No	City - Wide Smart Solutions	Details of implementation	Area
1	City Improvement (Retrofitting)	In order to make the area more efficient and livable, a modern, smart city will require extensive infrastructure and high-end applications.	For area more than five hundred acres.
2	Redevelopment	Concentrate on the area that is currently occupied and facilitate the creation of a new layout with improved infrastructure that makes use of blended land and has increased density.	For area more than fifty acres.
3	Greenfield Development	focuses on using creative planning to implement smart solutions in a previously vacant area while providing affordable housing, particularly for the poor.	For area more than 250 acres.
4	Pan City Development model	Anticipate the implementation of the chosen smart solution, such as an intelligent traffic management system, in the city to improve service.	Pan City

Many of the initiatives which fuel use of Information Communication Technology (ICT) were part of the Pan City Development Model. Smart governance is a common focus area under SCM globally and in India (Sullivan, 2017) , (GOI, 2021), (Aman Kumar, 2020), (Habeeb, 2017), (Andrea Caragliu Chiara Del Bo, 2011). which comprises Bottom to top approach, connecting grassroot level, including stakeholders at all levels in decision making, increasing efficiency, effectiveness, transparency and trust, political strategies, and perspectives of by using ICT as a tool.

Use of Information Communication Technology (ICT) For Resilience in Pandemic

As the world deals with the devastating aftereffects of COVID-19, it is believed and debated that technology can be used as a tool to reduce or avoid the impact in the future. Technology has enabled us to manage cities and make them more resilient. Big Data, artificial intelligence, the Internet of Things, etc. are a few of the smart technologies that make this possible (Kummitha, 2020). It was noticed in these testing times that cities in China and Western democracies that have adopted smart city-based technologies were better able to manage this health crisis.

The smart city initiative has not only successfully retrieved critical data, analysed it, stored it, and disseminated it to mitigate outbreaks, but it has also simplified decision-making so that critical actions can be planned in less time (Daniel G. Costa, 2020). Smart cities, because of their advanced infrastructure (e.g., IoT and cloud computing) and good governance, are always ready and equipped for such disasters, whether they are caused by God or humans, and they can, in comparison, perform better in terms of facilitating better pre- and post-medical facilities and treatment. (Gade, 2019); (Duggal, 2020).

It has been well documented and understood how cities steered this journey by coupling smart city technologies, be it the use of mobile phone tracking apps to detect and subdue contaminations or the use of data analytics, which enabled the management of essential services by enabling real-time monitoring and management. The use of digital technology will be crucial in the future, too.

Best Practices of Data Governance and Technology of Indian Smart Cities during COVID – 19

The pandemic struck at a crucial historical intersection when smart solutions and technologies have become universal phenomena across the globe (Ayyoob Sharifi, 2021). Such planning methods, initiatives, and concepts are frequently referred to as "smart city solutions" in the urban planning community. (Ayyoob Sharifi, 2021). Different smart city applications such as enhanced innovative applications, healthcare management, data management, surveillance, and waste management were used. The Integrated Command and Control Center (ICCC), established as part of the smart city mission in various Indian cities, aid in mapping each COVID-19-positive case using Geographic Information System (GIS), following medical personnel, and creating containment plans using heat mapping technologies. (Nisha Shetty, 2021). Utilizing technology to improve crisis preparedness and recovery capabilities is one of the main planning strategies for lowering risks and vulnerabilities among populations. (Mahnoosh Hassankhani, 2021).

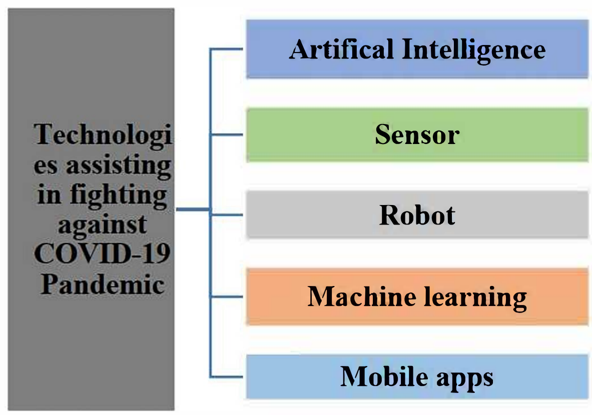

Figure 1: Technologies aiding in COVID-19 pandemic mitigation.
Source: (Hameed Khan, 2021)

BEST PRACTICES FROM INDIAN SMART CITIES: FROM DREAM TO REALITY

Smart cities have taken advantage of the technology and focused on health care management, safety, security, emergency response, traffic management, citizen engagement, and many more. The smart city mission in various cities not only helped in easing access to infrastructure but also enabled the interactions between government and people by using technology. One saw development of digital payments, smart transports, etc. and thus emergence of contactless societies.

Agra - Agra smart city introduced E – Doctor Seva - a video consultation service over the phone. As a result, people could schedule a medical professional appointment. Other initiatives include a smart city integrated command and control centre as a 24x7 covid-19 war room, Agra COVID-19 Tracker, Agra lockdown monitoring App, use of GIS-based dashboard and ICT-enabled monitoring system for fogging and sanitization of all prominent places, Sarvamsetu App – SOS portal for citizens by citizens, distribution of food and essential commodities and citizen COVID – 19 Self registry platform.

Varanasi - Kashi center for integrated command and control. was turned into a war room. The city deployed drones to spray sanitizer in and around COVID – 19 affected parts of the city. This initiative was taken up with help of Varanasi Nagar Nigam's Quick Response Team. The movement of the crowd was monitored using CCTV surveillance and GIS technology via a specific command and control setup in line with the smart city mission. All the services in Varanasi smart city had integrated with GIS and maps were used for real-time analytics and to provide real-time feedback to concerned authorities. Other initiatives include COVID- 19 safe Kashi mobile app, e – tele video consultation services, public address systems for quick communications, and variable messaging systems (LED signs) at prominent locations are a few of the initiatives which were enabled by technology.

Surat - Surat Municipal Corporation and Surat Smart City Development Limited had taken steps to fight the grim situation in the city. COVID – 19 Quarantine Reporting App, Smart city command and control centre – COVID - 19 war room and Active surveillance by health workers was done by a network of Auxiliary Midwives, Accredited Social Health Activists, and other primary health workers. Initiatives like passive surveillance: a common platform for reporting, surveillance in slums, etc. were used for tracking and monitoring. From diagnostics tracking acute respiratory infection cases, and providing augmented of health care facilities to sanitization and disinfection, solid waste management facilities were planned and taken care off.

Bangalore – The Bruhat Bengaluru MahanagaraPalike started COVID-19 in a very short time. The war room was developed in 24 hours with hand-holding from Its giants like Infosys and Microsoft engineers. It helped to focus on keeping track of citizens who evaluated positive, those under quarantine, and also the primary and secondary contacts. GIS was put in use to put out data on new COVID – 19 daily cases.

Table 3: The Bruhat Bengaluru MahanagaraPalike war room decision support system
Source: Author

S. No	Key Quadrants	Strategies	Appropriate Tools	Major Outcomes
1.	Information	Various Datasets and analysis	Dashboard	Situational analysis
2.	Communication	Data Integration	Webpage	City-to-city timelines
3.	Management	Data Visualization	GIS Mapping	Place of progression
4.	Integration	Source reporting	Applications Sahaaya Sethuve, BBMP IQMS	Real-Time – Information
		Online registration	Google forms	Predictive modeling
		Simulation	Tele - Consultation	Strategic planning and decision making

METHODOLOGY

The explorative research was conducted in four Indian smart cities using Agra, Varanasi, Surat, and Bangalore as case studies; these cities were touted as having the best practices of Indian smart cities during COVID-19 using information and communication technology. It was observed that distinctive and local interventions customized to the problem faced were exhibited in the study area. ICT-based applications for data management were adopted as a common intervention under the smart city mission. The COVID-19 pandemic has accelerated the smart city concept in spatial planning. The criteria identified for evaluating each case study are based on an extensive literature review and interviews with various city planners and urban designers from the various urban local bodies and development authorities. Each study was evaluated on five parameters, which are information dissemination, setting up public health facilities, maintaining the lockdown while providing food and shelter for the economically weaker section, contact tracing, managing lockdown, and delivery of essentials. Each parameter has been subdivided further into twenty–two indicators. As this research is still in its explorative phase, a weighted index matrix was chosen to give weight to each indicator. Using a random sample method, a questionnaire survey was distributed to various planners and urban designers from urban local bodies and authorities. The sample size was thirty-seven. The total weight for each parameter was one. Zero was allocated for each indicator where the city did not perform, and the maximum weight given was 0.4.

Graphs for each parameter and the performance of each city against each indicator of the parameters are plotted in the following section. Information dissemination through a mobile application is a common indicator, as all four case studies have performed well. Overall, information dissemination was highest in Surat.

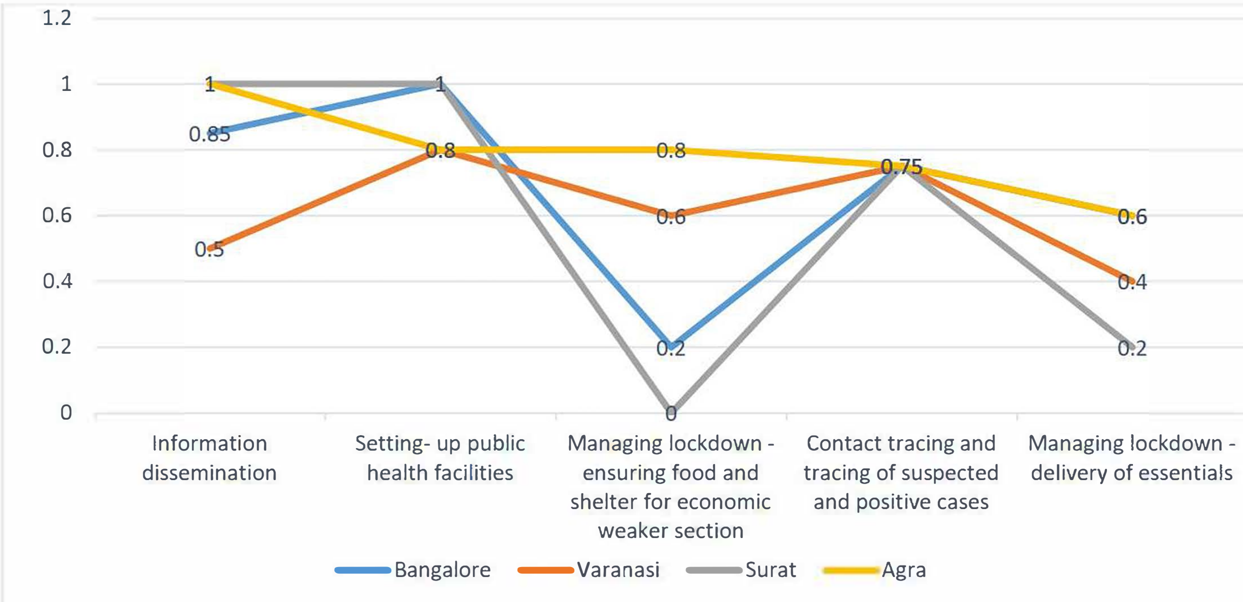

Figure 7: Technologies assisting in mitigating COVID- 19 Pandemic
Source: Author

Performance of setting up public health facilities in all the cities was planned equally well. Performance of cities in managing lockdown—ensuring food and shelter for economically weaker sections. The overall performance of Agra was better than the rest of the case studies because of initiatives like the Sarvamsetu App, an SOS portal for citizens by citizens, the distribution of food and essential commodities, and the citizen COVID self-registration platform. All the case studies performed admirably at locating contacts and cases that have been confirmed. The dashboard for real-time visualization of the COVID-19 tracking and use of heat mapping and geographic information systems was put to use. Managing Lockdown: Due to GIS-based tracking of supply vehicles, essential deliveries in Bangalore and Varanasi were made possible. Agra can be ranked first among all of the selected case studies, followed by Bangalore, Varanasi, and Surat in order of performance. It should be noted that the results can vary based on the weight assigned to each of the parameters.

CONCLUSION

The COVID-19 coronavirus has been declared a pandemic. It can be concluded that COVID-19. The initial cases were reported in all metropolitan cities, like Delhi. Mumbai, etc., and later it trickled down to Tier 2 and Tier 3 cities as well. Rapid urbanization and the growth of densely populated cities, combined with easy and quick transit infrastructure, transformed cities into transmission hubs, which made it more difficult for countries such as India. Many aspects of daily life, such as entertainment, education, and communication, were moved online following the outbreak of the COVID-19 pandemic. When the first nationwide lockdown occurred in March 2020, India's dwindling internet user base made the transition difficult. Allegedly, fifty percent of India's population does not have access to the internet. This led to exclusion of a large population from staying connected and, thus, being unaware of the growth of the pandemic. The lack of proper health infrastructure functioned as a barrier to containment efforts. After Lockdown was imposed, the city streets were deserted, the air was cleaner, and traffic was minimal.

Many smart cities made use of technology in the most viable way to contain and mitigate the impact of COVID-19. The current situation has aided cities all over the world in building momentum for smart cities. In India, smart cities like Agra, Varanasi, Surat, and Bengaluru have been forerunners of smart practices by integrating technology in this time of health crisis. Globally, cities like Singapore, South Korea, and Ho Chi Minh City (Vietnam) lead the path of smart practices through their e-government models and real-time distribution of information to all citizens.

The COVID-19 crisis has prepared the government for the future. The lesson we can learn from this pandemic is that technology should reach vulnerable groups as well and not be limited to certain groups of society. We need to have policies that are inclusive, grassroots projects, and strong leadership (Baharudin, 2020); (J.J. Zhang, 2020). Redesigning open spaces for public use is a requirement for spatial planning. Future city planning must also be able to intelligently mitigate events like the COVID-19 pandemic and other non-physical disasters. (Rini Rachmawati, 2021). The pandemic has posed an opportunity to reimagine sustainable, adaptive, resilient, and people-centric cities. There is a dire requirement for amending the planning guidelines and building bylaws to safeguard cities from unforeseen challenges. Using GIS and ICCC tools for creating micro zonation would help streamline efficient and quick decision-making to control/curb the spread of the virus.

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REFUGEE APPROPRIATION OF INHOSPITABLE URBAN TERRAINS: LEARNING FROM JABAR-DAKHAL COLONIES OF KOLKATA

Shreyasi Pal[1], Tapas Mitra[2]

[1]Research Scholar, School of Planning and Architecture, Bhopal; Faculty, BMS School of Architecture, Bangalore (shreyasipal@bmssa.ac.in)
[2] Faculty, School of Planning and Architecture, Bhopal (tapasmitra@spab.ac.in)

ABSTRACT

Refugee subject position is an evolving topic of contention in the world today with increased migrant and refugee mobilities. Urban refugee spaces are often segregated in the form of colonies, ethnic villages, even ghettos, embodying institutionalised discourses of apathy and violence. These spaces only occupy the cracks and margins of the normative, formal city, as appropriations of inhospitable natural terrains and urban systems. The paper discusses how refugees compete for resources for survival as "*bio-political*" subjects and are often held summarily responsible for causing ecological stress in host environments.

After the 1947 Partition of the Indian subcontinent, millions of Hindu Bengali refugees from East Pakistan flooded the Eastern Indian states of West Bengal, Assam and Tripura. Kolkata particularly drew millions for better livelihood prospects. Facing government apathy and local violence, East-Bengali refugees appropriated the urban fringes of Kolkata and claimed their right to urban space through the political act of squatting or *Jabar-Dakhal*. The intent of this paper is to investigate and map the spatial distribution of East-Bengali refugee squatters and elaborate on how they transformed the terrain and distributed resources through self-management tactics. This spatial history case-study attempts to uncover locational data from archival government records, existing academic literature and fieldwork to visualise where the 145 pre-1950 and the 123 post-1950 Jabar-Dakhal colonies were located in the Kolkata Metropolitan Area. This case of successful refugee self-settlement is qualitatively read in relation to the major areas of ecological stress in Kolkata. One of the UN sustainable development goals is to make cities and human settlements 'inclusive, safe, resilient and sustainable'. This paper hopes to encourage further studies of urban refugee self-settlement and local integration as a viable but complex socio-political-environmental process.

Keywords: Refugee Self-Settlement, Vulnerability, Post-Partition Kolkata, Jabar-Dakhal colony, Global South, Urban Ecology

REFUGEE 'RIGHT TO THE CITY' AS BIO-POLITICAL SUBJECTS

Refugee subject position is an evolving topic of contention in the world today with increased migrant and refugee mobilities and changing political conditions of refuge itself. Approximately 60% of all refugees and 80% of all internally displaced persons (IDPs) in the world today are located in urban areas, according to estimates by the United Nations High Commissioner for Refugees (2009). In recognition of this global urban refugee crisis, UNHCR adopted the 'Policy on Refugee Protection and Solutions in Urban Areas' in 2009 recognising cities as 'legitimate places for refugees to reside and exercise the rights to which they are entitled'. "Right to the City", originally conceived by French neo-Marxist Lefebvre and developed by Harvey, is a radical concept which advocates for the right to access and appropriate urban spaces for any city inhabitant, regardless of legal status (Harvey, 2020).

As sites of opportunities and hope, urban areas promise easy access to health and educational services, basic infrastructure and improved livelihood prospects. The proximity tendency of urban centres and refugee settlements is well established (Jacobsen, 1997; Crisp et al., 2012). In contemporary times, cities have to absorb millions of immigrants and refugees, often in a short notice, following conflict situations. Any city, when encountering and accommodating these 'others', generates socio-geo-political spaces which embody institutionalised discourses of apathy or even violence. Very rarely do cities welcome refugees and provide sanctuary. The idea of 'others' is constructed based on cultural assumptions, stereotypes and differences in class, race, gender, religion, ancestry, language, caste, nationality etc. This 'ecology of fear', suspicion and tension often spatially segregates these refugee communities into homogenous neighbourhoods, colonies, ethnic villages, ethnoburbs and in extreme cases, ghettos. Urban refugees have to compete with the other urban poor to stake their right to the city. This is particularly true in the Global South, where bustling megalopolises are anyway stretched to their limits. Yet millions of the urban poor sustain themselves here, through unconventional distribution of limited resources and socio-political negotiations with various State and Non-State actors. The marginalised position of Global South urban refugees stems from institutionalised and communal discrimination, lack of citizenship, legal exclusion, housing and land insecurity, health hazards, inadequate access to work, constant threat of eviction, violence and petty harassments from both the State and the host community. Agamben has famously analysed that the sovereign can reduce a refugee to "bare life" and the ultimate "biopolitical" subject, regulated and governed in a permanent 'state of exception'(Agamben, 1998). Sanyal (2011) has described refugee spaces as existing at the 'intersections of multiple layers of governance and legality'. Refugees behave like Chatterjee's 'political society' (Chatterjee, 2004) and claim rights and services through popular politics and informal institutions. Refugees produce informal spaces which do not and cannot conform with formal laws and norms. Refugees are characterised as victims and their agency is often not validated. In this paper however, we acknowledge the agency of urban refugees in shaping their built environments. We discuss, employing a historical case study, how the East-Bengali refugees claimed their 'right to the city' through grass-root social consolidation, and community-led equitable distribution of resources.

IMPACT OF REFUGEE INFLUX ON URBAN ECOLOGY

It is established that rapid population influx causes overexploitation of resources (Berry, 2008). A majority of the millions of refugees and IDPs in the world today are located in developing countries (Jacobsen, 1997) where their presence is associated with heavy ecological stress. Refugees are considered "exceptional resource degraders", often leading to deforestation, denuding of grazing pastures, depletion and contamination of water resources, waste accumulation (Black & Sessay, 1997). Refugee presence may create increased competition among the farmers, herders and other local communities leading to over-farming, overgrazing, deforestation, landuse change and subsequent land and soil degradation. Both surface and groundwater may get affected due to rapid and unplanned water extraction and poor sanitary infrastructure. Atmospheric pollution may increase due to use of fuelwood and waste accumulation. Biodiversity may be reduced due to habitat loss of native fauna, irreversibly damaging unique ecosystems. There is also often an increased risk of infectious diseases, endangering the refugees themselves, the host community and even local wildlife (Jacobsen, 1997). UNHCR Environmental Guidelines (1996) enlists specific concerns like "Natural Resources Deterioration" (degradation of forests, soils and water resources, biological impoverishment, contamination of surface and groundwater), "Irreversible Impacts on Natural Resources" (impact on biodiversity, endangered species etc), Impacts on 'Health", "Social Conditions", "Local Populations" and "Economic Impacts".

It is imperative that our sustainable urban development goals are sensitive and inclusive enough to acknowledge the complexities of urban refugee experiences and recognise the trade-offs between human costs and ecological costs, particularly in the contingent urban contexts of the Global South. UNHCR's (1996) Environmental Guidelines mention some refugee environmental impact indicators like deforestation, loss of biodiversity, competition for agricultural land, but they also enlist positive socio-economic indicators like increased agricultural production, increased local income, installation of educational, health, and other social services infrastructure as well as water supplies, among others. Oucho (2007) acknowledges that "little research has been undertaken on long-term negative impact" of displaced people. Elaborating on the concept of environmental impact, he emphasises the reciprocal nature of the relationship between man and nature- as man shapes his environment, both the natural world and the man-made world become essential to his well-being. Previous studies of environmental impact of refugees mostly conclude that "flora and fauna, energy and heating sources, water bodies, soil quality, environmental sanitation and a variety of infrastructure" are affected (Oucho, 2007). He opines that these studies conceptualise environmental impact only as "the process of change that occurs with respect to forests, soil and water" (Jacobsen, 1997). Such studies often unduly underscore the negative impact (Black & Sessay, 1997) and conveniently attribute to the refugees some of the negative ecological effects which pre-date their presence in the area. This is directly an effect of the disenfranchised status of refugees. Discussing 'desubjectivation', Judith Butler (Butler & Athanasiou, 2013) has said that the ontological status as subjects is suspended when a space is understood to have invoked 'states of emergency'. In a similar strand, Agamben describes the refugee 'state of exception' as a 'state of emergency produced through the sovereign's suspension of the juridical order" (Agamben, 1998). Such subaltern informalities tend to be criminalised and rendered vulnerable to eviction or demolition. Thus refugees are easy targets to blame for environmental degradations, not of their making (Allan, 1987), with researchers often interpreting correlation as causation.It is in this context that we have read Jacobsen's (1997) observation

"...we should bear in mind that environmental degradation is partly in the eye of the beholder. What local people and refugees perceive as necessary and even sustainable use of natural resources may be seen by national governments and international agencies as threats to the conservation of particular ecosystems."

Refugees suffer from public image issues (Zetter, 1991) as they are often not recognised as vulnerable victims but as 'problems' themselves, rather than "persons with problems". The degree of environmental degradation depends on the form of refugee settlement, the duration of their presence in an area and social dynamics with local, host community, State assistance and refugee access to and control of land (Black & Sessay, 1997; McGregor, 1994). There is limited study on the environmental impact of 'self-settled' urban refugees. Jacobsen (1997) makes a clear distinction between authority-mediated settlements and self-settled refugee areas, highlighting differences in perceived stake and hence attitude towards local natural resources. In refugee camps, it is argued that damage can be contained due to control of resources by relief agencies. Due to perceived long-term stake in the area, self-settled refugee settlements cause less concentrated resource extraction and have a higher recovery tendency as against camps. The lack of local knowledge, environmental or otherwise, might lead to insensitive resource consumption in some cases. Constant interactions with host society may induce the refugees to adapt to local ways of life which are usually sensitive to local ecological patterns, and improve chances of refugee access to land and local knowledge (Hansen, 1990; Zetter, 1991). Self-settled refugees may bring positive environmental, social and economic benefits to an area as they learn to coexist with the host community, invest in the area and apply local knowledge.

Refugee relief agencies, according to UNHCR, try to minimise environmental degradation associated with refugee influx through environmental management practices. Outlined in the UNHCR sourcebook 'Refugee Operations and Environmental Management' are technical themes. Among others, they include Community-Based Strategies for Natural Resource Management, Domestic Energy, Environmental Education, Refugee Diet and Livestock. Leach laments that refugees are not approached to be involved in ecological resource management decisions by local authorities and often have no incentive or stake in conserving the environment. It is not the measurement of the degradation but the socio-political-economical context specific resource management practices of the refugees that deserve research attention. It is an extension of the observation made by Jacobsen that perception of environmental change as a 'problem' is context and subject specific. Our paper thus focuses on a specific case of refugee self-management and the socio-political-economical context which enabled refugee agency in Jabar-Dakhal colonies.

SPATIAL HISTORY CASE-STUDY TO INVESTIGATE GLOBAL SOUTH URBANISM

In areas of study where measurable indicators are not agreed upon, and, where nuanced and subjective insights are required, a case-study approach is called for. In the oft-cited publication "Five Misunderstandings About Case-Study Research", Flyvbjerg (2016) systematically argues that both natural sciences and social sciences are strengthened by case studies. Context-dependent knowledge adds value to human affairs as critical cases have strategic significance in relation to general problems and paradigmatic cases establish a metaphor or a school of thought for the domain. Case Studies are also valid epistemological strategies to decentre urban theories from Eurocentric roots. This is particularly true for the Global South context where the complexities of lived, empirical experience can only be captured through a discursive analysis and qualitative methods. It is part of the significant counter paradigm which emerged in urban studies, following Roy's call for provincializing urban theories from 'new geographies of theory' (Roy, 2009). Ideas of "ordinary cities", "comparative urbanism", "subaltern urbanism" (Roy, 2009) and "southern urbanism" (Schindler, 2017) argue for generating urban theories from specific and complex postcolonial urban situations in the Global South. Barnett (2020) has also debated for the status of case-studies in urban studies, involving casuistry as reasoning, rather than aiming for explanatory theory.

Spatial history cases engage with digital humanities and critical spatial inquiries, using visualisation and mapping tools to illustrate the 'contours of power'. Spatial history borrows tools from other disciplines to map archival geographical data (often textual and/or tabular) to reconstruct past landscapes to understand how they were produced. Partition refugees suffer from a negative image as they were perceived to be a strain on Kolkata's resources. Here, we map Partition refugee squatters or Jabar-Dakhal colonies which were not reflected in the official maps of 1960-s, partly because of their illegal, unsanctioned nature and partly, because of the political nature of the 'refugee problem'. Their details are available as tabular data in the 1976 Report of the Working Group on the Residual Problem of Rehabilitation in West Bengal. produced by the Ministry of Supply and Rehabilitation, Government of India. The same have been geo-coded using ArcGIS to produce the attached maps, in conjunction with the growing boundaries of Kolkata Municipal Area and Kolkata Metropolitan District and the major water resources of the city. This superimposition enables a reading of the refugee influx with respect to the encroachments on the most ecologically vulnerable area of Kolkata.

JABAR-DAKHAL COLONIES OF KOLKATA

UNHCR estimates that 15 million people were involuntarily displaced during the Partition of India in 1947 making it one of the largest mass migrations of human history. After the Partition of the Indian subcontinent, millions of Hindu Bengali refugees from East Pakistan flooded the Eastern states of West Bengal, Assam and Tripura. The city of Kolkata particularly drew millions for better livelihood prospects. Comparatively better off *bhadralok* refugees either 'opted' for migration to West Bengal before Partition or did so in the immediate wake of Partition. The government arranged for both relief and rehabilitation measures, in a limited capacity, for these so-called 'OLD' refugees. A majority of these refugees, however, used their kinship ties and political awareness to negotiate with the State and self-settle in squatter (Jabar-Dakhal) colonies, in and around the city of Kolkata.

Large-Scale Refugee Assimilation in Kolkata

Between 1946-1958 about 31.32 million refugees came to West Bengal. 24 Parganas and Kolkata accommodated about 70.48 percent of the total refugees coming into West Bengal. Between 1958 to 1971 about 6 and half lakhs refugees are estimated to have further arrived in Kolkata (Mandal et al., 2019). According to CMDA estimates, in 1961, refugee migrants to the city comprised 18% of total city population as these early refugees were mostly non-agriculturalist, middle class groups. Increasing tensions across the border prompted millions more of socio-economically weaker, lower caste refugees to trickle in over the years. The government woke up to the refugee crisis late. Taking a stern stand, all incoming, so-called "NEW" refugees, arriving after 1954, were to be provided rehabilitation aid, only if they settled outside

West Bengal. All camps closed down in West Bengal by 1959. "NEW" refugees were compulsorily dispersed to distant inhospitable sites. Many would later return as deserters, often back to Kolkata.

Table 1: Types of Refugee Colonies
Source: Report of the Working Group on the Residual Problem of Rehabilitation in West Bengal. produced by the Ministry of Supply and Rehabilitation, Government of India

Types of Partition Refugee Colonies in WB	
GOVERNMENT sponsored colonies	Urban Colonies for Middle Class Refugees
	Rural colonies for Non-agriculturists
	Colonies for Agriculturists
	Barujibi colonies
	Fishermen's colonies
SQUATTER colonies	**Pre-1950 (Before Eviction Bill; OLD refugee settlements)**
	Post-1950 (After Eviction Bill; NEW refugee settlements)
PRIVATE colonies	Built by refugees using legal means; limited records

Partition Refugee colonies in Kolkata Metropolitan District (424+77) 304 urban (46 in KMC) 120 rural			
JABARDAKHAL Squatter colonies in KMD (268)			
	urban	**rural**	**total**
	221 (43 in KMC)	**47**	**268**
Pre- 1950	**84 (26 in KMC)**	**75**	**145**
Post- 1950	**100 (17 in KMC)**	**13**	**123**
Government sponsored colonies in KMD (156)			
	urban	rural	total
1950-1973	81 urban (03 in KMC)	72	156
Private colonies in KMD (77)			
(Including all)			77

'Government-Sponsored Colonies' and 'Approved Squatters' Colonies' (set up before Dec, 1950) received conferment of Right and Title to land by 1976. The government moved slowly to regularise and formalise the Jabar-Dakhal colonies, many of which received 99-year leases only in the mid-1990s and finally title deeds over the next 20 years. Left politics became central to the refugee movement. Refugee protests and demands were mainly for access to land and rehabilitation and against the 'Dispersal' Policy of the Government. Kolkata of the '50 s and '60 s was a politically volatile city, with many grassroots movements for land, housing, food, transport, jobs- all linked to the broader refugee movement. The act of squatting was in itself a political act. East Bengali refugees negotiated with their change in social status, citizenship and nationality, gender, caste dynamics and community ties as they spatially organised themselves as consolidated, socio-politically homogenous communities (Basu & Chaudhury, 2009).

Terrain Transformation and Resource Management in Jabar-Dakhal colonies

Refugee tactics of shaping their environment are complex, interconnected socio-spatial productions. The existing urban landscape of Post-partition Kolkata was already heavily contested. It afforded little scope for large-scale spatial appropriation by refugees. Urban citizenship and access to opportunities were contingent on their proximity to formal systems of the city. There were inhospitable and uninhabited wastelands and marshes in the Southern and Eastern fringes of the city limits. Strategic planning and awareness, community networking and political consolidation were the keys to finding these pockets. Once these areas were identified, the refugees engaged in Jabar-Dakhal (or forcible acquisition) and squatted on the land, collectively resisting local resistance. Besides these colonies, refugees also occupied all available urban public spaces of Kolkata like footpaths, stretches of land along railway tracks, open grounds etc.

Responses collected during primary fieldwork suggest that overnight filling up of marshes, grading and site development, through sweat equity was a common spatial fix. Families would quickly construct their own homes by collecting locally available hogla leaves for shade and tying together woven bamboo sheets as walls. Community-monitored equitable distribution of resources, coordinated by colony committees, was the bedrock of their self-management practices and was a critical factor for their subsequent social integration. Some of the educated 'elders' of the community formed the colony committee which did the initial survey of the land, allocated open spaces for public use, demarcated relatively habitable pockets, plotted the layout into wards and distributed the parcels on a first-come-first-serve basis. Urgent need of community consolidation prompted the refugees to consciously disregard long-practised caste identities and caste dynamics. Specific areas were *not* demarcated for specific castes, unlike the normative caste-based divisions of their native villages. There were however natural clusters of people from the same village or from the same extended families, which was important to foster kinship ties. The colony committee was responsible for funds collection for shared infrastructure. These committees were entrusted with making long-term visions for the settlements, and hence they did not allow for hasty measures. As and when they could afford, they would commission, plan and coordinate the construction of brick lined roads, makeshift bamboo bridges over water bodies, pit latrines, shared tube-wells for water supply. Gradually they also set up markets, schools, clinics and then temples, libraries and youth centres. These were set up initially as shacks or temporary structures and later upgraded. They proactively marked the colony territory with curated socio-cultural institutions to create a public image of a socio-culturally progressive *urbane* community. The process of decision-making was democratic in spirit. Socio-spatial practices of Jabar-Dakhal colonies indicate tendencies of Lefebvrean *autogestion*. Their community-led self-management produced robust systems of urban space appropriation with a keen eye for long-term resource management.

Mapping Jabar-Dakhal Colonies

Our scope of refugee self-settlement mapping includes only the pre-1950 and post-1950 Jabar-Dakhal colonies (i.e. it excludes Government sponsored colonies, private colonies), located in Kolkata Metropolitan District (i.e. it excludes colonies in other pockets of West Bengal), set up by 1947-Partition refugees in 1950-s and 1960-s (i.e. it excludes later colonies set up by Bangladeshi migrants after Bangladesh Liberation War). According to archival data, there were 145 pre-1950 and 123 post-1950 Jabar-Dakhal colonies in Kolkata Metropolitan District. The refugee colonies' distribution was mainly to the south and the North East, showing minor overlap with the East Kolkata Wetlands which is the most vulnerable, eco-sensitive zone of the city. EKW started getting engulfed by the growing city in the 1960-s and 1970-s. Primary interviews reveal that filling up of minor water bodies, deforestation and landuse change, invariably took place in every Jabar-Dakhal colony. However, the convenient correlation between refugee influx and Kolkata's ecological stress is questionable, given that the refugee tactics never included drastic terrain transformations like large-scale wetlands reclamation.

URBAN ECOLOGY OF KOLKATA

Kolkata has been extending towards the east and the south. Kolkata's green and blue networks are disappearing at an alarming rate. Previous studies have established that urbanisation rate has correlation with reduction of waterbody and vegetation coverage in Kolkata. It is predicted that the city would have "67% built-up, while there will be only 3% water body, 14% vegetation and 16% fallow land" by 2051 (Mandal et al., 2019). Particularly of concern is the vulnerability of the East Kolkata Wetlands. Though designated a Ramsar site, it continues to be threatened by unscrupulous developers.

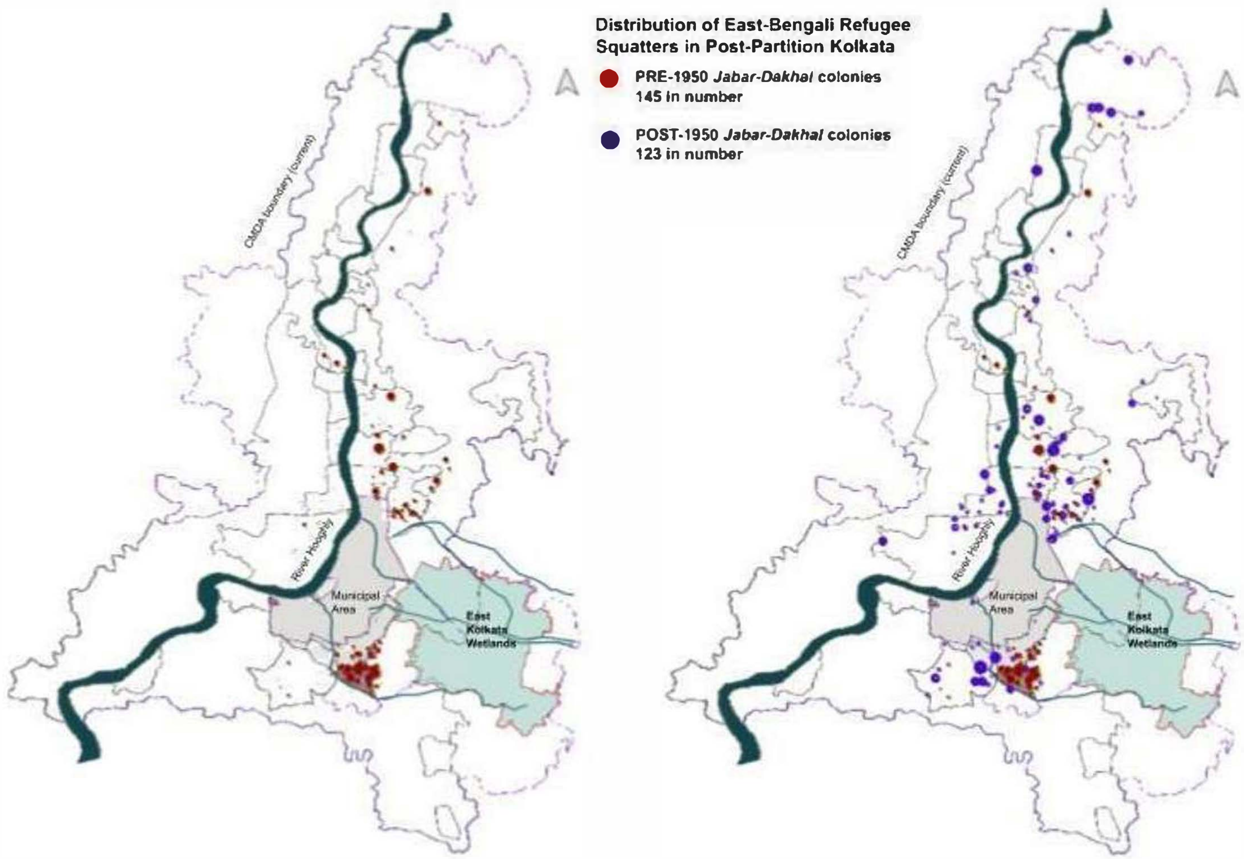

Figure 1. Distribution of East-Bengali Refugee Squatters in Post-Partition Kolkata

The southern fringes once had an extensive rich habitat of native flora-fauna which gradually extended to the south as denser forested areas, gradually merging into the Sundarbans. Much of that had already undergone deforestation and was converted into agricultural land by the 1950-s which is the time-period of our study. The eastern fringes had saltwater marshlands or the East Kolkata Wetlands (EKW), a resource recycling ecosystem. EKW acts as a natural sink and recycles much of Kolkata's daily wastewater. It operates through a system of canals artificially excavated during colonial times and also connects to extensive stretches of pisciculture ponds- a source of food supply and livelihood for the urban poor. When the British founded Kolkata on the banks of Hooghly River, it was an unhealthy, swampy site but they took advantage of the Ganges for navigation and these swamps on the East as defence. The colonisers excavated canals to reclaim marshes, converted the saline marshes to sewage-fed, freshwater wetlands.

The period during 1941–1951 saw the highest decadal population growth at 69.34% which has hence declined. Mukherjee (2015) has claimed that it is this post-independence refugee influx which has posed the most threat to the wetlands. While sudden influx of refugees must have caused increased resource depletion, our mapping of the refugee squatter colonies does not indicate significant overlaps. Rather in 1960, 3.75 square miles of North Salt Lake was reclaimed to set up the planned Salt Lake Township. Between 1962 to 1972 about 3800 acres of wetlands were converted to habitable lands. Further encroachments on the wetlands happened for the development of East Kolkata Township, Patuli Township, Eastern Metropolitan Bypass and the Municipal Solid Waste disposal ground. McDonnell et. al. (2009) have discussed that urban ecology is better understood as ecology 'of' cities than ecology 'in' cities, incorporating "both ecological and human dimensions" and integrating both natural and the social sciences.

Peri-urban interfaces particularly are vulnerable where urbanisation drastically transforms ecosystems to urban settlements affecting ecological sustainability. Kolkata as a case-study amply demonstrates this scenario. In this paper we have superimposed the refugee colonies of 1950-s - 60-s with the eco-sensitive zones to contribute to the discussion about the same. We reinforce Mukherjee's (2015) claim that there is a "need for integrating political ecology and historical frameworks for studying urban ecology moving towards the more inclusive ecology 'of' cities approach."

SUSTAINABILITY GOALS IN THE GLOBAL SOUTH

The concept of sustainable cities evolved from the concept of 'sustainable development', popularised in the Brundtland Report (1987) of the World Commission on Environment and Development (WCED) with the post-2015 UN development agenda focussing on 'sustainable urbanisation'. In the 2030 Agenda, Sustainable Development Goal 11 is to "make cities and human settlements inclusive, safe, resilient and sustainable". The New Urban Agenda (2016), adopted at the United Nations Conference on 20 October 2016, specifically mentions

"We commit ourselves to ensuring full respect for the human rights of refugees, internally displaced persons and migrants, regardless of their migration status, and support their host cities in the spirit of international cooperation, taking into account national circumstances and recognizing that, although the movement of large populations into towns and cities poses a variety of challenges, it can also bring significant social, economic and cultural contributions to urban life. We further commit ourselves to strengthening synergies between international migration and development at the global, regional, national, subnational and local levels by ensuring safe, orderly and regular migration through planned and well-managed migration policies, and to supporting local authorities in establishing frameworks that enable the positive contribution of migrants to cities and strengthened urban-rural linkages."

"Bare Life" vs Environmental Vulnerabilities: A Discussion

Karen Jacobsen calls the strategy of "local integration for refugees in developing countries' a "forgotten solution". Urban Ecology promotes an interdisciplinary approach to understanding urban social-ecological systems and decentres Global North perspectives. Lehmann (2011), argues that the Global South cannot have the "same strategies and debates" on sustainability as those in the North because of the peculiarity of their inherent potential, endowments, and limitations. The bio-physical attributes of Global South cities include decreased air quality, water and noise pollution, flooding, high waste loads and minimal contact with nature, climatic severity, high biodiversity, invasive species as a colonial legacy, urban livestock, ecosystem disservices and geophysical hazards (Shackleton et al., 2021). But it is the socio-economic differences which call for a different approach to urban sustainability (Hansen et al., 2018) in the Global South context. Sustainability measures have to take into account urban sprawl, informal housing and livelihoods, poverty and lack of access to basic services, vulnerability to economic, social and environmental stresses, technological limitations etc. . Economic inequality, institutional dysfunction and rampant poverty makes sustainability a secondary goal for the marginalised.

Nagendra et al (2018) argue that Global South cities often offer "unique but often overlooked capacity to innovate and experiment for sustainability" with bottom-up, decentralised systems "harnessing collective action around environmental remediation, urban food production and alternative green infrastructure". Kolorob in Bangladesh and the Mapping Kibera project in Nairobi are contemporary examples of grass-roots, participatory approaches common with postcolonial subjects. Trade-offs inherent in integrated "pro-poor ecosystem management" need to be carefully evaluated in such contexts. The importance of political economy of negotiations over natural resource use is highlighted by the success of the self-settled Jabar-Dakhal colonies of Kolkata. 'Ecosystem services', developed in the early 1980s, is a promising framework for analysing biophysical ecosystem processes from the perspective of human well-being (Mooney & Ehrlich, 2012). But on-field applications of the same have limitations. Defries and

Nagendra (2017) have presented ecosystem management as a 'wicked problem' with no simple solution and have recommended an incremental approach to addressing these problems. Reconciling competing objectives of human well-being and ecological gains remains a difficult proposition, with multiple vested interests competing and contributing to the local political economy.

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CITIES ACCOMMODATE SUSTAINABLE GROWTH

Divya Vora[1], Shivangi Narayen Waghray[2]

[1] Head of the Department, Facilities & Services Planning, School of Planning & Architecture, JNAFAU , Hyderabad,India,divyapatil.fsp@jnafau.ac.in.

[2] Head of the Department, Urban & Regional Planning, School of Planning & Architecture, JNAFAU , Hyderabad, India, shivanginarayen.plan@jnafau.ac.in

Key words: Global Issues; Place Identity; Climate Change; Global Economy; Sustainable Adaptive Growth.

INTRODUCTION

This paper attempts to explore urban design solutions to the global dilemma of supporting sustainable expansion while balancing responses to local demands using best practise case studies. It is critical that these strategies for resolving this problem may be transferred from a global scale to a local setting.

The technique taken to identify the major issue and the actions required to generate urban design methodologies and solutions utilising the test site as a platform for design experimentation, which will be detailed in this report.

The development of this paper is guided by the following five goals:

1. Recognize global challenges that contribute to development pressures;
2. Identify important sub-issues
3. Determine the current issues in your community.
4. Put the principles into practise on the test site
5. Draw conclusions from results in order to propose strategies and solutions for dealing with present pressures.

The methodology that is used to handle the key issue topic is discussed below. The concerns, urban design concepts, and tactics identified in this report's research will allow for more in-depth investigation. Global issues - What are the Current Global Development Pressures? The current global development pressures are

- **Global Economic Pressure** - Global economy defined by economy watch as: "an integrated world economy with unrestricted and free movement of goods, services and labour transnationally."
- **Place Identity** - Place identity is considered in Identity by design to be: "how the place affects the way the individual conceive of themselves, or how they imagine it will affect the way other people will conceive of them".
- **Climate Change** - Climate change is defined by the UNFCCC as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere.

These global development pressures and worldwide challenges can be classified broadly into three categories: economic, social, and environmental.

Environmental Benefits

- Improved Air Quality
- Smaller Carbon Footprint
- Decreased Car Dependence

Economic Benefits

- Lower Cost For Residents
- Reduced Congestion Costs
- Higher Property Values
- Improved

Social Benefits

- Improved Public Health
- Greater Human Mobility
- Increased Equality Of Access

An approach that favours sustainable urban form and transportation results in an impressive array of environmental, economic, and social benefits that leads to these 8 Principles, which are:

1. Walk- Improve neighbourhoods that facilitate walking.
2. Connect. - Build compact networks of streets and paths for non-motorized movement.
3. Transit - Create a comprehensive, premium transit system. Establish links between the modes.
4. Cycle - Give protected lane bicycle networks priority.
5. Mix- Area for mixed-use neighbourhoods.
6. Density- Actively promote increased density near important transit hubs.
7. Compact-Plan for compact regions with short commutes and set growth limitations.
8. Shift- By controlling parking and traffic, mobility is increased.

SUMMARY OF GLOBAL DESKTOP STUDIES

Parameters	HAMMARBY Stockholm	VAUBAN Germany	LIUYUN XIAOQU China
Walk	26% trips are made by bicycle and on foot. (Cervero and Sullivan, 2010).	Walking and bicycling account for 63% of journeys, while 70% of the district is green or open space. (Fraker, 2014)	60% of the district has green or open space.
Cycle	Special paths for biking.	There is at least one bike parking space per residence.	The neighbouring BRT station provides access to Guangzhou's public bike sharing programme.
Connect	Blocks are small, 60-70 meters by 120-200 meters (Fraker, 2014).	Block sizes range from 70 to 190 by 90 to 130 meters.	Blocks are small, 40-140 meters by 50-90 meters.
Transit	There are numerous ferry and bus connections, and a light rail tram is 300 metres away from every home (Fraker, 2014).	The region is served by tram and bus routes, and every residence is 400 metres or less from a stop;	The BRT stop is 300-500 metres walkable from the neighbourhood.

Mix	Buildings having dwelling on the top floors and business space on the bottom two floors.	Schools, businesses, shopping, and cooperatives all within a 10-minute walk (Field, 2011).	In the 0.31 square kilometre area, there are 800 retail stores and service establishments.
Densify	Density of 13,200 residents per square kilometer (Foletta, 2011).	Density of 12,300 residents per square kilometer (Field, 2011).	Density of roughly 9,500 residents per square kilometre (ITDP, 2014).
Compact	Located 3.6 km from center city Stockholm.	Located 3.5 km from center city Freiburg	This neighbourhood is established rather than a recent construction.
Shift	There is no free parking during the hours of Monday through Friday, 10 a.m. to 4 p.m. (Foletta, 2011); 5% of households participate in car-sharing services (Facts on Hammarby, 2009); and 74% of vehicles run on biofuels (Foletta, 2011).	Car ownership is only about 15%; There are no parking spaces at homes, and the streets around them are car-free (Fraker, 2014);	The development's late 1980s date is reflected in the lack of parking.
Economic	The district's energy criteria only resulted in a 2-3% cost increase for developers. The employed methods were affordable and reproducible.	Vauban was just 4-6% more expensive to build than conventionally built developments;	According to ITDP, "Prior to the refurbishment programme [conducted for the Asian Games in 2009], commercialization had already multiplied values multiple times."
Environmental	Compared to a typical district constructed in the 1990s, the environmental impact is 30–40% lower.	Compared to a typical district constructed in the 1990s, the environmental impact is 30–40% lower.	Reduced use of cars means less local air pollution and carbon emissions.
Socio – Cultural	The neighbourhood has grown in popularity, particularly among families with children.	The community is friendly to both young people and the elderly due to its safe and convenient transportation options, multigenerational housing, and kid-friendly activities.	Children and elders will live in a better environment thanks to expanded
Conclusions from Findings in Three Sustainably Developed Communities	**Hammarby** – About 30-40% of lower environmental impact. Car transport accounted for only 21% of all journeys taken by Hammarby residents. Most notably, the stricter standards barely increased	**Vauban** - The district design in Vauban has successfully downgraded the car in favour of transit, walking, and biking. Only 16% of people possess vehicles, with non-motorized travel	**Luiyun Xiaoqu** - After the area was converted to accommodate mixed use, vibrant commercial space currently dominates the ground floor space in Liuyun Xiaoqu. As a result, the value of the bottom floor building space increased by 30%.

	development expenses by 2-4 percent.	accounting for 64% of all trips.	The neighbourhood has become significantly more pedestrian and suitable for children and the elderly as a result of its mixed-use character and people-centered urban design.

NEED FOR THE STUDY AND STUDY AREA IDENTIFICATION

After reviewing the desktop studies, we have concluded that mobility is an important component that contributes to the city's long-term sustainability. It is a culmination of all socio-economic, place identity and climate change environmental factors, and this parameter is critical to achieving the city's long-term sustainability.

By incorporating urban design imperatives into the urban design framework, we can better comprehend the case and its circumstances in terms of making the city more sustainable.
Hyderabad is a growing neopolis, The Hyderabad Master Plan 2031 (HMDA Master Plan 2031) envisages a population of 184 lakhs by 2031, work force of 65 lakhs, the present trends of developments, the Inner Ring Road, the Outer Ring road and radial roads. One of its growth corridors, Khajaguda - Gachibowli, is an important link between the old and new city. Gachibowli's covers about 1200 acres area, which provides us with ample opportunity to create our framework for this research study.

Figure 1: Skyline of Gachibowli
Source: https://sumadhuragroup.com/why-investing-in-gachibowli-property-market-makes-sense/

DEVELOPMENT PROCESS OF GACHIBOLI IN MAPS OVER THE YEARS

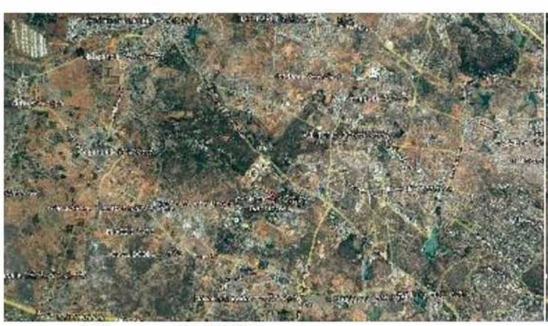

Figure 2: 2003

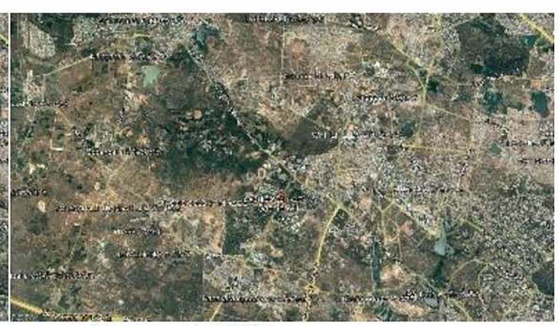

Figure 3: 2008

Figure 4, 2011 **Figure 5, 2021**

Source: Google Maps

RESEARCH APPROACH

In order to accommodate sustainable expansion, the study examined difficulties, challenges, and opportunities for Gachibowli. It included pedestrian interviews as well as a field walkability assessment. For the field study, two residential communities, a commercial centre, a transit hub, and an educational area were all picked. The study's results are displayed below using urban design guidelines.
In all, 14 percent of people walk as their main form of transportation, while 62 percent walk some distance to get to work.

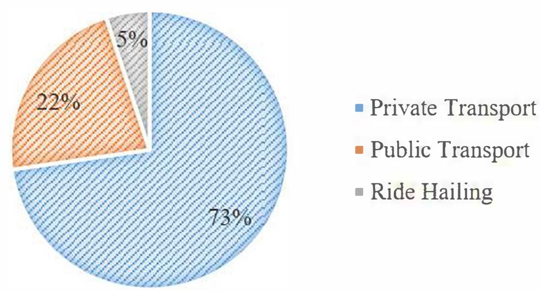

Figure 6, Mode of Transport.

FREQUENCY OF WALKABILITY TO A CLOSER DESTINATION

Common people make up 22 to 23 percent of the population and typically use public transportation as a mode of mobility. In contrast, 73 percent of the sample uses private transportation, and the final 5 to 6 percent use ride-hailing apps. Out of the entire sample, 45 people opt to walk the majority of the time, 32 people rarely walk, and 23 people walk frequently to nearby destinations.

Figure 7: Public Transport.

PEDESTRIANS - SIDEWALKS AND ZEBRA CROSSINGS.
Zebra crossings are used by roughly the same number of individuals whether frequently or infrequently. There was just one person who insisted on always using the sidewalks and zebra crossings. Pedestrians adhering to the law According to this survey, only 15% of pedestrians rarely observe traffic laws, yet they are the ones who encounter problems most frequently. Among those who do follow rules, 62 percent do so occasionally and only 23 percent do so consistently.

Figure 8: Sidewalk in Gachibowli.

Drivers of vehicles observe traffic regulations A total of 42% of drivers always abide by the law, 49% occasionally do so in accordance with their wishes and will, and 9% rarely do so. These drivers are typically the ones that get into difficulty or cause problems for other pedestrians.

SAFETY FOR CHILDREN, WOMEN OR DISABLED PEOPLE ON THE STREETS

Overall, 42% of respondents think that women, children, and people with disabilities are not safe in Khajaguda's streets. On the other side, 58 percent of individuals opt to think that women and children are safe on the streets (Figure 9).

Figure 9: Safety for Children & Women on the Streets.

Figure 10: Lack of connected pathways to provide safe walkability in Gachibowli.

With regard to whether more people would favour walking if pedestrian conditions improved, 79 percent of those polled agreed that more people would. However, 21% of people said they would still rather not walk.

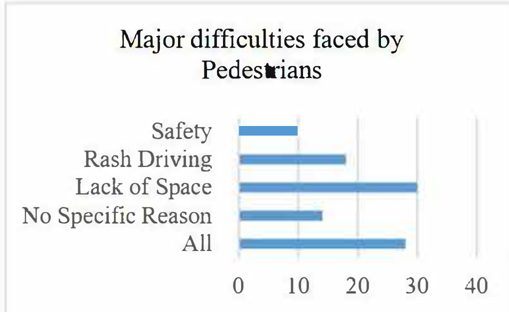

Figure 11: Significant challenges encountered by pedestrians in Khajaguda.

In all, 28 percent of those surveyed had no idea what is worrying them the most, and 44 percent say all of the aforementioned issues are the biggest challenges they are now facing.

Figure 12: Despite the fact that a bus bay is provided, it eats into the sidewalk.

Figure 13: Lack of designated parking space for commercial spaces.

Overview of urban form and transportation for a better understanding of walkability (or lack thereof).

With 70% of all trips taking place in cars, Khajaguda's urban shape and transportation methods have produced amazing outcomes. The figures below show that significant progress can be made in this direction:

- Non-motorized transit: 3 %
- Public transit: 19 %
- Parking space per resident; 5 sqmts
- Cars ownership: 325 cars per 1,000 residents;
- Car sharing: 3 %

Summary of study of user's perspective using urban design principles:

Principles	User Perspective	Remarks
Walk	The graphic depicts how pedestrian infrastructure, such as elevated pathways and skywalks, is often ineffective and even dangerous. Zebra crossings, subways, and walkways are designed to keep pedestrians safe, yet	There are no sidewalks, subways, or zebra crossings, which is a significant disadvantage for pedestrians. Many portions in Gachibowli lack the room to support even a decently constructed road, let alone a walkway. Because of this, pedestrians are

	most people do not take advantage of them to their full potential.	forced to stroll on the streets, which leads to accidents. Many sections of the road are not paved and are used as parking lots, which forces people to walk in the street.
Cycle	Many Indian cities are easily accessible by walking or bicycle, as most people commute between 1 and 7 kilometres every day. The issues that Gachibowli cyclists face are numerous. The roadways and footbridges are densely occupied by informal sector merchants selling a variety of goods and foodstuffs, additionally to beggars, leaving little room for pedestrians to stroll on, forcing them to do so on the street. The air quality has deteriorated as a result of trucks, vehicles, buses, and taxis using the streets throughout the day. People do not want to cycle.	The roads of Gachibowli are quite traditional. Despite the fact that road building appears to be proceeding throughout the year, little visible progress has been made. The roads are so uneven that even a comfortable automobile journey, let alone cycling, is impossible. One of the main reasons that cyclists feel insecure is reckless driving.
Connect	100ft road is planned across these areas all the way until Shaikpet Flyover Two main roads (Lanco Hills Road & Avatar Road) will be interlinked with series to other roads These roads increase connectivity between main city and the IT areas And these roads are bound to have more movement than Gachibowli areas Nandagiri steel bridge was built recently as well Chitrapuri – Lanco Hills road was developed as well. Connectivity from Alkaapuri township to Lanco hills will improve the connectivity in these areas with ORR service road	Gachibowli has a great potential to set an example for intelligent urban planning and transportation. The combination of residential, business, and retail uses can promote walkability. Additionally, short blocks and pedestrian pathways add to walkability, while large, safe, and dedicated bike tracks can ameliorate the loss of connectedness in routes.
Mix	SAS – EMBASSY JV. 37-story mixed-use building Once completed, the tower will dominate the skyline in the neighbourhood, housing office spaces, a mall, a cinema, and maybe a five-star hotel. The hills of Khajaguda have been envisioned as a tourist attraction.	Due to its appealing, accessible, and safe surroundings, Gachibowli boasts a substantial number of gated communities. The neighbourhood demonstrates how architecture may have a significant impact on how residents utilise available space. Children can play and adults can socialise in communities that are conducive to community involvement.
Densify	1000 – 2000 PER SQ KM	The neighbourhood is undergoing extensive development. The difference in density will be visible in near future.

Compact	A new - established neighbourhood	The neighbourhood is not quite compact because it is still being developed; it is spread out with gated communities and mixed-use infrastructure that follows the walk-to-work concept.
Shift	Increase mobility by regulating parking and road use	Road quality has a significant impact. Many people experience injuries or something similar as a result of various potholes, bumps, and cracks in the road. Every few months, the government repairs the roads by digging them up. This is rather inconvenient for non-motorized transportation.
Transit	Extensive, top-notch transit. Create links between nodes.	Gachibowli has rich transit options, sharing autos, buses, metro are available. The anticipated new links will make it easier to travel to new locations.

BENEFITS

Environment Benefit

Indian roadways are particularly dangerous for pedestrians, and this needs to be addressed immediately. As the number of cars has grown exponentially, pedestrian safety and requirements receive little attention. A legislative shift is required that allows humans to dominate the urban landscape rather than automobiles. Walking comfortably for short distances to do daily tasks adds to greater levels of physical activity and improved liveability. The core of the conflict and tension between sustainability and liveability is that many of the populations' immediate wants and wishes to improve living quality have unsustainable long-term effects. This aspect of research in one way looks to address the concerns of climate change caused by human action that modifies the global atmosphere's composition, either directly or indirectly.

Social Benefit - Integration of Children and seniors into the Neighbourhood.

The pedestrian survey gave participants a chance to voice their opinions, which provided useful first-hand data. The neighbourhood's residents are neither lazy nor complacent, and they insist that the area should be made better for walking. The difficulties that pedestrians in Khajaguda endure are severe, and they call for immediate solution. The pedestrian must undoubtedly receive more attention. A shift in focus is required, with people taking centre stage. The main challenges that pedestrians confront, according to this study, are as follows:

- Lack of authorised walking space;
- Reckless Driving;
- The weather and climate
- Distances
- The victims' lack of prompt access to first help;

This aspect of research looked at the concerns of place identity as it is conceived by the people living there and how they it will affect them. From the opinion survey people living there insisted on improved walkable environment and pedestrian safety.

Economic Benefit - Property Values have skyrocketed

Property values have risen dramatically, and the Telangana government's intention to build new IT corridors at Madhapur, Gachibowli, and is expected to have a long-term favourable influence on both the capital and rental segments of the city. This particular aspect of economic development highlighted the economic growth in terms of free movement of goods, services and labour transnationally and increased property values in the study area that contribute for economic development of the area and city. Therefore, all the three i.e., environment, social and economic aspects of the study area highlighted and recognise the global challenges that contribute to development pressures to accommodate sustainable adaptive growth in study area using urban design principles discussed in the research paper.

CONCLUSIONS

After analysing the case study we can conclude that environmental, economic and social benefits play important role in understanding the challenges of cities towards accommodating sustainable growth. This was very clearly examined through the eight principles stated in this research paper. This study emphasised the value and necessity of public transportation connectivity as the main skeleton, which is then reinforced by a network of pedestrian-friendly streets. This means that any future development should consider the needs of both pedestrians and public transportation, allowing for sufficiently wide roadways for buses and locations for bus stops, ensuring last-mile connectivity, and making public transportation simple to access on foot from a person's home or place of employment. The study hints at the need for change in both social and governmental policies as well as the difficulties facing cities in accommodating sustainable growth.
There is further scope of study

- Social studies,
- Government policy framing
- Holistic approach towards planning for sustainable growth using various parameters.

Therefore we can conclude that *"If cities do not deal with the problems and challenges of the sustainable growth in constructive way, they will deal with the cities in a destructive way*".

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SURFACE URBAN HEAT ISLAND IN LARGE CITIES IN INDIA USING LOCAL CLIMATE ZONE CLASSIFICATION

Siva Ram Edupuganti[1], Atul Kumar[2], Mahua Mukherjee[3]

[1] PhD Research Scholar, IIT Roorkee, Uttarakhand, India, sivaedupu@gmail.com
[2] PhD Research Scholar, IIT Roorkee, Uttarakhand, India, akumar5@ar.iitr.ac.in
[3] Professor, IIT Roorkee, Uttarakhand, India, akumar5@ar.iitr.ac.in

ABSTRACT

The world is urbanising at a frantic pace. Cities account for only 2 percent of the earth's land surface but house about 50 percent of the world's population. By 2030, urban areas will hold 60% of the world population. Indian cities are also undergoing an enormous transformation. Some of this transformation is haphazard. Urbanisation significantly impacts thermal stress, air pollution, urban flooding, etc. in the city. Urban Heat Island (UHI) is a byproduct of urbanisation characterised by higher temperatures. UHI has an adverse impact on health and comfort, further on the city's energy efficiency. The morphological structure of the city dictates the severity of these impacts on the cities' health and wellbeing. We can optimise the cities by understanding the UHI in relation to the morphology. Most of the existing studies on UHI are on metropolitan cities. This paper focuses exclusively on the UHI of the 5-10 lakh population bracket. This bracket is categorised as large cities as per Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines. There are various types of UHI, but this paper will concentrate on Surface Urban Heat Island (SUHI). SUHI is computed using Landsat Satellite earth observation data. The Local Climate Zone (LCZ) classification framework is adopted to delineate the city's morphology. LCZ classification framework is widely accepted in UHI studies. The paper will aim to identify the predominant morphological types in the Large category of cities in India and SUHI behavior concerning these morphological types. The results will give insight into the ideal morphology concerning SUHI, which can further help frame optimised development controls related to morphology.

Keywords: Local Climate Zone Classification, Morphology, Surface Urban Heat Island, Land Surface Temperature, Thermal Stress

INTRODUCTION

Urban Settlements account for less than 2 per cent of the land surface but house 50 per cent of the world's population (UNEP, 2015). These urban settlements are the primary sources of pollution and are responsible for most greenhouse gas emissions(Oke *et al.*, 2017). India is also urbanising at a swift pace and, as of the 2011 census, is a 33.6 per cent urban population. Urbanisation is characterised by reducing natural cover like vegetation and water bodies and increasing materials with high heat retention capacity and impermeable surfaces. Urban areas store twice the heat as rural areas. These changes adversely impact the energy and water balance and increase pollution (air, soil, water, light, and noise), thus, deteriorating the biodiversity and ecosystems and impacting food security (Ren, Ng and Katzschner, 2011). Climate change is also exacerbating, and, in this age, we can see the impacts everywhere. Climate change is impacting weather patterns. A slight increase in temperature can significantly increase the frequency and intensity of extreme events (Masson-Delmotte *et al.*, 2018). Climate change and haphazard urbanisation can dramatically impact the city's health and well-being. Urbanisation changes the city's thermal characteristics, reduces air movement, and has a localised impact on the precipitation and extreme temperatures impacted by climate change. Every 0.03°c increase in temperature can increase the number of polluted days by ten per cent, and with every 0.6°c rise, the energy usage also increases by 1.5-2%(Akbari, 2018). Hence, uncontrolled urbanisation can negatively impact the health and comfort of urban populations. As a result, the energy requirements to ameliorate these extremities can be very high, which will degrade the environment in the long run (Pitman, Daniels and Ely, 2015)

URBAN HEAT ISLAND

Urban heat island (UHI) is a byproduct of urbanisation and is characterised by higher temperatures in urban areas when compared to a rural setting. According to the Environmental Protection Agency of the United States, the term Urban Heat Island is described as "built up areas hotter than nearby rural areas . UHI is influenced by materials and surface properties, urban morphology, and anthropogenic heat. According to Oke, the main types of UHI include the Canopy Layer Urban Heat Island (CLUHI) and Surface Urban Heat Island (SUHI)(Oke, 1976). CLUHI can be tracked using weather stations that record air temperature, whereas SUHI could be measured using remote sensing techniques. UHI can significantly impact the energy efficiency of the communities, increase emissions, and thus climate change. It can also affect thermal comfort and air and water quality. During extreme heat events, UHI can further increase the stress on the population. The health risk of the older and socially vulnerable population can also grow further due to UHI, especially during extreme heat events. Some studies have investigated the presence of UHI in urban settlements in India(Pandey *et al.*, 2014; Thomas *et al.*, 2014; Mathew, Khandelwal and Kaul, 2016). Research has also highlighted the significance of urban morphology and materials on the occurrence of UHI (Hu, White and Ding, 2016; Mohajerani, Bakaric and Jeffrey-Bailey, 2017). Especially, morphology is considered a mitigative measure to tackle UHI(Yuan *et al.*, 2020; Vujovic *et al.*, 2021). Urban Morphology is deemed to have a significant impact on wind movement and hence the exchange of the polluted air with the clean air and dissipation of the heat absorbed. Thus, it is imperative to understand the city's morphology so that these learnings can inform the planning and design of urban settlements. This paper looks into the Surface Urban Heat Island(SUHI) and the morphological structure of large cities in India with a population between 5 lakh and 10 lakh.

REMOTE SENSING

Remote sensing works on spectral reflectance; every object on the earth's surface has a unique spectral signature. This signature will depend on the surface type if it is water, type of vegetation, rock etc. Advances in remote sensing make it possible to study UHI by calculating Land Surface Temperature (LST). Wide access to satellite imagery through cloud computing and high-performance computing and the availability of high-resolution imagery has made this possible (Wang *et al.*, 2015). When using satellite imagery, care needs to be taken as the accuracy gets affected when it is cloudy. There are two different approaches for calculating LST: the multiple thermal band approach and the single-band approach. The split-window approach falls under the multiple thermal band approach; unlike the single-band approach, it doesn't need to use the radiate transfer equation and uses differences in absorptions of thermal bands to compensate for the atmosphere. Single-band approach requires the estimation of surface emissivity and atmospheric water vapour content. Various data sets are available, such as Bhuvan, Copernicus program and other US government platforms.

Table 1. Classification of Cities as per URDPFI guidelines

Classification	Sub-Category	Population Range	Number of Cities as per Census of India 2011
Small Town	Small Town I	5000 - 20000	7467
	Small Town II	20000 - 50000	
Medium Town	Medium Town I	50000 - 100000	
	Medium Town II	1 lakh - 5 lakh	372
Large City		5 lakh - 10 lakh	43

Metropolitan City	Metropolitan City I	10 lakh - 50 lakh	45
	Metropolitan City II	50 lakh - 1 crore	5
Megapolis		More than 1 crore	3

CITY CATEGORIES IN INDIA

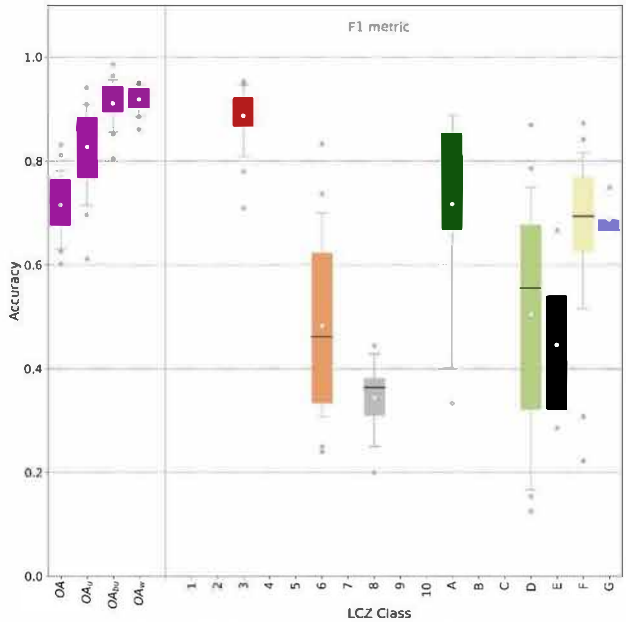
As per the 2011 census, there are 468 urban settlements in India with a population above 1 lakh. This is as per the classification provided by Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines(Town & Country Planning Organisation, 2014) (Table 1). Lakh is used in the Indian numbering system and is equal to one hundred thousand. The urban settlements with a population above 10 lakhs come under Metropolitan city and Megapolis. Most of the research is focused on this category. But there are around 43 cities in the large city category with minimal research studies, and these urban settlements are in the nascent growth stage. It is essential to understand these settlements at this stage so that any mitigative measures, especially in terms of morphology, can also be incorporated earlier. They will also contribute to a significant urban population in the future.

LOCAL CLIMATE ZONE CLASSIFICATION

There have been various explorations to understand urban morphology. But the initial studies were more segregated and hence couldn't be standardised. Having a standard methodology for evaluating morphology can make up for this gap. The local Climate Zones (LCZ) framework was proposed by I. D. Stewart and T. R. Oke to understand urban morphology (Stewart and Oke, 2012). They proposed 17 different morphological classes for the categorisation of urban settlements. These classes include both built and land cover classes (Table 2). These classes are defined by the land cover and the structural properties like building height and spacing, pervious surface fraction, tree density and soil wetness. These classes can also be combined to form subclasses that accurately represent urban morphological structure more complex than the singular 17 classes mentioned. These classes are instrumental in urban climate studies as they act as zones of representation for thermal characteristics. Hence LCZ classification helps in studying the urban morphology in relation to the urban climate behaviour, including phenomena such as UHI. This proposed LCZ classification framework was also subsequently validated. The classes clearly showed distinguishable thermal behaviour (Stevan *et al.*, 2013)(Stewart, Oke and Krayenhoff, 2014). This validation was done for air temperature studies, but subsequent research has also focused on surface temperature. This led to quantifying temperature differences in classes and quantifying the UHI magnitude. This is similar to the traditional UHI studies, which looked at the difference in the urban and rural areas to quantify UHI magnitude. This has led to LCZ classification being accepted universally to characterise the morphological structure of the cities and subsequently in the urban climate studies. This has led to tools or databases such as World Urban Database Access Portal Tools (WUDAPT) and LCZ Generator.

WUDAPT AND LCZ GENERATOR

WUDAPT is an open-source, community-driven initiative to collect urban climate-related data(Ching et al., 2018). WUDAPT initiative involves developing different levels of data starting from Level 0. The higher the levels, the more data resolution. LCZ mapping forms the base of Level 0 of WUDAPT. The methodology for creating these maps is available on the WUDAPT website (www.wudapt.org). LCZ Generator further simplifies the process of generating LCZ maps of urban settlements. This web-based tool uses machine learning techniques to automate this process (Demuzere, Kittner and Bechtel, 2021).The input of training areas by someone who understands the location is still needed to generate LCZ maps. LCZ generator also does quality control by checking the accuracy of the maps generated.



Overall Accuracy of Moradabad

METHODOLOGY

The first step of the process was to screen the cities from the group of 43 cities from the large city category available for the study. The idea is to reduce the number of parameters that can impact the thermal characteristics of the city. India has five climate zones: Warm and Humid, Hot and Dry, and Composite. Temperate and Cold. To simplify the process, only composite climate zone cities were considered as composite climate zone accounts for the largest population among all climate zones. Even in the large city category, there are numerous cities. Cities were also screened based on their city form, which can be radial or linear. Cities with linear growth were avoided. Most coastal cities or any cities adjoining a river have this pattern. Coastal cities were screened initially only as most are in warm and humid climate zones. Subsequent screening pattern checks for the presence of any significant macro factors such as Hills, rivers, lakes etc., which can impact the thermal characteristic of the city. Any planned city such as Chandigarh was also not considered for the study based on the premise that it will have a different thermal characteristic from an unplanned city which is more common in India. Any presence of predominant nonresidential land use, such as industrial, has also resulted in the city's exclusion.

The second step of the methodology involves checking of availability of LCZ maps for the city on the LCZ generator platform for shortlisted cities from the first step. All the LCZ maps generated using the LCZ generator are available on their platform for open use by acknowledging the tool. At least a minimum accuracy of 65% is considered a threshold, though the minimum requirement suggested in the existing literature is around 50%. For example, the overall accuracy of the Moradabad LCZ map was 73% (Niyogi, 2021). The accuracy results can be seen in Figure 1. Similar accuracy results are available for all the cities considered but are not explicitly shown in this paper. The shortlisted cities were Aligarh, Jalandhar, Moradabad, Jhansi, Ujjain, and Saharanpur through these two steps. But only 3 cities were studied in detail for this study: Jalandhar, Moradabad, and Saharanpur. These cities have a population of 862,886, 887,871 and 705,478 respectively. Further, these cities have similar form and don't have any distinct morphological characteristics while being in the same climate zone.

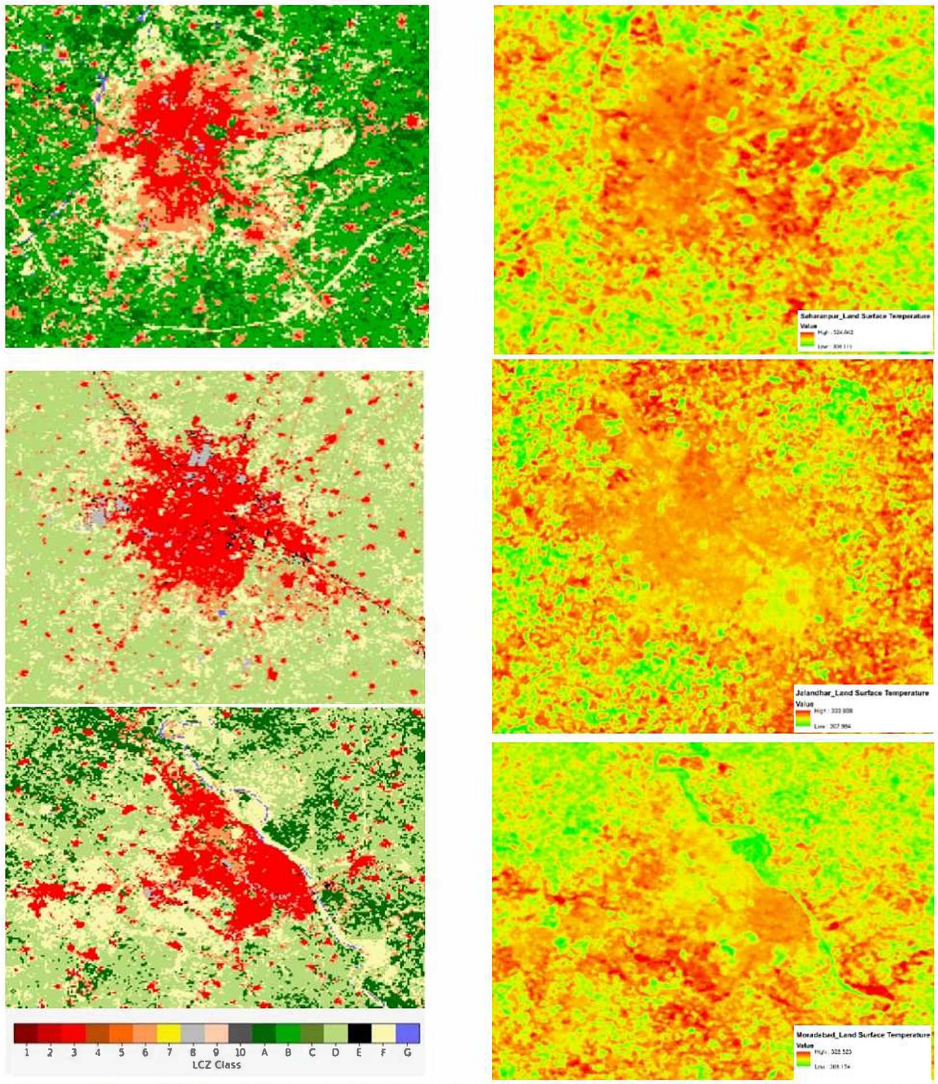
LCZ maps are generated for a much larger region of interest by the LCZ Generator tool needed for accurate processing. Hence the maps are cropped for a smaller area of interest which focuses only on the city urban areas and reclassifies using the ArcGIS platform. Though the focus is on built cover types, the analysis was done for both built and landcover types. THE SUBSEQUENT STUDY DID NOT CONSIDER any LCZ classification with less than 0.5% of the total analysed area. Coming to LST estimation, the Single band approach proposed by Qin was used in this paper (Qin, Karnieli and Berliner, 2001). The surface emissivity was measured using the Normalised Difference Vegetation Index (NDVI) method. The near-surface temperatures to calculate atmospheric transmissivity. Landsat Satellite data is used in the study due to its high spatial resolution of 30m, making it possible to study LCZ morphology data related to LST. The temporal resolution is 16 days which is okay for the study. Though other satellite data products like MODIS have a high temporal resolution, the coarse spatial resolution(1km) makes it unsuitable for this study. Landsat data from May was used for this study which has typically 2 instances of Landsat Satellite data. The data with the lesser cloud cover was used for the study; it is suggested to use data with less than 10% cloud cover while estimating LST from the data. The final step involves correlating the zonal statistics of LST and LCZ classes on the ArcGIS platform. To calculate the SUHI, the inter LCZ difference is checked. The Low plant LCZ is considered the reference to calculate the SUHI magnitude. In a non LCZ scenario, when you must quantify UHI, the rural area natural setting becomes the reference for the calculation.

Table 2. Percentages of Built-up Area of Cities Analysed

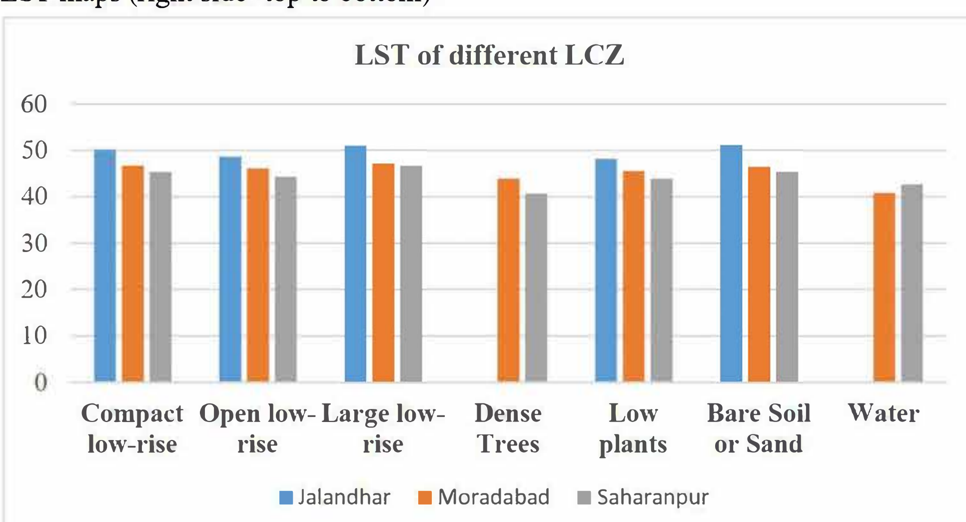
	Percentages of Built-up Area of 7.5-10 Lakh Population		
LCZ Type	Saharanpur	Jalandhar	Moradabad
Compact low-rise	33.8	56.4	66.6
Open low-rise	64.3	32.4	30.0
Large low-rise	1.9	8.8	3.4
Lightweight low-rise		1.7	

ANALYSIS

The analysis was done for the following cities, Jalandhar, Moradabad, and Saharanpur. As discussed before, all these cities are in the composite climate zone in India. The results of the LCZ classification for these cities with their respective LST's can be seen in Figure 2. The analysis of the LCZ classes and their extents in the different cities reveals the predominant morphology types in the built are Compact low-rise and Open low-rise (Table 2). They account for more than 88 per cent of the area in all three cities. Saharanpur, which has a smaller footprint than Jalandhar and Moradabad, have more Open low-rise, but Jalandhar and Moradabad have predominant Compact low-rise LCZ. This ties with the general understanding that open typologies can get converted into compact ones when the cities expand in India. From this, it can be seen that the morphology of large cities in India is more homogenous. In terms of urban climate response, heterogeneity in morphology is preferred to homogeneity (Liao et al., 2021). This homogeneity is evident not only in the built types but also evident in landcover types. Also, the current development pattern points towards a segregation of built and landcover types where most of the city center areas predominantly only have built morphology types. Unfortunately, if these gaps exist in the large cities category, these schisms will be compounded when they become metropolitan or Megapolis category cities. Predominant periphery areas of the cities are of low plants, bare soil, and scattered or dense trees. Saharanpur has predominantly scattered trees, while Jalandhar and Moradabad have low plants and bare soil. The LST results of the three cities for their respective LCZ classes are shown in Figure 3. Jalandhar seems to have higher LST in general than Moradabad and Saharanpur. Also, Dense Trees and water LCZ classes have lesser LST when compared to other classes.



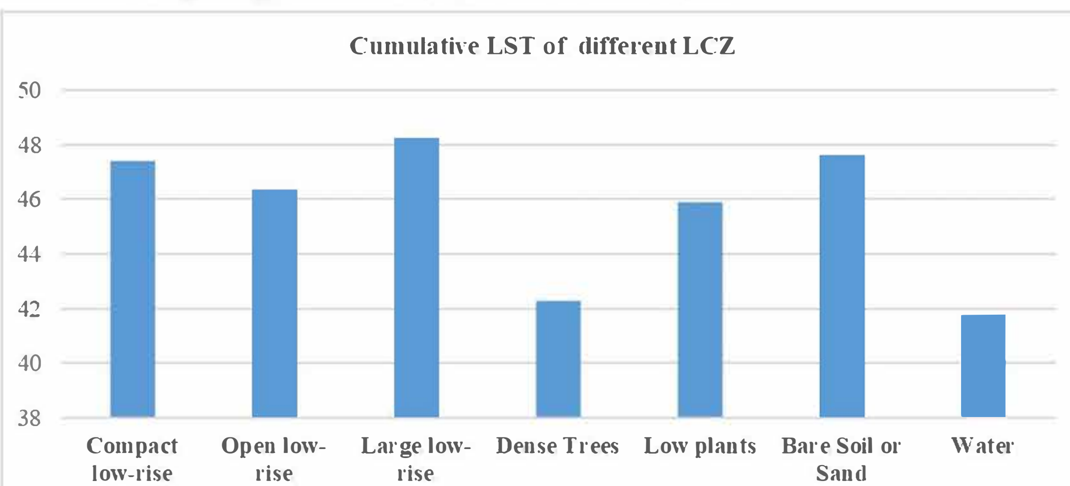
Local Climate zone Map of Saharanpur, Jalandhar, Moradabad (left side- top to bottom) Urban settlements along with LST maps (right side- top to bottom)



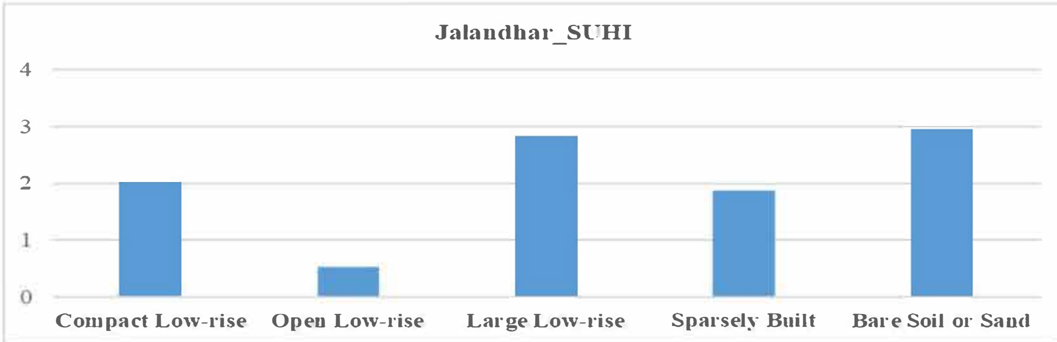
Land Surface Temperature (LST) of different LCZ's in Celsius across three cities

The cumulative LST of an LCZ type is the mean of the LST of different cities. Only the LCZ's in at least 2 cities were considered for cumulative LST calculation. The LST was least in Dense trees and Water LCZ types (Figure 4). The highest LST was observed in the Large low-rise, Compact low-rise and Bare Soil LCZ. This gives an insight into the LCZ morphologies more prone to higher surface temperatures. The temperature differential between water and Large low-rise is 6.2°c. As mentioned in the methodology, low plants LCZ is considered the reference to calculate temperature differential and inter LCZ SUHI. In the case of Jalandhar (Figure 5), the SUHI is most evident in the Large low-rise and Bare Soil, as high as 3°c. When it comes to the compact Low-rise, it is around 2°c, whereas the Open low-rise has the least SUHI, as low as 0.5°c. In Moradabad (Figure 6), a similar SUHI behaviour can be observed, though to a lesser magnitude. SUHI of 1.5°c is found in Large low-rise and 1.2°c in compact Low-rise. Additionally, Dense trees and water show a positive effect in terms of negative SUHI magnitude of almost 2°c and 5°c, respectively. Water LCZ class shows a significant cooling effect. Finally, in the case of Saharanpur (Figure 7), dense tress seems to have a significant negative SUHI effect of 3.2°c than that of water which is 1.2°c. Even scattered trees seem to have a more negative SUHI effect than water to the tune of 1.5°c. But in the case of other LCZ's, similar to that of Jalandhar are observed in terms of magnitude, where Large low rise seems to have the highest SUHI magnitude of 2.8°c and Compact low-rise and Bare soil coming next at 1.1°c and 0.9°c respectively. SUHI magnitude is the highest in Jalandhar and very low in Moradabad. Saharanpur also has high SUHI magnitude slightly lesser than that of Jalandhar.

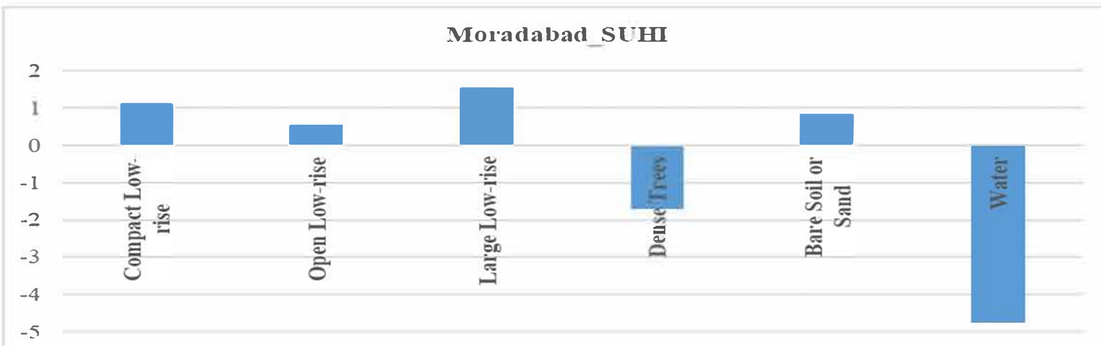
The cumulative SUHI behaviour of the three cities, which is the mean of the SUHI of all the cities, was summarised in Figure 8. Dense trees and water show the most mitigative potential in reducing SUHI. Scattered trees also show promise but were not listed in this figure because they were evident only in Saharanpur. In terms of the high potential of SUHI, Compact Low-rise, Large Low-rise, and Bare soil respectively a significant magnitude of SUHI. These classes need to be clubbed with other classes showing mitigative potential to lower the thermal stress of the city and hence reduce the adverse effects of urbanisation and climate change. Further, Suppose the growth projection of morphologies is not analysed and optimised, which is the case in the business-as-usual scenario. In that case, most periphery landcover types will be converted into built cover types. This will be especially stark in the large cities or medium towns categories in the nascent growth stage. This is not ideal for cities, especially in this era of climate change, where the focus is to improve the urban risk resilience of the cities. It is imperative to understand urban settlements' morphology and thermal behaviour to achieve this.



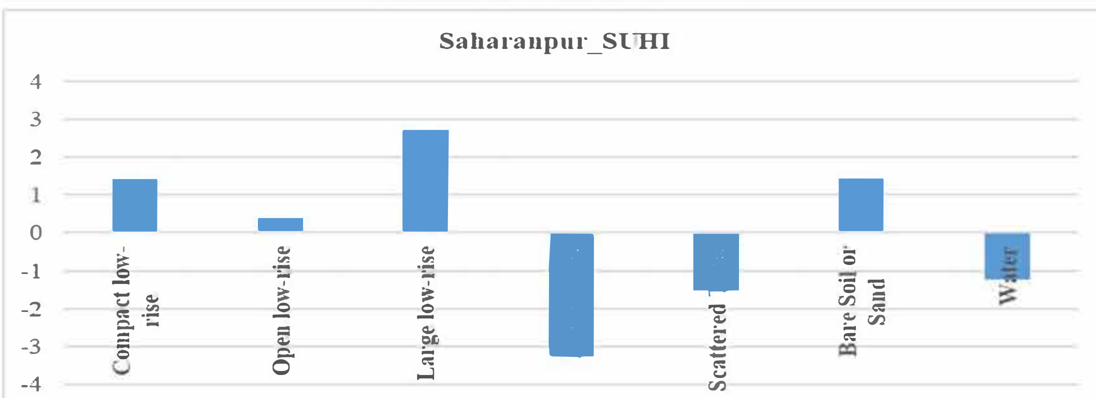
Cumulative Land Surface Temperature (LST) of different LCZ Classes in Celsius across three cities



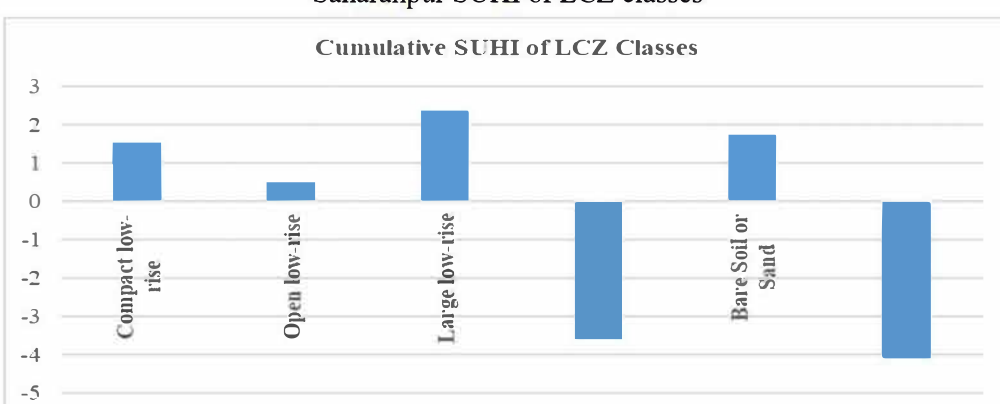
Jalandhar SUHI of LCZ classes



Moradabad SUHI of LCZ classes



Saharanpur SUHI of LCZ classes



Cumulative SUHI of LCZ Classes across three cities

CONCLUSION

India is urbanising at a breakneck speed, and there is a need to understand the morphology and its impact on the thermal characteristics of the city to mitigate urbanisation's adverse impacts. LCZ classification and remote sensing advancements enable us to do this. LCZ also allows us to standardise research and inform urban planning disciplines, while the LCZ generator tool allows the streamlining process. The results point towards a homogenous structure in the morphology of large cities in India. It is necessary to investigate the reasons behind homogeneity due to the existing developmental controls. Also, the results show the thermal characteristics of different LCZ classes. While Large low-rise has a high SUHI magnitude along with Compact low rise. This can be alleviated with Dense or scattered trees LCZ class and water LCZ class. It is imperative that planning consider the morphological transitions over time and the built classes have to be integrated with suitable land cover classes. Cities have to expand organically integrating the green peripheral elements. It is widely accepted the urban risk resilience of cities against climate change can be improved by incorporating green Infrastructure as natural corridors and patches to protect the ecosystems and develop morphological heterogeneity. But planning without these specific considerations will result in the breakup of ecosystems which will have a detrimental effect and increase the vulnerabilities for the future. These changes can have a significant impact, especially if the cities are at a nascent growth stage. Further, planning bodies should use the LCZ classification system to bridge the urban climate and planning gap.

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COMPREHENDING THE NEXUS OF VERNACULAR ARCHITECTURE WITH SOCIO-CULTURAL ASPECTS AND CLIMATIC FEASIBILITY: LEARNING FROM THE ALLEYS OF LUCKNOW, INDIA

Chinmayi Saxena

Assistant Professor, BMS School of architecture, Bangalore, India, chinmayi@bmssa.ac.in

ABSTRACT

"The future of Architecture is culture" as quoted by famed architect Philip Johnson is certainly unerring. Unequivocally, one of the stupendous attainments of Indian civilizations is the varied diversity of cultural and traditional localism. Culture carving architecture is an ineffable notion. On a related note, one can espy the instance of vernacular architecture and socio-cultural aspects converging in the alleys of Lucknow. Lucknow is a city located in the plains of North India, on the banks of river Gomati. The Vernacular houses of Lucknow not only harmonize well with the socio-cultural aspects but also respond well to the climate. The city is culturally prolific, with a typical composite climate having perceptible sundry seasons, the vernacular houses have been proven to be climatically convenient.

The paper elucidates the three types of vernacular houses that exist in Lucknow. The courtyard type, the bungalow type, and rural mud house type in different locations of Lucknow are introduced because of their climatic feasibility. The three types are unambiguously different from one another but are thermally congenial and foster socio-cultural events. The paper further chronicles the spaces that emerged on account of socio-cultural aspects in the Narhi settlement, a well-known locale in Lucknow.

Backing the introductory line, the paper ceases with how culture and traditional architecture shape the future of habitats since it harmonizes surrounding, climate, geography, landscape, and the human psyche. With disparate cases, the paper elucidates that edifice is not just the ramification of silhouettes, but how the culture of the locale serves as the quintessence of a building, at the same time also bestowing the user with thermal comfort. Hereby, unveiling the ethos of an edifice.

Keywords: Vernacular architecture, Socio-cultural aspects, climatic feasibility, Lucknow, culture

COMMENCING WITH PARTICULARS ABOUT THE LOCALE OF STUDY

Lucknow is the capital of an Indian state Uttar Pradesh, the most inhabited state of India. It is a culturally and architectonically rich city noted for its profuse "*Nawabi* culture" and intricately sculpted edifices. Celebrated for its awe-inspiring gateways, clock tower, mosques, mausoleums, palace complexes, and *Imambadas,* Lucknow is an institution with a unique finesse of architecture. Beings who have been to Lucknow would acknowledge culture is not just in its architecture but in language, drapes, cuisines, folklore, music, etc. The cause of culture being in every nook and corner of the city is that it has witnessed varied rulers fluctuating from the Hindu and Mughals pursued by the British and post-independent evolution. The city has the earliest habitations in the central part of the city commonly called *Purana Lucknow* and the latest settlements all around the periphery. Purana Lucknow witnesses' high density and pre-colonial settlement buildings. The latest settlements have been established in the post-Independence period. Lucknow is a city, synonymous with culture.

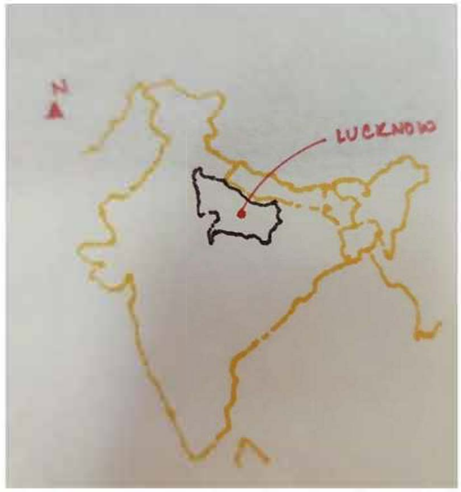

Figure 1: Map of India showing Lucknow's location

OUTRIGHT FACTS ABOUT THE CLIMATE OF LUCKNOW

Lucknow has an acute type of continental climate because of the stretch from the sea. The air of the oceanic region invades this locale only for four months from June to September which originates from humidity, rain, and cloudiness. Three sixty-five days of the year can be split into four seasons. From December to February is the cold season. This is pursued by the hot weather which continues till mid-June. The monsoon climate periods from mid-June till September end. Around eighty percent of the rainfall is received during this phase. October and November mark the transition season from Monsoon to Winter. Residents of Lucknow experience extreme temperatures in summers and winters. The temperature may rise to about forty-eight degrees Celsius in summers and the temperature may fall to three to four degrees Celsius in winters.

TRADITIONAL HOUSES OF LUCKNOW

Mud houses

A bunch of mud houses around forty-five houses, clumped on reasoning of occupation and caste is found on the rim of the city, which contributes to the semi-rural community. Mud houses are built with rammed earth with other materials like thatch and other native materials which are spread evenly across the Gangetic plains. Mud houses are constructed in square or rectangle shapes. Families predominantly involved in farming are the occupants of mud houses. The generic form of mud house generally has shared walls with neighbors and encompasses an aangan (courtyard), wrapped up by kamras (rooms) of varied sizes separated by dalaan (verandah). The chowka (kitchen) is in of the rooms. The verandah outside acts as a transition space from the outside to the inside. The windows are small openings to the verandahs mostly facing the internal courtyard. The materials used for wall establishment are regionally convenient clay amalgamated with straw and polished with mud and cow dung slurry on the other hand, the roof is fabricated of bamboo purlin structure, coated with thick clay, straw mud, and cow dung slurry. Floors are also polished with and verandahs had thatch roofs. The built form, orientation, layout, shape, form, materials like mud, and fenestrations contribute to the thermal comfort of a locale. The visual comfort depends on how light brightens the areas and environment with the factors of spatial daylight, shadows glare, etc.

The method to examine thermal comfort was that of the field examination approach which also has been used for years. As per the survey, residents experienced less warmth during summers in the evening while sitting near the courtyards. The mellow air of the courtyard, which was heated during the daytime advances and is moderately removed by cool night air from above. The cool air hoards into the courtyard and flows into the nearby rooms hence cooling them. Another paramount factor in providing thermal comfort to the residents is the building material that is used. Mud is a non-conductor of heat. During summer, the outside temperature is more than the inside temperature, hence residents feel cooler in mud houses. The properties of materials, particularly high thermal mass have been proven to be paramount plan in reducing indoor temperatures to a very large degree

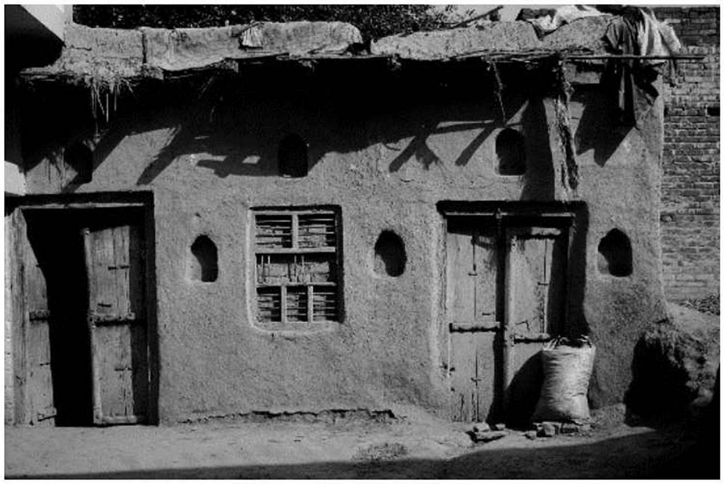

Figure 2: Mud House

Figure 3: Lane with mud house on two side

Figure 4: Typical mud house massing

COURTYARD HOUSE TYPE

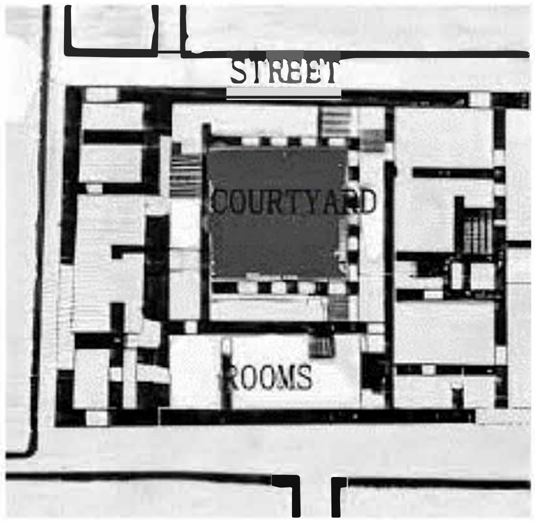

Figure 5: Plan showing typical courtyard house

One can espy plenty of courtyard-type houses in *the Chowk* area of Lucknow. This is one of the oldest markets and residential locality of Lucknow. The locale is where one can spot the cultural and historical heritage of Lucknow. "Tulsi kutir "is located in Chowk near the Koneshwar mandir. The orientation of the house is North East- Southwest direction. The fenestrations and entrance are in the windward direction i.e on the northeast side. On the southwest side, there are no openings. The nonexistence of fenestrations on this side helps reduce heat. The main entrance unlatches into a narrow street, which is the case with almost all the houses in the Chowk area. The courtyard in the abode creates shaded spaces and promotes ventilation in the interiors. The eaves protrude in the courtyard, which provides shade and keeps solar radiation from entering the rooms. The *Jharokhas* window projecting from a building on an upper floor overlooking the road on the north side of the building catch winds that cool the rooms on the first floor. The walls are thick around 90 cm which acts as a backing for thermal comfort. Walls are made of lakhauri bricks and lime plaster. Roofs are also thick around 36cm. Roofs and walls offer great thermal resistance.

Figure 6: Interior of typical courtyard house type

Figure 7: Chowk area of Lucknow

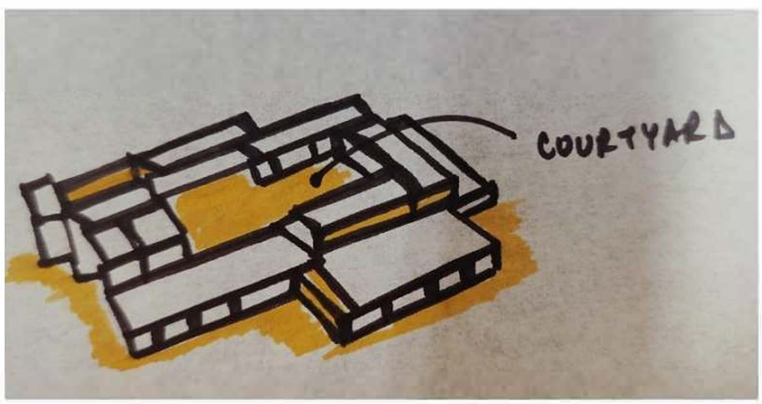

Figure 8: Typical courtyard house massing

Colonial bungalow house

Houses of this type can be witnessed in and around Raj Bhavan colony, and Railway colony. Locales where higher income groups reside. These disconnected houses arranged in a centripetal manner, are located in huge shaded landscaped flee with flat topography. The study context is a house situated in a railway colony, the abode of the Divisional railway manager. The single-storied house has six rooms attached, confined by verandahs on two sides. House has no shared walls with any other structure hereby the residents have the privilege of sun and wind. Modular bricks are used with lime surkhi mortar. High roofs are made of jack arches finished with mud phuska. Floors are made of brick and lime surkhi mortar with tiles. Huge lawns can be spotted at the front and rear setbacks.

Figure 9: View of a colonial bungalow house

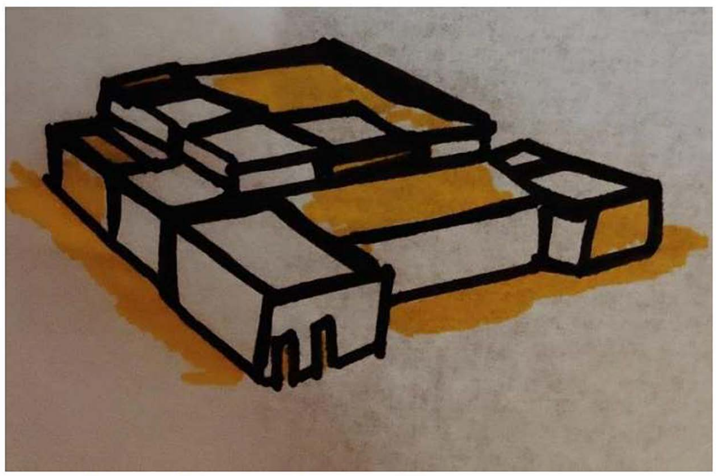

Figure 10: Typical colonial bungalow massing

VERNACULAR ARCHITECTURE: KNIGHT IN SHINING ARMOR

The three types of vernacular houses of Lucknow have survived for generations. They all have existed for hundreds of years. Mud houses, courtyard house types, and colonial bungalow houses might be varying in building material and techniques, they belong to different communities with varied lifestyles and social structures. Yet all are comfortable and sustainable. Houses are located in the unalike background within city premises but seem to provide thermal comfort to the residents.

Lucknow's season varies from Hot and Dry between March to May to Warm and Humid between June and September and cold and wet from November To January throughout the year. The transposing the location of the sun throughout the day and all through the year consequences changing thermal and visual conditions yet it is commendable to observe the houses both thermally and visually comfortable. The flow of culture and tradition in a progressive society can be well depicted in vernacular houses. Verandahs, balconies, jharokhas, courtyards, thick walls and roofs, high ceilings, ventilation apertures, and space planning as per user's needs are the key highlights in the vernacular houses to contribute to thermal comfort. The traditional houses of Lucknow were built considering the major pointers – privacy and segregation between men and women. Lucknow has always had a Hindu population more than Muslims but one can sense the influence of Muslim culture in many of the city courtyard houses. Hereby, establishing the fact that socio-cultural aspects have a huge impact on architecture.

VERNACULAR ARCHITECTURE ALIGNING WITH SOCIO CULTURAL ASPECTS

"Narhi settlement" is located near Hazratganj. Hazratganj is the prominent shopping center of Lucknow. It has shopping complexes, restaurants, hotels, theaters, cafés, and many offices.

Narhi settlement consists of hundreds of courtyard type houses. A courtyard house is one of the three types of vernacular houses in Lucknow. Residents of each entity flucturate from 5 to 6 members involved in employement. Residents of Narhi settlement have alike social customs like celebrating Holi, Diwali, etc. Houses of this settlement were constructed by the residents with the aid of trained laborers using vernacular materials available. Initial construction was commenced with the ground floor consisting of single-bay rooms like kitchens, toilets, stores etc placed around a courtyard . As time passed by, the staircase was constructed in the verandah which led residents to the upper floors. As already discussed in previous pages, the courtyard-type house was thermally comfortable due to the benefits received from the courtyard, thick walls jharokhas, etc.

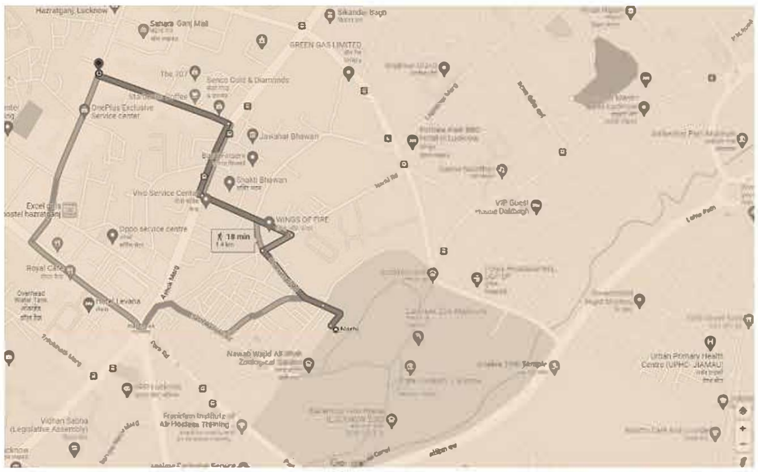

Figure 11: Map focussing Narhi locality of Lucknow
Source: Google map

LOCALES THAT PROMOTE SOCIAL CULTURAL EVENTS IN NARHI SETTLEMENT

Plinth platform

The platform located just outside the main entrance of the house acts as a transitional element from the indoors to the street outside. The average height from the street is around 90 cm and the width is around 1200 mm. The plinth platform is the space where residents interact with the visitors and neighbors. Most interactions happen in the evening of summer. Winter afternoons also witness the most interactions as residents come out to soak the sun.

Figure 12: Plinth platform at entrance

Jharoka or balcony

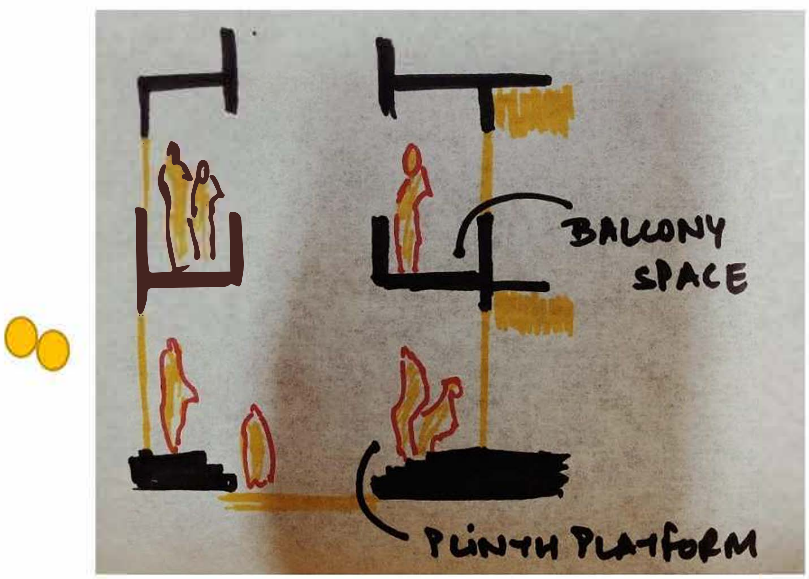

Figure 13: Jharoka or Balcony

Balcony space on the upper floor facing the street encourages socio-cultural activities. Residents soak in the winter sun and relish summer breezes in this locale. Apart from this drying their clothes, women enjoying a cup of tea, and chopping vegetables are the activities which can be seen here. The narrow streets also present favorable reciprocity through the projected balconies that serve an area for enculturation with neighbors. Balcony width varies from 500 mm to 1250 mm.

Aangan or courtyard

Aangan or courtyard acts as important locale for the residents. Aangan can be considered the focal point of the abode. It also serves as an antidote to extremely hot summers. Aangan or courtyard can be used as a semi-living area, where family interactions take place. Usually, women are seen spending time with their family members and after finishing their chores. Semi living area transforms into a multifunctional space when it changes to a place to sleep in summer nights and winter afternoons with foldable cots. This large space is also used to celebrate festivals.

Figure 14: Aangan or courtyard

THE AMALGAMATION OF VERNACULAR ARCHITECTURE AND SOCIO-CULTURAL ASPECTS IS THE FUTURE OF ARCHITECTURE

The key advantages of vernacular architecture are establishing a paramount connection between inhabitants and the environment, maximum usage of local knowledge and materials, and henceforth providing a sustainable environment. As quoted by Frank Lloyd Wright "we have to create an architecture that speaks for its time and place and yet yearns for timelessness". Modern architecture encourages the latest technologies and construction methods, and manufactured materials are becoming a norm but such methods and materials have a huge impact on the environment. The notion of modernity is screening the vernacular methods. Vernacular architecture can foster brimming environmental abasement. Vernacular architecture is connected to green architectural principles of energy efficiency and utilizing materials. Architecture has unfolded over years and is still evolving. Design that is veracious to the earth will continue and changing the existing architectural elements can fix our changing needs. The unique character pertaining to a place can be retained, without compromising the needs of habitats. A typology that is feasible for both vernacular and contemporary architecture is imperative.

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ASSESSING AND EVALUATING SEISMIC SENSITIVE PARAMETERS OF HISTORIC CONSTRUCTIONS: A TAXONOMY OF KATHMANDU VALLEY, NEPAL

Abhilasha Pathak[1], Sudipta K Mishra[2], Aanchal Sharma[3]

[1]Ar, Associate Professor, G.D. Goenka University, Gurugram, India, omabhilasha11@yahoo.com
[2]Dr, Sudipta K Mishra, G.D. Goenka University, Gurugram, India, sudipta.mishra@gdgu.org
[3]Dr, Aanchal Sharma, DIT University, Dehradun, India, s.aanchal@gmail.com

ABSTRACT

Historic constructions are a by-product of culture, livelihood, tourism, and pilgrimage which also elevates socio-economic beneficiaries to the local societies. It is relevant to comprehend traditional geometry, shape, and proportions that are the living essence of heritage structures that continued to be used, inhabited, and preserved by the local order. It is imperative to a) Assess the damage level of heritage monuments by evaluating the geometric configuration and proportions, and b) Reduce the seismic impact through structural intervention. Both these objectives can be achieved by assessing and evaluating the seismic-sensitive parameters during the preservation stage of the ancient heritage temples. To reduce the lateral force during an earthquake sustainable alternatives with minimum interventions are required. This will also help preserve the structure more efficiently within the existing levels of damage. Since the ancient monuments are the single largest segment of the tourist sector and a prime source of livelihood, the sustainable preservation of historic construction against seismic forces holds major importance and concern. This paper enlightens the investigation of historic constructions of Kathmandu Valley Nepal which are highly enduring architectural amplitudes, rooted in their place.

Keywords: Geometry, Historic preservation, Seismic Sequence, parameters, Intervention

INTRODUCTION

Safeguarding heritage structures is to principally serve the traditional style of an anticipated occupancy and cater the socio-economic needs for a contemporary society. Cultural diversity is the variability among living inhabitants in a given socio-economic complex (Gurung, 2000). Currently, there are more than 125 distinct ethnic groups in Nepal, (Mofaadmin, 2019). It is vital to maintain the social livelihood and long-term survival of the local systems (NPTEL, 2019). As per the seismological station located in Kathmandu; Nepal receives earthquakes every 75 - 100 years Figure 1 is one of the most ancient evolutions in the world (Menon A, 2015). The report from PDNA states that there is an urgent need for the preservation of three main historic towns of Kathmandu Valley, namely Kathmandu, Lalitpur, and Bhaktapur due to severe shaking amid earthquake shocks (VII-XI on the Mercalli scale) damaging the world heritage sites of Kathmandu Valley (Assessment, 2015). Thus, preservation of historical construction against seismic forces holds major significance(Standards, 2002). Since seismic forces are three-dimension (3D) higher seismic force causes larger deformation.The forces that pass through diverse structural features culminate in the foundation are significantly influenced by the overall geometric configuration (Murthy, 2006). This paper performs a correlation analysis on the moment of inertia MI and slenderness ratio SR on four historic temple sites of the Kathmandu Valley Monument zone, in Nepal. The systematic seismic assessment is used to investigate the structural condition of pagoda-style brick masonry temples, is the distinctiveness of the paper.

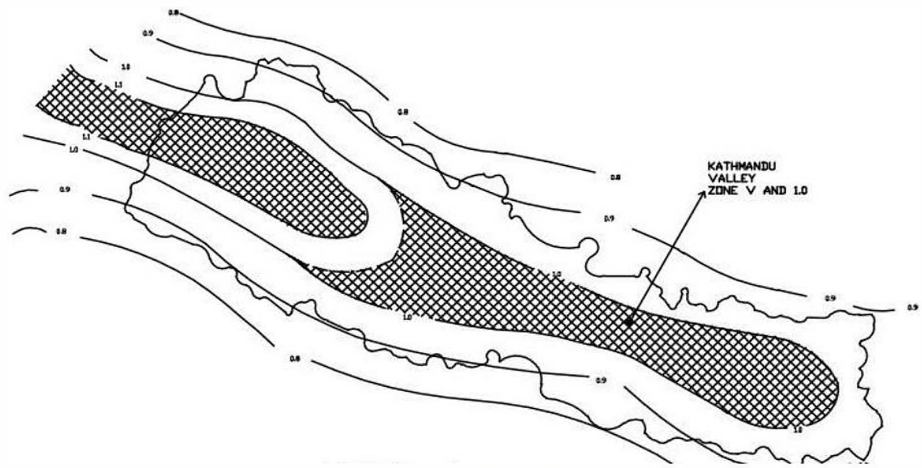


Figure 1 Seismic active zones of Nepal
Source: Seismological station, Kathmandu,Nepal

LITERATURE REVIEW

The displacement caused by the seismic force banks Inertia forces, causing structural damage to the various elements of the structure (Muddaraju, 2008). Consequently, the mass and centroid axis are to comprehend the stability of such structures. The higher mass is directly proportional to the inertia force, see equation 1,

$$I = M X F \qquad (1)$$

There are a few studies in the past based on Geometrical performance and structural integrity analysis based on IS codes (Institution, 2002) . According to (Sanyal, 2016), building configuration and seismic design of a structure will benefit greatly from timely interaction between architects and structural engineers to understand seismic behavior by four major characteristics. Namely, good geometrical configuration (shape, size, and structure), appropriate strength, stability, and adequate ductility (Murthy, 2006). An exhaustive literature review was studied, to sum up, the inferences from similar established works that Geometrical configuration is necessary (H.Varum, 2012). For tall structures proportions are extremely significant, rather than only considering the height of the structure (Murthy, 2006) suggested that the behavior of a structure during a seismic event critically depends on the shape, size, overall geometry, structural systems and the role of materials are the efficient structural key drivers (Pawan, 2014). The present paper is a thesis research work to preserve the ancient cultural heritage of Kathmandu Valley, Nepal for the present and upcoming generations taking seismic disasters as a context.

Moment of Inertia (MI)

During the seismic activity, seismic forces are developed. The Moment of Inertia (MI) is considered a property of geometry to apprehend the propensity of a structure to remain intact in its novel position about a reference axis passing through the Centroid (CG) *resistance* (I.B.Prasad, 2000). Lacking shape regularity in building Plans and Elevations implies the absorption of seismic forces due to eccentricity of central mass augmenting torsion during seismic activity. This makes a structure twist and *resist deformation*. Thus we can say that if structures have the same configuration shape, with different mass, the heavier structure posses elevated MI along with one of the axis Ixx or Iyy. This literature review is piloted to understand the effect of MI on the geometrical shapes of pagoda roofs, Area Moment of Inertia / Transfer, see equation 2.

$$I_O = Ic + A d^2 \qquad (2)$$

Where A= area of shape distributed about the required reference axis.
Ic= $\iint r^2 dA$ And d is distance from the centroid.

Geometrical Configuration GC, Plan Aspect Ratio PAR, and Slenderness ratio SR

According to (S.Nienhuys, 2003) symmetrical construction is less vulnerable than asymmetrical construction. A high plinth platform can avoid shear stress to the foundation and absorb seismic jolts. Tapering roof configurations can withstand better pushover during a seismic event. The above study reveals the trial and error of earthquake traditional construction techniques used by the ancestors. The temple roofs have symmetrical geometric patterns pitching from the center of the inner masonry structure with a radial arrangement of rafters from the edges supported by wall plates, timber pegs, and purlins for temple roofs Figure 2. These rafters are responsible for the dead load of the roof. The high temple roofs are cantilevered and supported by diagonal wooden rafters (usually 45*<, > or = to) called iconographies.

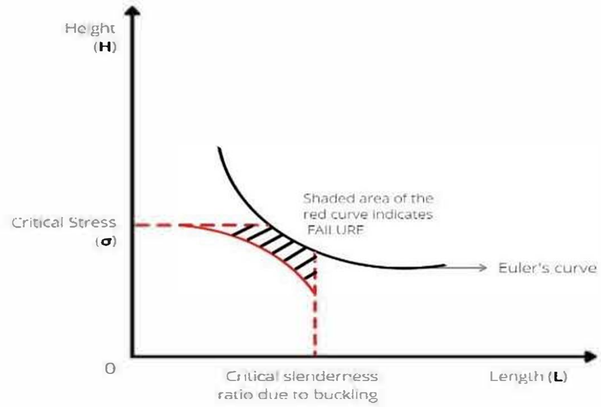
Figure 2: Twin-tiered Pagoda temple roofs reflecting significant geometrical configuration
Source: KVPT Lalitpur office, Patan, Kathmandu valley, Nepal

A large slenderness ratio enhances extreme horizontal dislodgment which is not considered desirable. The increased height of a structure leads to an increase in mass decreasing the overall stiffness figure 2. It is also known that SR is the ratio of effective height to its least effective Length see equation 3.

Y = f (a), the function of a, similarly (3)

More chances of bending or bucking are due to the larger length of a section. According to (Pawan, 2014), to understand the effect of lateral deformation (*bending and buckling*) the geometrical configurations involving Plan and structural configuration are essential for seismic force studies. This reveals in understanding the below equations to be used for analysis purposes in the subsequent section of this paper. According to the mathematical equations

Slenderness ratio = H/L and *SRR = f (H, L)* slenderness ratio of the roof is a function of effective height and effective length Figure 3. Similarly, Plan Aspect Ratio *PAR = effective length / effective width and PAR = f (L,W)* plan aspect ratio in plan is a function of effective length and effective width.



. **Figure 3:** Effect of slenderness ratio on tiered pagoda roofs, relationship between length and height
Source: J.B.Johnson's Parabola critical load and Timosshenko, S.P. & Gere, J.M.(1961). McGraw- Hill.

Second Moment of Area (Parallel and Perpendicular axes analysis)
The second moment of area analysis is an algebraic measure for the evaluation of shape performance and its deflection caused due to seismic stress of existing and proposed structures (Muddaraju, 2008). The parallel axes method or second moment of the area also known as the Huygens – Steiner method is applied to determine the Moment of Inertia (MI) about any axis. It reveals that large MI leads to lesser deflection and forces (C.V.R, 2002). The parallel axis Method can be stated as an equation, see Equation 4.
MI = f (L, H)

$$I\,x\text{-}x \;=\; I\,x - x \;+ Ad^2 \qquad (4)$$

The above equation implies that the moment of inertia about any axis (Ixx) passing through the Centroid (CG) of the area is either larger or smaller than the moment of inertia about any other parallel axis (Muddaraju, 2008). The second moment of the area method is adopted to evaluate the Intertia forces under various conditions and assess the performance predictions, for the parallel axes method which is the prime objective of the basic methodology adopted for this research paper (Resource, n.d.). More importantly, it identifies the property of a shape that is used to predict its deflection and bending due to seismic stress generated. Predictive Analysis using the Regression equation, see Equation 5

$$Y = a + bx_1 + cx_2 + \ldots\ldots xn \qquad (5)$$

Summary of Literature Review
An extensive literature study with the inferences was noted down. It is well established from several studies that MI and SR detailing are necessary to resist seismic events. It is also found that Geometry is critical to good seismic performance (Murthy, 2006). Many works have been done regarding the resistance of Moment of Inertia and Slenderness ratio on various buildings. There are very few studies that have been done, based on the above criteria in combination (heritage architecture and seismic sensitive parameters) concerning IS codes for preservation purposes.

AIM AND OBJECTIVES OF THE STUDY

The aim is to propose a seismic vulnerability assessment methodology for brick masonry twin-tiered pagoda roofs on structural aspects related to the performance of heritage Pagoda temple roofs as case studies.
The prime objective of the paper is to study the comparative performance of MI and SR using parallel and perpendicular axis analytical methods followed by regression analysis, see equation 5.

$$Y = a + bx_1 + cx_2 + \ldots\ldots\ldots x_n \qquad (5)$$

The objectives of the study can be acknowledged as follows:

1. To perform a comparative study of seismic parameters of brick masonry temples with twin-tiered pagoda roofs in horizontal and vertical configurations and investigate the effect of slenderness ratio.
2. To evaluate the effect of seismic forces on different roof sections at various levels along with the increasing height and length.
3. To investigate the performance level/behavior of pagoda roof shapes in terms of MI, SR, and PAR using the parallel axis method, correlation, and regression analysis.

METHODOLOGY

The present paper uses *IS Code 1893:2000* as a base reference for analyzing the seismic parameters. This study involves a comparative analysis of the behavior of low and medium-rise twin-tiered pagoda roof temples having different geometrical configurations both (horizontal and vertical), and slenderness ratios for square and rectangular plan-shaped brick masonry temples.

The following steps of methods are adopted for analysis purposes:

- Step 1:Selection of 4 temples having different geometrical configuration for analyzing MI on roof shapes and SR on No. of tiers height.
- Step 2: Analyzing model combinations for seismic sensitive parameters by parallel axis and correlation analysis.
- Step 4: Regression modeling of pagoda structures using ANACONDA 6.1.4 Jupyter software.
- Step 5: Comparative study of results in terms of Moment of Inertia, slenderness ratio, plan aspect ratio center of gravity, and roof displacement during the period of seismic force.

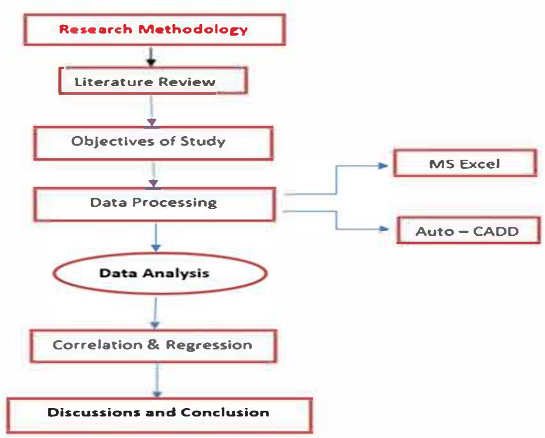


Figure 4: Research Design Methodology
Source: Authors

Study Area and Limitations.

The scope of this research paper is restricted to the variables influencing the heritage temple typology only, by keeping the context as seismic activity *Zone – V*, of Nepal. The geographical context for the study is the Monument Zones a region of the historic cities in the Kathmandu Valley of Nepal (UNESCO, 2006). The selected study area is declared the World's most seismic hazardous zone having a high *MMI scale* (*VII-XI*) with a 7.8 M_L to 8.1 M_L considered severe. (NSC, 2016).

Table 1: Data set *Parameters* assumed for analysis
Source: Authors

S. No.	Selected Parameters	Value	Precident
1.	Seismic Active Zone	V (VII-XI)	As per IS code 1893:2000
2.	Zone factors(Z)	1.00	As per NBC -105, clause pg.14
3.	Importance factors (I)	1.5	NBC -105 pg.15,19
4.	Roof types	Pagoda Style	

Pagoda roof Processing and Analysis
This section deals with the selection of Temples and their plan shapes (*Square and Rectangular*) **Error! Reference source not found.** as per the IS Code **(13828:1993, 1998)** procedures. The roof shapes are analysed for defining the parameters of temple pagoda roofs, the elementary assumptions, and the geometry of the selected Temples for the study are argued. This includes the assessment of MI and SR for Trapezoidal shape pagoda roof sections keeping in view the PAR performance assessment of the Pagoda roof sections.

Figure 5: Geometric Plan shapes adopted for analysis
Source: Authors

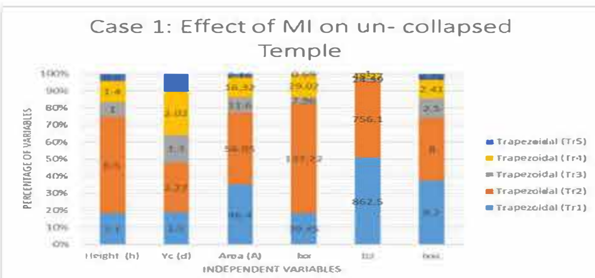
Geometric configurations and roof shape details
This section deals with the performance assessment of the heritage temples. The temples are assessed in Ms. Excel and Anaconda software for the parametric test. The parallel axis analysis for MI of the pagoda roof discussed in the above sections was conducted. To evaluate the MI on pagoda (trapezoidal) roof shapes. The moment of Inertia versus slenderness ratio at each analysis step was obtained. The graphical representation and plot curves are presented in each case. A comparison study is carried out to observe the difference in performance behavior of each selected temple.The analysis is carried out by conducting the parallel axis method for MI, a correlation for evaluating the relationship between the MI, SRR, and PAR. The material properties and the geometric parameters considered in the study are enumerated as suggested by IS 1893:2000.

Consider four twin-tiered temples with 3.15, 6.5, 6.8 & 19.5 mt story height. Thus the four temples have a slenderness ratio *SR* of roof and overall as mentioned through a detailed description of all the pagoda roofs is presented in Table 1.

Table 1: Data Evaluation and assessment
Source: Authors

Selected Case Study	Roof Height	Slenderness Ratio Roof (SRR)	Slenderness Ratio Overall (SRO)	Plan area ratio Roof (PARR)	Plan area ratio overall (PARO)	IxxO
T-1 Pashupati Nath	19.5m	0.97	1.97	1.0	171.60	1692.27
T-2 Changu Narayan	6.5	0.65	2.12	1.0	120.00	93.87
T-3 Bishnu Narayan	3.15	0.79	4.34	1.0	23.66	6.04
T-4 Char Narayan	6.8	1.05	2.59	1.0	95.91	52.71

RESULTS AND DISCUSSIONS



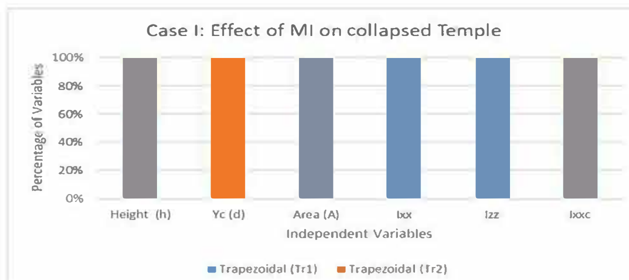


Figure 6: Comparison of Critical Seismic Variables **Source:** Authors.

The comparison of results obtained from the above analysis based on seismic sensitive parameters has been carried out tier-wise for each vertical and horizontal axis passing through the centroid and then for overall effective height, length and width. It has been observed that as the slenderness ratio increases, the structure becomes more acute. The effect of MI and seismic forces increases for the higher slenderness ratio and defines in what way shape configurations will behave during the seismic force. The values of Ixx and Iyy were studied for understanding the bending and twisting effect of MI. It is interesting to note that MI of a rectangular base (horizontal) is twice the MI of the triangle (vertical and trapezoidal) in this study. In case one it is observed that the performance of twin-tiered pagoda brick masonry roofs with larger height faced complete collapse when compared to lesser height temples.

It is observed that the high slenderness ratio increases the buckling effect of the roof sections reducing the stability during the seismic force event, irrespective of its wide plinth base. However, the effect of PAR is unity Table 1, which reveals that all selected structures are stable in plan configurations. This reveals that the base platform must be grounded but on the superstructure part and the heavy mass arrangement of trapezoidal roof section geometry along with its centroid (h, Yc) needs correction **Error! Reference source not found.**, Table 2. However, temples with a low plinth platform (horizontal) and small slenderness ratio (vertical) performed better against the seismic forces in case one **Error! Reference source not found.**. Additionally, the role of material quality and its deterioration along with poor maintenance, rotten wooden members, and loose connections have been observed during the site visits responsible for the cause of damage in both cases.

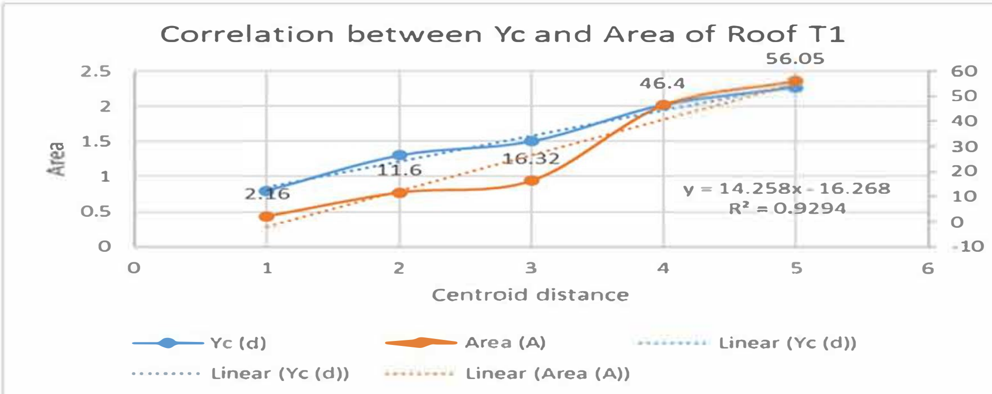
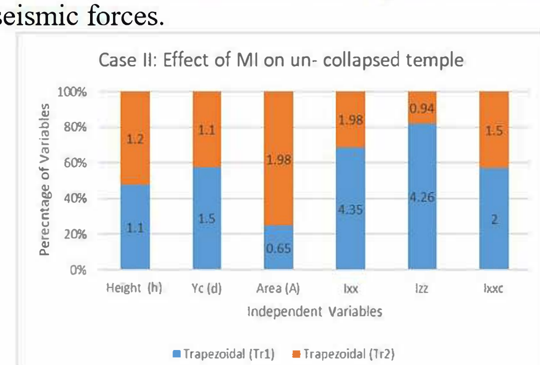


Figure 7: Relation between centroid distance and area of roof sections **Source:**Authors

Further, it is observed that the geometrical configuration in case two, the twin-tiered pagoda temple has an appropriate slenderness ratio assembly is least effective of seismic forces **Error! Reference source not found.**. The use wooden wedges rather than nails for the connections supplements flexibility to the temples' facilitating interlocking structural provisions. The twin-tiered temple partakes in a proportionate geometric roof configuration with a lighter and smaller rooftop of trapezoidal shape than the heavy bottom and larger roof of trapezoidal shape is causative to good seismic performance Figure 4. Thus the analysis demonstrates both positive and negative seismic performance revealing that is not just influenced by configuration alone Figure 5 but also by many other factors as mentioned above. It is also analyzed through correlation analysis on the above data that as the Plan Aspect Ratio (PAR) increases Table 2, the structure becomes more critical to seismic forces.



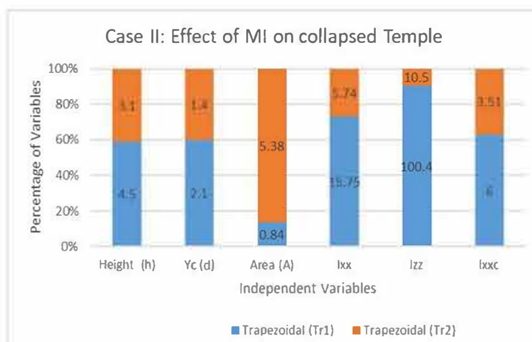


Figure 8: Effect of MI on the collapsed temple

Source: Authors

The result analysis reveals that the square configuration performs best during seismic activity as compared to rectangular or elongated plan configurations with appropriate width at the base.

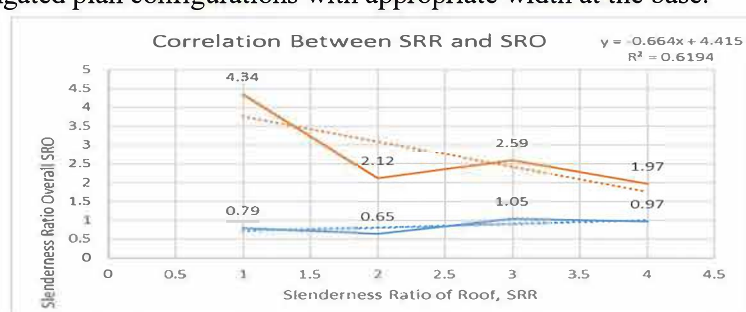


Figure 9: Relation between effective slenderness ratios

Source: Authors

In comparison as a whole, the present study demonstrates that the structures whose slenderness ratio of roof *SRR* viz. 0.65, and 0.79, Table 1 and slenderness ratio overall *SRO* viz. 2.12, and 4.34, **Error! Reference source not found.** did not perform seismically sound with respect to the ratio of effective height to effective width, whose Plan Aspect Ratio is 1.0 Table2. The study concludes that the temples with slenderness ratios less than 4 have reasonable seismic performance, as larger SR are more suspectable to bending and lower SR value adds rigidity. Above this, the worst effect of roof height and seismic forces needs structural retrofitting during the preservation stages. Hence, they should be discarded due to their unsatisfactory and weak performance when analyzed on the above-identified parameters which can be detrimental and cause devastating effects, if they are not furbished with appropriate geometrical configuration (plan- horizontal and elevation- vertical), along with earthquake-resistant materials, elements, and traditional techniques.

Table 2: Data analysis case I and II
Source: Authors

Case 1. Moment of Inertia (MI) and Slenderness Ratio of Un- Collapsed temple									
Temple	**Shape**	**Height (h)**	**Yc (d)**	**Area (A)**	**Ixx**	**Iyy**	**Izz**	**Ixxc**	**IxxO**
Pashupati Nath Temple	Trapezoidal (Tr1)	2.1	1.5	46.4	39.45	823.05	862.50	8.2	1692.27
	Trapezoidal (Tr2)	6.5	2.27	56.05	137.22	618.88	756.10	8	
	Trapezoidal (Tr3)	1.0	1.3	11.6	7.96	16.43	24.39	2.5	
	Trapezoidal (Tr4)	1.4	2.02	16.32	29.02	19.25	48.27	2.41	
	Trapezoidal (Tr5)	0.5	0.8	2.16	0.69	0.31	1.00	0.76	
Moment of Inertia (MI) and Slenderness Ratio of a Collapsed temple									
Temple	**Shape**	**Height (h)**	**Yc (d)**	**Area (A)**	**Ixx**	**Iyy**	**Izz**	**Ixxc**	**IxxO**
Changu Narayan Temple	Trapezoidal (Tr1)	3.5	0.98	15.6	6.76	70.85	77.61	5.0	93.87
	Trapezoidal (Tr2)	2.4	4.7	6.48	1.49	10.10	11.59	3.0	
Case 2. Moment of Inertia (MI) and Slenderness Ratio of Un- Collapsed temple									
Temple	**Shape**	**Height (h)**	**Yc (d)**	**Area (A)**	**Ixx**	**Iyy**	**Izz**	**Ixxc**	**IxxO**
Bishnu Narayan Temple	Trapezoidal (Tr1)	1.1	1.5	0.65	4.35	3.48	4.26	2.0	6.04
	Trapezoidal (Tr2)	1.2	1.1	1.98	1.98	0.77	0.94	1.5	
Moment of Inertia (MI) and Slenderness Ratio of a Collapsed temple									
Temples	**Shape**	**Height (h)**	**Yc (d)**	**Area (A)**	**Ixx**	**Iyy**	**Izz**	**Ixxc**	**IxxO**
Char Narayan Temple	Trapezoidal (Tr1)	4.5	2.1	0.84	15.75	5.09	100.40	6.0	52.71
	Trapezoidal (Tr2)	3.1	1.4	5.38	5.74	0.85	10.5	3.51	

Multiple R	0.906966742				
R Square	0.822588671				
Adjusted R Square	0.467766014				
Standard Error	0.368232913				
Observations	4				
ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.628704522	0.314352261	2.318309315	0.421202242
Residual	1	0.135595478	0.135595478		
Total	3	0.7643			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.428659399	0.495086511	0.865827264	0.545701035	-5.862011172
Ixxc	0.054319318	0.065383561	0.830779439	0.558676606	-0.776457595
srr	0.719624078	0.355956921	2.021660583	0.292433031	-3.803237444

CONCLUSION

The above analysis demonstrates that the performance of heritage temples during the earthquake differs from temple to temple. An up-front conclusion can be observed that the slenderness ratio *SR* affects the stability of low and medium twin-tiered pagoda roof brick masonry structures during the seismic event. Hence it can be considered an appropriate parameter to address *stability*. Based on literature reviews irregular geometric configuration undergoes compressive loads making a member deflect perpendicularly (vertically) generating torque on the particular axis Ixx or Iyy. This exposes that there is a need to focus on the axis with the maximum MI value.

Additionally, it is analyzed that brick masonry temples also called un-reinforced masonry (URM) with timber as roof elements (sal wood, case of KV, Nepal) performed better than brick masonry in the lime mortar or mud mortar.

Also, the role of material quality and its deterioration along with poor maintenance, rotten wooden members, and loose connections have been observed during the site visits responsible for the cause of damage in a few cases. If the deflections are larger, the structure collapses. The structure behaves like a box and the elements contribute to the resistance if the deflections are lower. Most importantly, it is also concluded that the structural shape of tiered Pagoda temples and dome shapes performed better than Shikhara-style temples with square and rectangular Plan shapes. The complexity of such analysis signposts the necessity of further study.

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THEME II

Environmental Experience Design and Wellbeing

MIDDLE-INCOME HOUSEHOLDS' FLOOR PLAN PATTERNS FOR DOMESTIC ENVIRONMENTAL EXPERIENCE DESIGN IN DHAKA, BANGLADESH

Sajal Chowdhury [1], **Masa Noguchi** [1] and **Hemanta Doloi** [2]

[1] ZEMCH EXD Lab, Faculty of Architecture, Building and Planning, The University of Melbourne, sajal.c@student.unimelb.edu.au; sajal_c@yahoo.com

[2] Smart Village Lab, Faculty of Architecture, Building and Planning, The University of Melbourne, masa.noguchi@unimelb.edu.au; hdoloi@unimelb.edu.au

ABSTRACT

Due to the difficulty of horizontal expansion leading to a shortage of land in Dhaka, Bangladesh, the need for vertical development of high-density urban housing is fast rising to solve the challenges. By building high-density, small-sized flats, the housing sector in Dhaka is now shifting its target demographic from higher and upper-middle-income groups to lower-middle and middle-income groups. Middle-class families typically reside in these cramped domestic settings where physical design aspects are the primary focus of today's local housing sectors, given the financial restrictions and relatively expensive rents. The domestic household patterns of middle-class residents must be properly researched so that the living experiences of the occupants can be exploited as a tool in the architectural design process. Through rigorous field observation, this study examined the floor plan pattern and circulation structure of 50 domestic units among the chosen middle-income households from Dhaka, Bangladesh. The results of this investigation point out that the floor designs and circulation patterns of homes directly impact the inhabitants' domestic living experiences or quality of living, which may encourage new directions for environmental experience design (EXD) research. The domestic living environment impacts residents' quality of life and mental well-being.

Keywords: Occupants' experience, Floor Plan Pattern, Circulation Structure, Middle Income, Bangladesh

IDENTIFICATION OF THE ISSUE

The city of Dhaka's housing market is dependent primarily on both state and private sources (BRAC, 2017). The private sector makes up most of the housing market, and around 70% of private real estate developers target upper-class and higher-income demographics with homes and flats larger than 1000 square feet (92 square meters) (BRAC, 2017). Only 7 to 10 percent of all housing is provided by the public sector, mainly for government employees who work in public service. Additionally, it is anticipated that by 2020 there will be a shortage of around 0.5 million housing units, as opposed to the 25000 units the private sector produces each year.

Therefore, it becomes increasingly difficult for middle-class families to purchase or afford good residential space (such as an apartment or home) in metropolitan areas like Dhaka, especially when single earners support families (BRAC, 2017). To solve the issue, the public and private housing industries are currently shifting their target demographic from higher and upper-middle class to lower-middle and middle-class groups by building high-density, small-sized flats or apartments (BRAC, 2017; Kamruzzaman & Ogura, 2007). Due to the difficulty of horizontal growth brought on by the lack of buildable land in urban areas, the demand for vertical expansion of high-density housing developments in Dhaka has expanded tremendously in recent years (RAJUK, 2015). This scenario is notable given the cost of housing. Lower-middle and middle-income families live in cramped or small domestic spaces in high-density apartments, where physical design factors (such as room numbers, sizes, configurations, and layout) are the primary consideration in the architectural design process. These tight accommodations are frequently congested and lacking in privacy and environmental amenities, which may lead to unfavorable living circumstances and, as a result, may harm residents' well-being directly or indirectly.

Low-income and middle-income families are particularly susceptible to mental health issues because they have limited options for changing or modifying their current domestic living conditions due to socioeconomic constraints (BRAC, 2017; Shams et al., 2014). The local architectural design considerations for the high-density urban dwelling may not adequately address the problem of residents' well-being in the local setting. Residents' quality of life standards is influenced by their home environment, which impacts their well-being. Therefore, the design of residential living spaces may affect how well people feel. As a result, in a very crowded domestic environment, the floor plan patterns of middle-income families for domestic environmental experience need to be researched and included in the architectural design and decision-making process, which may inspire new possibilities for EXD study (Chowdhury et al., 2020).

DEFINITION OF THE DOMESTIC SETTING

Historical evidence shows an interaction between numerous architectural elements and human social, physical, and psychological characteristics in residential spaces (Kopec, 2018; Ma et al., 2017). People can fulfill their social, emotional, and material requirements at home. It is a crucial setting where humans may maintain connections (Stokols, 1972). Mallett (2004) wrote an article titled "Understanding Home: a Critical Review of the Literature" that examined several literary works to explore the idea of home (Mallett, 2004). It demonstrated that "It is obvious that the term "home" serves as a clearinghouse for intricate, linked, and occasionally conflicting socio-cultural concepts about how people relate to locations, spaces, and objects as well as to one another, especially family. It may be a location to reside, a hub for interactions between places, objects, and people, or perhaps both. Wise (2000) addressed it in his paper "Home: Territory and Identity." "The development of space and the arrangement of markers (things) are aspects of home, a collection of milieus. Home is a region and an expression, yet, more than this. A person's home might be a collection of items, furniture, etc., that they transport from place to place (Wise, 2000). According to Pennartz (1986), there are five possible atmospheric experiences at home, e.g., interacting with each other; being available to one another; relaxing after finishing work; being able to accomplish what one wants, being busy, and lacking boredom. According to the literature, the personalization of a home's environment is intimately tied to its identity. However, a resident's house is integral to their social life and connections. These elements help make a house cozy and welcoming, fostering a sense of contentment and comfort (Colombo et al., 2015; Smith, 1994). Home, then, is an integrative schema that connects the experience of residence with the larger geographical, chronological, and socio-cultural framework in which it originates while also serving as a means of tying people to their physical surroundings. The place people call home serves as a center for their lives and a link to the social, physical, and historical worlds (Dovey, 1985). For the most part, a home is a domestic setting with a variety of goals, purposes, and significance, including attachment, identity, social rules, affordance, happiness, belongings, security, privacy, relationship, emotion, self-identity, ownership, aspirations, values, preferences, control, activities, and experiences (Moore, 2000)

STUDY CONTEXT

Dhaka's crowded neighborhoods with high densities of multi-story urban housing units have been selected as the study's first location. These housing units were created for families with moderate incomes, including lower-middle, middle-class, and upper-middle-class households. High-density, compact housing complexes are being constructed in various areas of Dhaka, especially for middle-class families struggling economically. These housing options were chosen because of the cramped quarters that the tenants must endure. Most of these multi-story, high-density apartment complexes have been built to address the housing needs or issues of today, as well as the land constraints in the Dhaka metropolitan region. Adverse living circumstances can result from crowded living, including lack of natural ventilation, dim lighting, increased stress from daily life, crowded living situations, access issues, isolation from the outdoors, and a lack of social interaction. These circumstances may negatively impact inhabitants who cannot shift their living arrangements. Depending on their various socio-demographic situations, the residents of this tiny home may also experience mental stress directly or indirectly.

RESEARCH STRATEGY AND DATA COLLECTION

To gather qualitative (contextual) data, observation and interviews with middle-class residents of certain high-density housing neighborhoods in Dhaka, Bangladesh, were done to learn about their experiences in their homes and their preferences and limitations. During the field study (May 2021 to October 2021), detailed observations of residential units (random sampling from each building/apartment) among the chosen housings were made to examine residents' domestic life experiences. However, during the field data collecting period, unpredictable local conditions or limits related to the COVID-19 epidemic altered and changed this study's placement of building instances in Dhaka and data gathering tactics. The University of Melbourne has granted this project ethical approval for use in human research (Ethics approval ID 20752). To accomplish the study's goals, the technique is to listen as the inhabitants (also known as respondents) describe their domestic life experiences in light of various indoor spaces, unique preferences, and limitations. The participant was initially briefed about the research subject and given the go-ahead before the field observation. Each participant is over the age of 18. The highest involvement rates are among women. The data collection did not impact participants. They were free to remain silent at any point throughout the interview or observation if they chose to withhold any information. Permission has been requested to contact them once again for study. Through meticulous field observation, this study looked at the floor plan layout and circulation structure of 50 residential units among middle-class households selected from Dhaka, Bangladesh.

USERS' DOMESTIC EXPERIENCES

The contextual analysis was applied to extract useful background information from occupants' narrative responses collected by semi-structured interviews from the field study about their domestic spaces. In the following section, different areas of domestic settings have been elaborated to extract space-related relationships and priority between analytical variables (**Fig. 1 and Fig. 2**). During data transcription, the meaning of the occupants' narratives remained unchanged.

Figure 1. Indoor space of middle-income occupants' domestic environment

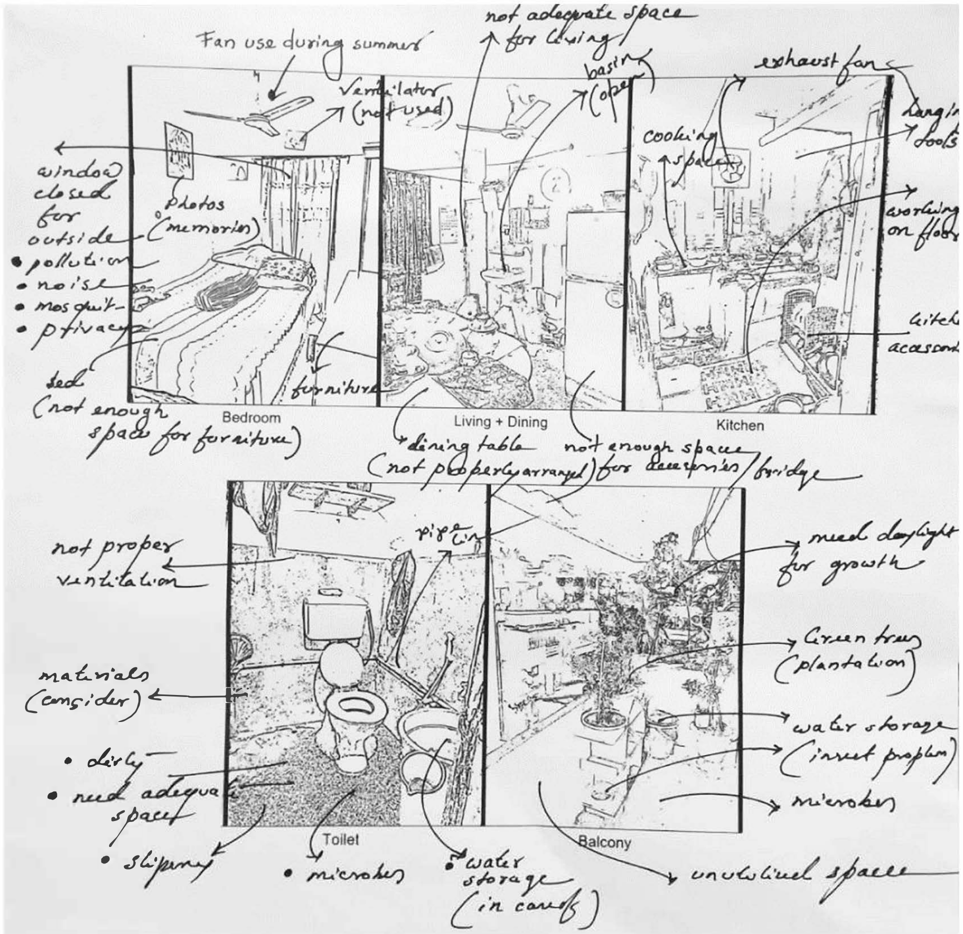

Figure 2. Field notes of a middle-income domestic space (*case study*)

Master Bedroom/ Child Bedroom/ Guest Bedroom

'... We spend most of our time in the bedroom, watching television and other things. As it is on the 3rd floor, lots of light and air comes through the windows, lots of cold air. There is better light in the guest room compared to the master bedroom. And the master bedroom is colder than the guest room if you want to compare. I will say that the comfortable feeling is medium. Now it feels a little hot in the bedroom, but it cools down very quickly when windy or rainy...' (R25)

'... The thing about the master bedroom is that our whole house is quite airy; we get good air since we don't have massive buildings around us. There is no building up to a certain level, so we get a lot of light. The problem is, the light is too much. It causes glare. The heat is also straightforward, as there is no sunshade provided in the building. And as there is a problem with the shading device, the sun comes directly from the east. The south façade also gets the sun, so there is a lot of heat on those sides for a long time during the day...' (R49)

'...The bedrooms are small. So, you can place only three pieces of furniture in each room; otherwise, the space feels congested. The biggest problem that we are facing that cannot be modified is the pillars. In this house, there are exposed columns inside the rooms. Due to this reason, many spaces have been wasted. Since I cannot remove them, I use them by putting some shelves there or turning those negative spaces into cupboards where I can put the things that cannot be kept on the floor. Sometimes when you walk into the rooms, some furniture gets into your way.' (R42)

Attached/ Common Toilet

'... The toilets are also at the backside, so they do not get much light. The ventilation of the toilets is such problematic that if we open the ventilator completely, it is visible from the large window of the building next to us. So, we cannot open it properly...' (R24)

'There is a problem with the attached toilet. Its size and placement of the fixtures are not proper or useful. For example, the mirror is placed in exact the opposite direction of the door. So, if someone forgets to take any necessary thing, he cannot ask anyone for it. Because as soon as the door is opened, the inside can be seen in the mirror.' (R35)

'...The opening seems a little small to me. It would be better if the ventilator were bigger and larger horizontally along with the space above. In the case of a ventilator, the pivoted window seems to me to be convenient, as it can be fully opened.' (R9)

Kitchen

'The kitchen is in the South, although this is not a suitable location for kitchen. Most of the time air comes from that side and the smell of spices goes inside the room. And if we cook anything with dried chili, the person inside the room immediately gets a cough. So, we do not open the kitchen window much during cooking.' (R1)

'In Bangladesh, many people cannot use a knife. Such as, our mother or a sister use 'boti' for cutting purpose which requires a usable space on the ground which they do not get here in this kitchen.' (R35)

'Here are some mental impacts especially because of the kitchen. Another problem I should mention. The gas pipe in our kitchen is connected from outside. The gas line came through the window. Rats almost always come through this pipe through that window. It will definitely have an effect on health, because rats are a very unhealthy animal, spreading many kinds of germs.' (R40)

Drawing/ Living Space

'In the living-dining space, there is no problem of privacy. The problem is that there is a building beside the balcony, so the air flow is blocked. There is no bright light in the living room, and a building next to the window. So, it is quite shady. And the wind doesn't flow to the living dining space. As it is a combined space that is not designed in a proper way, so it is not so aesthetic. If you change the furniture, it may feel a little better. My mother prefers wood. the sofas are old school. This is our parents' preference. I think it would be better in bamboo or cane in our living room. then it would not feel congested as it is now. Especially bamboo furniture looks very nice and cozy. The cushion set can brighter in color.' (R2)

'Here I like the living room because it is quite large, but it has the same problem as There is another flat on the other side of the void, due to which the light does not get inside. So, in this room the light is insufficient. there is no such problem with the living room rather than the light. and the inside of the house is not visible from the seating area.' (R3)

Dining Space

'It requires artificial light while eating in the dining room. The dining room is very large. Most of the area of the house is used in the dining room. So, it looks like a hall room. It is a big space. Previously I only had a fridge and a dining table in this space. But now I am working on it. I am arranging the prayer room with

a partition wall. I used the guest room as my prayer room before. Now that my dining room is large, I have renovated it combining with the prayer room.' (R7)

'Our dining room is a little darker because there is no connection from outside or any window. When we sit here in the dining space, we need to keep the fan and artificial lights on. The space is very small. If it was a little bigger, we could bring the table in the middle and sit around it. If we place the table in the middle, there will be trouble walking. Due to which the table is kept in one side. Our current dining room used to be a balcony before. That's why there was a window here. But now that it has been modified.' (R9)

Balcony

'We had lots of flowerpots with roses and some other plants. Also, when we moved to this new house, we bought some beautiful flower plants and decorated the balconies. It looked very beautiful with all the flowers blooming in the winter. But within one month, all those plants died. My mother informed this to the person who sold us those plans. He said that those plants might not getting the sunlight they need. To be honest, our balcony is too small and does not get enough sunlight. looking out at this place makes me sad. Even when I look outside from the balcony, all I can see is buildings.' (R5)

'There is another house on the other side of the balcony. That is why it cannot be used properly. Even though there is a balcony, we cannot always go there and work. The balcony is slightly on the inside, so proper light is not available there. If it could be extended a little further, a little more enhanced, it would be better because there would be lighter. Also, if plantation had been done, it could have been utilized better, which is not possible for us now. So, it remains as unused. The balcony in the living room is serving some purpose, but the balcony here cannot be utilized that way.' (R11)

Corridor

'There was no need for the corridor. Things like these are a little extra. It would be great without them. But these are not easy to change.' (R16)

'If I am upset or if I get bored or frustrated ever, I like to take a walk inside my house. Specifically, I walk in the corridor.' (R17)

The association between the wants and demands of space-related inhabitants based on field observation is contextualized below for perception (**Fig. 3**).

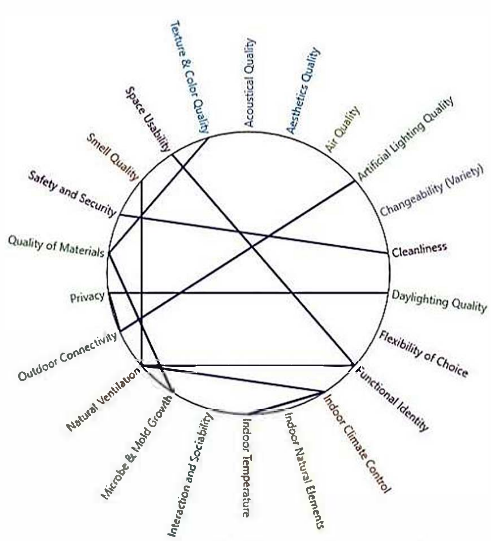

Figure 3. Space-related occupants' needs/demands correlation (*Contextual analysis*)

HOUSEHOLDS' FLOOR PLAN PATTERNS

In a domestic setting, there are mainly three different types of spatial areas: private spaces (such as bedrooms, study rooms, bathrooms and prayer rooms), semi-private spaces (such as living rooms, kitchens and dining rooms), and public spaces (such as foyers, drawing rooms, guest rooms and powder rooms), which are used by visitors who are not family members. These inner spatial zones might be connected to some outdoor expansions categorized as private, semi-private, or public spaces (like a garden, porch, or balcony). According to the field observations, a typical middle-class domestic setting is split into seven functional areas: primary bedroom, child/guest bedroom, corridor, kitchen, dining room and living room, in that order and an attached or shared bathroom. Most homes are rectangular. Two-bedroom houses are frequently available for middle-class families. A bathroom in the attic has a bedroom attached to it, while another bathroom is public. The drawing and dining rooms are combined because the house isn't massive. For their seclusion, the living and dining rooms frequently use drapes to separate them. The bedrooms in such places are often north-south oriented. In rare circumstances, though, exceptions do occur. On the east-west side are also the bedrooms. In that circumstance, the internal temperature tends to climb significantly during the day. According to studies, women often spend most of their day performing home tasks in the kitchen and dining area. Therefore, the residents of these areas must deal with several issues if there is improper ventilation and illumination. The patterns of home space utilized by middle-class households are seen in the examples below (**Fig. 4**).

Figure 4. Floor plans pattern of middle-income occupants' domestic setting
(From field observation)

HOUSEHOLDS' CIRCULATION PATTERNS

Field observations show that the apartments built for middle-class families have a main entry door. Due to the tiny size of the flat, middle-class families typically use the wide area immediately inside the front entrance for two purposes (**Fig. 5**). The front portion of the room is used as a living space, with a traditional sofa for seating against one side wall. In front of it is a small table. The television is mounted on the side of the sofa opposite the couch. A typical cabinet is kept there if there is space next to it. Decorative objects or a variety of books are usually included in cabinets, depending on the users' preferences. Most of the day is spent by housewives not doing anything in this area.

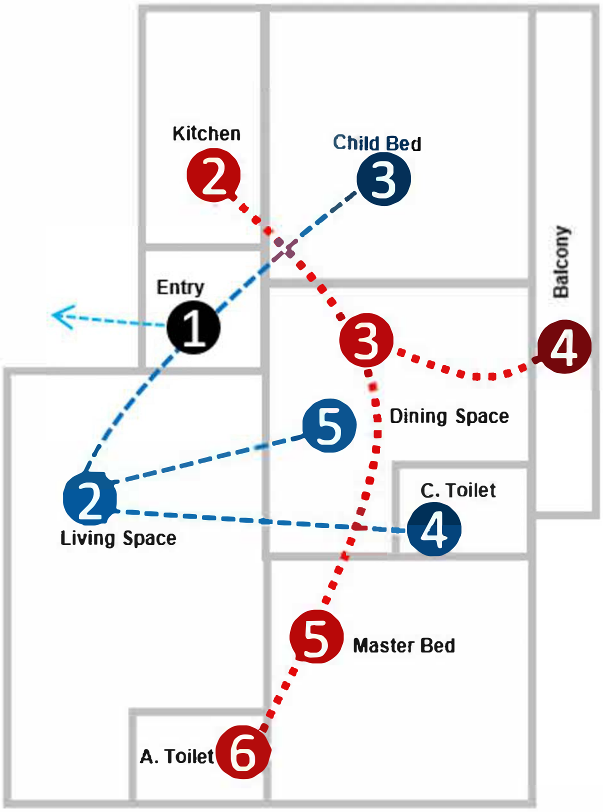

Figure 5. Typical circulation pathway of middle-income occupants' domestic setting
(From field observation)

Housewives often spend most of the day in the space around the kitchen and dining room area. They put a fridge next to the dining area if there is extra space. For privacy, thin screens are used to divide the eating area from the drawing room. Therefore, a little larger kitchen is frequently preferred by everyone. If the kitchen does not receive enough natural light and ventilation, residents will suffer from various adverse environmental problems. They don't spend much time in the bedroom unless required, particularly during the day. The location of the communal bathroom (common toilet) should be chosen to be between the public and private spaces. The most often used areas in middle-class families, from a field level, are the kitchen, dining room and balcony. Therefore, the connecting pathway (circulation) between these three places needs to be simple and effective. The master bedroom is often the concluding room. It is convenient if the second bedroom is usually connected to the living room. These residences have a balcony that is connected to the master bedroom. However, the amount of light available influences how useful using the balcony will be. A store is typically kept in the space above the kitchen or bathroom. For all rooms, functionality is a significant concern. The usability and functionality of the area are connected. Problems arise in a household when functionality is insufficient, especially for women. For instance, in Bangladesh, most women from middle-class families wash the dishes while seated on the kitchen floor. It isn't easy to carry out those tasks correctly if there is not enough space in the kitchen. Whether or not there are distinct areas in the kitchen for cutting, preparing and cooking food, there is an issue. In addition, harmful insects might enter via the window if the gas line is attached to the inside. Users like that all spaces have all accessories placed correctly and used promptly. They frequently use various cabinets or steel racks for that purpose. Their demands are addressed if the area is arranged and circulated correctly, is more prominent and adjacent to a balcony. **Fig. 6** illustrates patterns of domestic circulations for middle-class occupants of Dhaka, Bangladesh.

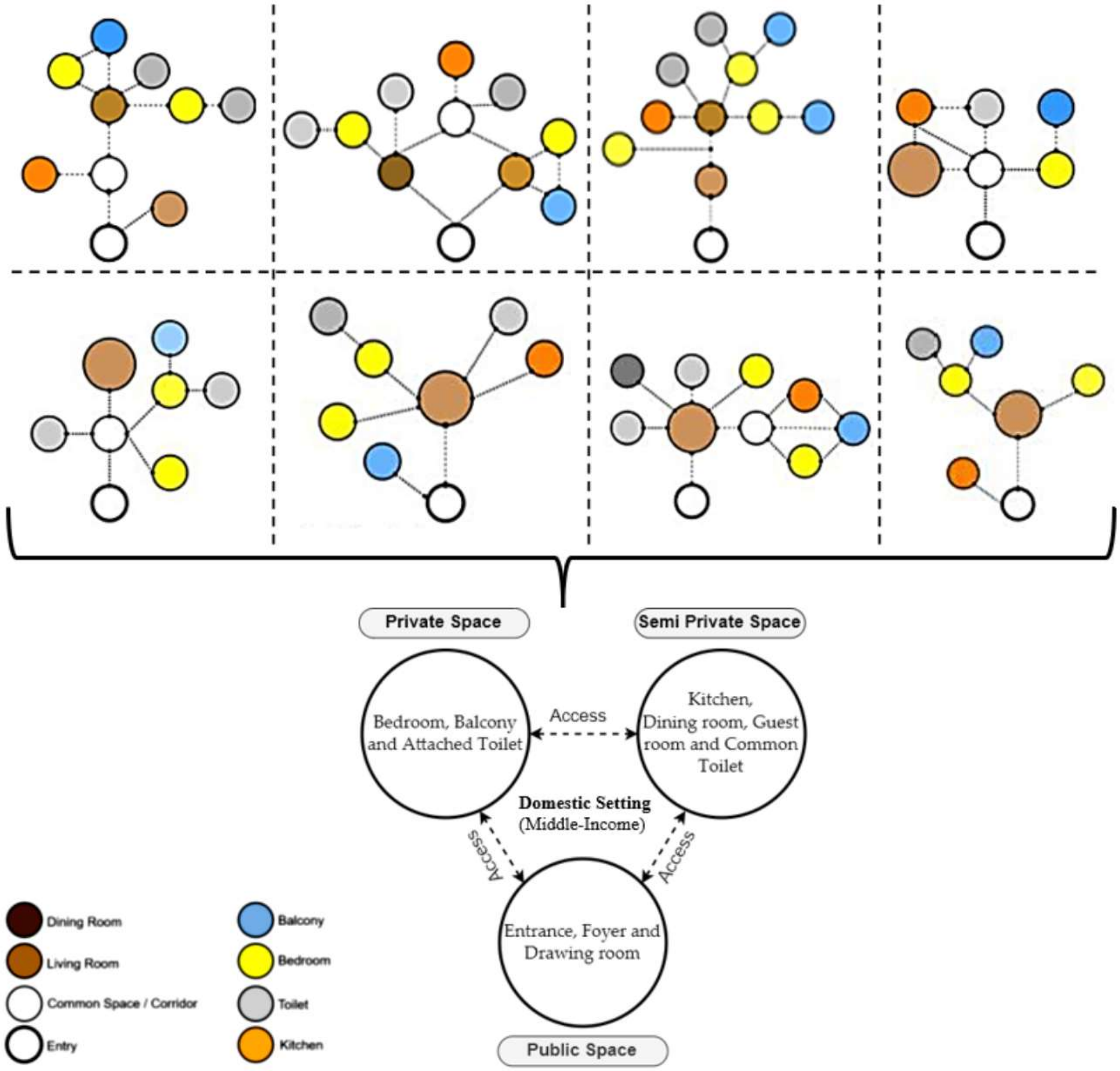

Figure 6. Circulation structure pattern of middle-income occupants' domestic setting
(From field observation)

DESIGN RECOMMENDATION

Fig. 7 shows an early design suggestion for a dwelling for middle-income residents based on the preferred floor layout and circulation pattern identified during the field observation.

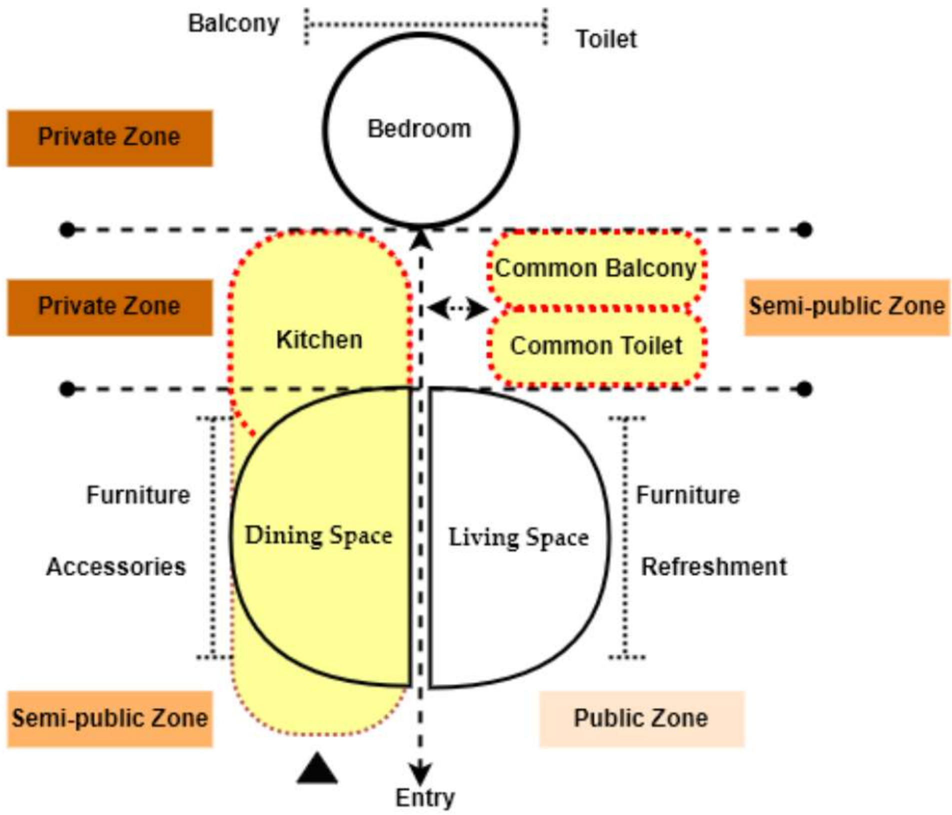

Figure 7. Design recommendations based on a floor plan and circulation pattern

FUTURE RESEARCH DIRECTION AND CONCLUSION

This study examined the local residential units' floor plans and circulation patterns among the middle-class families chosen from Dhaka, Bangladesh, using rigorous field observation. The findings of this analysis demonstrate that the floor plans and circulation patterns of dwellings directly affect the occupants' domestic living experiences or quality of life. Given their limited resources and relatively expensive rents, middle-class families frequently reside in these cramped living conditions which are the primary focus of today's local housing sectors. The domestic environment influences the quality of life and mental well-being of occupants. Therefore, domestic household patterns of middle-class residents (i.e., floor plans and circulation patterns) need to be adequately examined to explore domestic environmental experience design (dEXD) which may be utilized as a tool in the architectural design process.

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ADAPTIVE THERMAL COMFORT IN THE NATURALLY VENTILATED RESIDENTIAL BUILDINGS IN THE COMPOSITE CLIMATE OF INDIA

Aanchal Sharma[1], Ashok Kumar[2]

[1] Associate Professor, School of Architecture Planning and Design, DIT University, Dehradun, India, s.aanchal@gmail.com, Aanchal.s@dituniversity.edu.in
[2] Scientist 'H'/Outstanding Scientist (Energy Efficient Building Technologies); Head, Architecture & Planning Group, CSIR-CBRI Roorkee India, ashokkumar@cbri.res.in , kumarcbri@rediffmail.com

ABSTRACT

Adaptive thermal comfort has been a promising area of research ever since the Adaptive Comfort Standard founds its way into the ASHRAE Standard 55-2004. In developing countries like India which has a significant pool of naturally ventilated buildings and a wider thermal comfort ranges of the occupants, investigating the thermal comfort characteristics becomes a viable area of study. India, do not have a defined adaptive thermal comfort standard for the residential buildings. National Building Code (NBC) 2016 specifies the indoor comfort conditions for air-conditioned buildings expressed in terms of a Tropical Summer Index (TSI), regardless of their climatic location. IMAC proposed comfort limits based on study conducted in office buildings. The Energy Conservation Building Code (ECBC) – Residential, 2018 cross refers NBC and remains silent on specific comfort conditions in naturally ventilated or mixed mode buildings. Some efforts have been made by research and academic institutions, but the policy implements like ECBC and NBC may not hold good without integration of the real- time studies. The adaptive comfort that is widely accepted as an efficient tool for enhancing human comfort in conditioned buildings and to enhance energy saving holds the idea that occupants play an important role as an active agent in creating their thermal environment. However, in naturally ventilated buildings, it is useful to realistically evaluate extent to which buildings are able to provide comfort conditions to its occupants. Common adaptive actions include use of fan for air circulation, opening and closing of windows, change of clothing, change of work and body posture and other actions like change of thermostat setting in air conditioners. This study presents the results of a field study conducted in naturally ventilated residential buildings to assess the adaptive thermal behaviour of the occupants in representative composite climate of India during monsoon season.

INTRODUCTION

Adaptive thermal comfort has seen considerable growth since the first Adaptive Comfort Standard (ACS) for Naturally Ventilated (NV) buildings paved the way in the ASHRAE Standard 55 (ANSI ASHRAE Standard 55, 2004) (ANSI ASHRAE Standar 55, 2010) (ISO 7730, 2005) (ISSO 74, 2006) (EN 15251, 2007) (GB/T 50785, 2012) (NBC., 2016) (Manu, et al., 2016). Several thermal comfort studies are conducted in the Indian subcontinent (Nicol, 1974), (Sharma & Ali, 1986), (Sharma, et al., 2021) which propose a widespread comfort ranges suggesting further exploration to evaluate the comfort conditions provided by existing buildings. Field studies for residential buildings are taken up and this paper presents the results of a pilot study carried out during the monsoon season in the representative composite climate of India i.e. Dehradun. This study aims to: understand subjective thermal comfort i.e. sensation, preference and acceptance of temperature, humidity and air velocity; clothing and metabolic activity of the residential subjects; sweating sensation and productivity analysis; individual adaptive actions along with natural ventilation controls and electro-mechanical devices usage exploration.

METHODOLOGY

Thermal comfort investigation survey along with real-time monitoring of indoor and outdoor environmental data is deployed in five naturally ventilated residential buildings ensuring the Class- II protocols of the ASHRAE (Indraganti, et al., 2013), (Manu, et al., 2016). All the subjects were settled for at least 10 minutes prior survey and explained their importance and objectives. Each instrument was placed on a table at 1.1 m level from the floor and stabilized before recording readings. The survey is divided into various sections as follows:

- Socio-demographic details i.e. native place, age, gender, BMI, educational background, and highest education.
- Indoor/outdoor environmental parameters i.e. Ta, Tg, Tout, iVa, oVa, iRH, oRH
- Subjective thermal comfort i.e. TSV, HSV, ASV on 7-point ASHRAE Scale, TPV, HPV, APV on Nicole's 5-point scale and TAV, HAV, AAV and OAV on McIntyres 3-point scale
- Personal comfort variables ie. Clothing (clo), metabolism (met), sweat and productivity; and
- Other environmental control variables ie. adaptive actions, natural ventilation controls, and electro-mechanical devices

This field study was conducted in naturally ventilated residential buildings in Dehradun, India in August 2021. Dehradun (30.32° N, 78.03° E and +430 msl) lies in the foothills of the Himalayas in Uttarakhand State and experiences 'composite climatic' conditions as per NBC and 'Cwa' i.e. Humid Subtropical climate as per Köppen-Geiger climate classification. This type of climate faces extreme summers and extreme winters along with heavy rainfall during the monsoon season (NBC., 2016). This field study was conducted in the peak monsoon months which face discomfort due to high humidity and temperature. Real-time monitoring of indoor environment variables (Ta, Tg, iRH, iVa) was carried out using calibrated quick response handheld digital instruments Lutron WBGT-2010SD Meter and Testo 410i and the outdoor environment data (Tout, oRH, oVA) was noted using the mobile weather app AccuWeather. The data was recorded four times during the day i.e. morning, afternoon, evening and night for each respondent for seven monsoon days resulting in twenty-eight responses by a single participant in a day.

RESULTS AND DISCUSSIONS

A total of 113 response forms comprising 407 readings were collected over seven days in August 2021 (Table 1). 44% males and 56% females participated in the surveys, wherein 39% of the participants are native to the region in the composite climate. However, the non-native participants of the survey were well-acclimatized to the climate of the Dehradun region and were healthy Indian Nationals with an average BMI of 23.95. 72% of the participants are from $18 \leq 69$ age group and a few to below 18 and above 70 years. It is believed that education and income levels alter the thermal comfort expectations of an individual, therefore, the education background and highest education achieved are also sought in the conducted survey. The average activity & clothing of the subjects was recorded as 1.6 met and 0.5 clo respectively (Table 2). The mean value of overall acceptability of the thermal environment based on the demographics i.e. native, age, gender, highest education and educational background is depicted in Table 3. The acceptance of native respondents and non-native respondents is almost same, depicting no effect of the birthplace on the acceptance of the thermal environment if the subjects are acclimatized and have been living for more than a year. The participants from 70 and above age group and females were more accepting of the overall environment. The participants from humanities educational background and highest education up till secondary were slightly uncomfortable with the overall environment. The commerce educational background participants and the ones holding post-graduation degrees were most accepting of the overall environment.

Table 1 Demographic Data of the Respondents

Birth Place		Age Group		Gender		Highest Education		Educational Background	
Non Native	61 %	*≤18*	6 %	*Female*	56 %	*Secondary*	11 %	*Arts/Humanities*	17 %
Native	39 %	*18≤29*	39 %	*Male*	44 %	*Senior Secondary*	44 %	*Commerce*	22 %
		30≤39	-			*Graduation*	28 %	*Science*	61 %
		40≤49	33 %			*Post-Graduation*	11 %		
		50≤59	11 %			*Doctorate*	0 %		
		60≤69	-			*Diploma*	6 %		
		≥70	11 %						
No. of respondents =18, No. of data sets 113, Total valid data entries = 407									

Table 2 Personal Data of the Respondents

	BMI	Met	Clo	Sweat	Pro
Average	23.95	1.6	0.5	0.18	0.18
Min	19	0.7	0.36	0	-2
Max	32	4	0.72	2	2

Table 3 Mean Value of Overall Acceptance Vote based on Demographic Variables

		Mean	N	Std. Deviation	Maximum	Minimum	Range
Native	No	0.30	245	0.957	2	-2	4
	Yes	0.29	162	0.950	2	-2	4
	Total	0.30	407	0.953	2	-2	4
Age	18≤29	0.43	166	0.981	2	-2	4
	40≤49	0.20	127	0.979	2	-2	4
	50≤59	0.27	44	0.788	2	-1	3
	70 and above	0.14	49	0.935	2	-1	3
	below 18	0.19	21	0.873	2	-1	3
	Total	0.30	407	0.953	2	-2	4
Gender	Female	0.22	230	0.966	2	-2	4
	Male	0.40	177	0.930	2	-1	3
	Total	0.30	407	0.953	2	-2	4
HE	Diploma	0.25	16	0.775	2	-1	3
	Graduation	0.30	106	0.948	2	-2	4
	Post-Graduation	0.04	49	0.935	2	-2	4
	Secondary	-0.14	49	0.764	2	-1	3
	Senior Secondary	0.48	187	0.975	2	-2	4

	Total	0.30	407	0.953	2	-2	4
EB	Humanities	-0.08	61	0.900	2	-2	4
	Commerce	0.10	96	0.912	2	-2	4
	Science	0.46	250	0.945	2	-2	4
	Total	0.30	407	0.953	2	-2	4

Subjective thermal comfort evaluation

Correlation of thermal comfort variables with the subjective thermal comfort parameters (Table 4) reveals that TSV, TPV and TAV correlate significantly with Ta, Tg and Tout. iVa does not correlate significantly with the overall acceptance vote. The overall acceptance vote (Figure 2) revealed more subjects were comfortable with the indoor environment. Overall acceptance vote correlates significantly with the thermal, humidity and air velocity acceptance votes (Table 5), which validates the role of all environmental parameters ie. temperature, humidity and air velocity in the acceptance of the thermal environment.

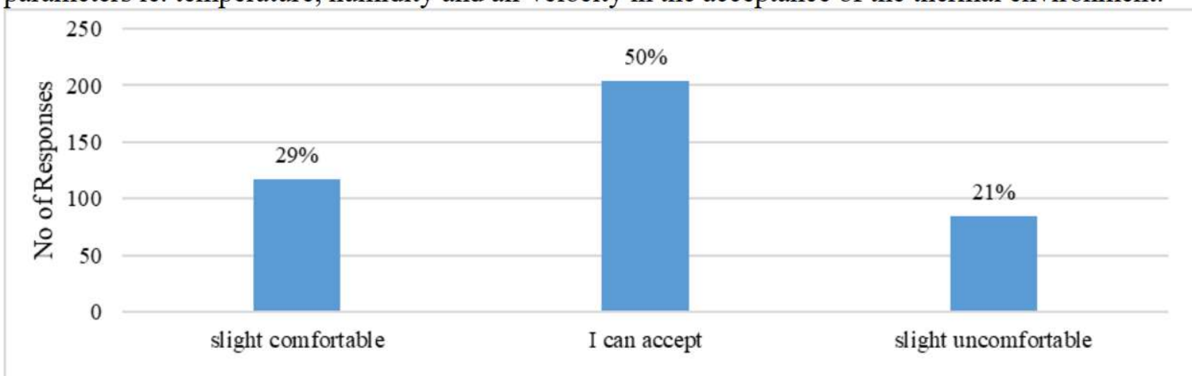

Figure 2 Overall Acceptance Vote

Table 4 Correlation of Thermal Comfort Variables with the Subjective Thermal Comfort Parameters

	TSV	**TPV**	**TAV**	**ASV**	**APV**	**AAV**	**HSV**	**HPV**	**HAV**	**OAV**
Ta	.283**	.336**	-.238**	-.101*	.117*	-.148**	-.211**	-.255**	-.269**	-.249**
Tg	.225**	.313**	-.120*	-0.074	0.092	-0.030	-.104*	-0.182	-.165**	-.173**
iRH	0.019	-.107*	0.037	-0.084	0.018	-0.025	-0.093	-0.081	-0.079	0.006
iVa	-.123*	-.105*	0.089	.148**	-0.068	.172**	0.015	0.071	0.037	0.040
Tout	.220**	.153**	-.109*	-0.033	-0.028	-0.075	0.085	.200*	-0.006	0.033
oRH	-.161**	-.102*	.269**	.108*	0.009	.239**	0.060	-0.129	.129**	-0.010
oVA	-0.064	0.013	.177**	0.059	-0.028	.269**	0.094	-0.007	.205**	.175**
Clo	0.065	0.009	-0.013	-0.014	0.083	0.050	-.136**	-.336**	-0.082	-.115*
Met	0.029	0.021	-.121*	-0.049	0.035	-0.094	-0.067	-0.060	-0.029	0.019

Table 5 Correlation of OAV with TAV, AAV and HAV

		TAV	**AAV**	**HAV**
OAV	Pearson Correlation	.504**	.564**	.536**
	Sig. (2-tailed)	0.001	0.001	0.001
	Sig. (2-tailed)	0.001	0.001	
**. Correlation is significant at the 0.01 level (2-tailed).				

Clothing adaptation

The mean clothing of the subjects is recorded as 0.49 clo where the favourite attire of the respondents was a T-shirt and Pyjamas (typical Indian attire) followed by T-shirt and shorts/short skirt and Cotton Salwar Kameez (typical Indian attire) (Figure 3). The clothing was found to correlate significantly with the HSV and HPV (Table 4) and contribute towards the Overall Acceptance of the thermal environment. The Pearson

Correlation of 'clo' is highest with Ta, therefore, clothing adaptation is significantly influenced by the prevailing indoor air temperature.

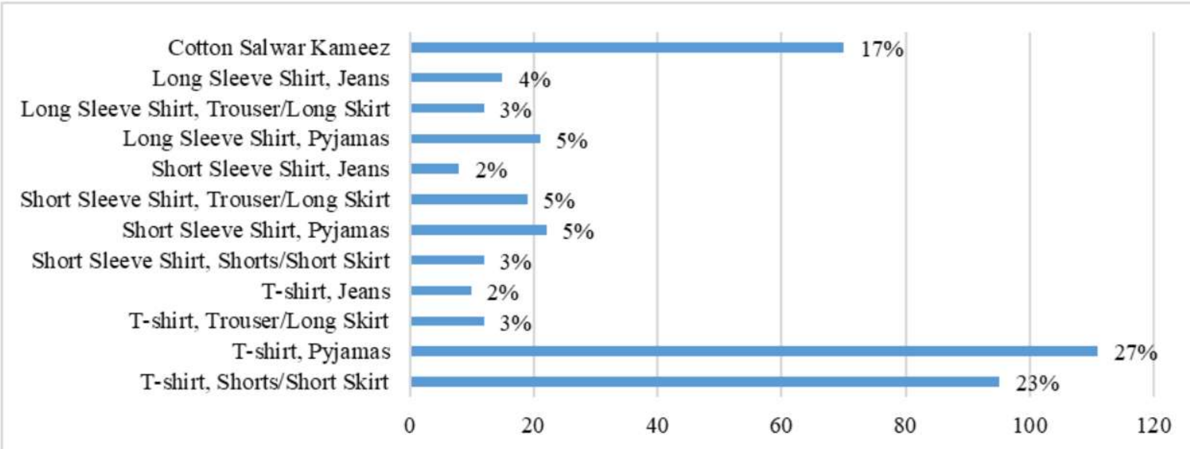

Figure 3 Clothing of the Participants

Metabolic Activity

The majority of the participants were observed sitting either doing passive or active work before the survey period along with working in a standing position (Figure 4). The average metabolic level of the subjects under consideration is 1.6 (Table 2) and it correlates significantly only with the TAV of the participants (Table 4).

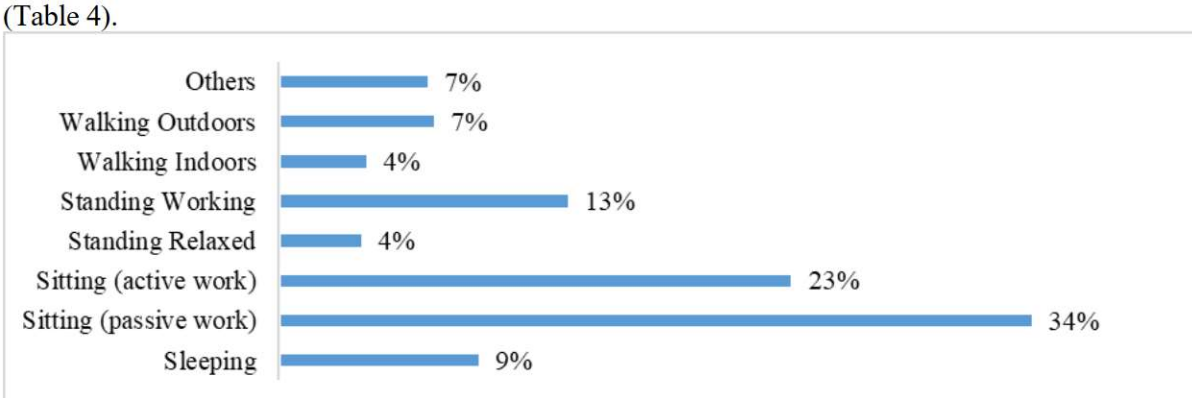

Figure 4 Metabolic Activity of the Participants

Sweat Analysis

The majority of the respondents reported no sweating and very few reported slight sweating and moderate sweating leading to a mean sweat sensation to 0.18 (Table 2) hinting at slight sweating amongst the subjects even though the majority of the respondents reported no sweating at all.

Productivity analysis

Very less participants reported productivity as much higher or lower during the survey period (Figure 6). 37% of the participants reported no change in productivity whereas 30% and 24% of participants reported slightly higher and slightly lower productivity, respectively. The mean of productivity is +0.18 hinting at optimum productivity levels and slightly towards the higher side.

Individuals adaptive action analysis

Adaptive actions of the participants are also studied wherein various actions were reported by the subjects at the time of the study (Figure 7). Resting, drinking hot/cold beverages, staying in/away from airy places and tying up their hair were the most favourite adaptive actions taken by the respondents. Rinsing hands and face, avoiding direct sunlight, removing/adding clothing layers, staying away from hot areas were the second-best adaptive actions. Since the temperature was not very low at the time of the study none of the participants chose staying in warm places and moving close to direct sunlight as an adaptive action. None of the respondents reported walking outdoors possibly because of heavy rains observed during the monsoon season in the studied area.

Natural ventilation control analysis

Of the total number of responses, about 74% responses were reported wherein subjects were using one of the natural ventilation controls i.e. windows, external doors, balcony doors, and blinds/ curtains. At many locations, all the natural ventilation controls were found to be in use at the time of the survey. 76% of times, windows were found open, 59% time external doors and 58 % times blind or curtains were open too. Very less balcony doors i.e. 27% were found open (Figure 8). Dust, followed by noise, mosquitoes and loss of privacy were the main reasons of the non-usage of a control (Figure 9). The only barrier in the usage of blinds and curtains was the loss of privacy. Few subjects also reported rain water coming inside as a barrier in usage of windows, external doors, balcony doors for natural ventilation.

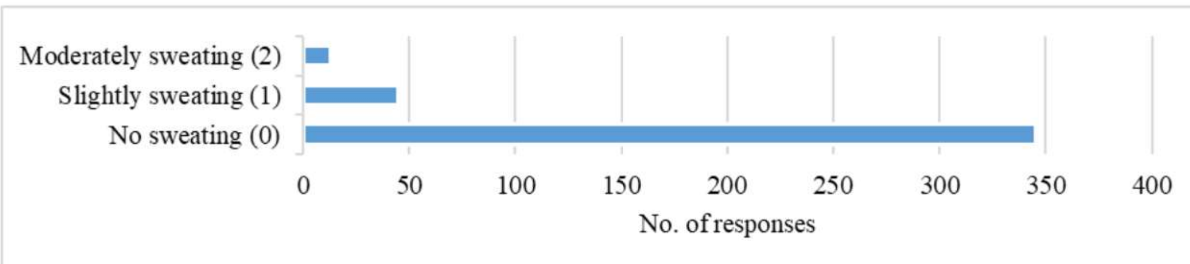

Figure 5 Sweating sensation of the participants

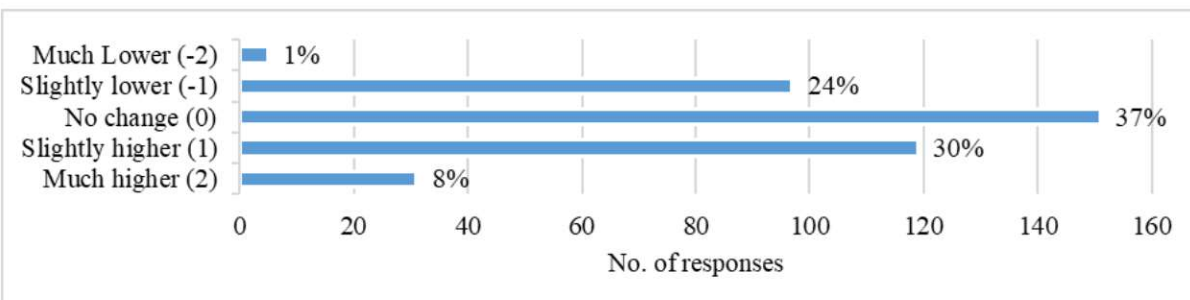

Figure 6 Productivity Data of the Respondents

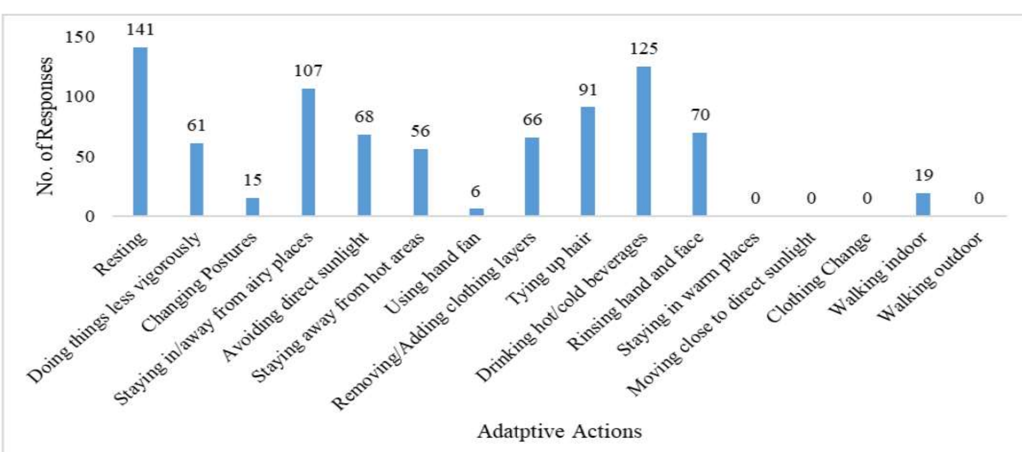

Figure 7 Adaptive Actions of the Users

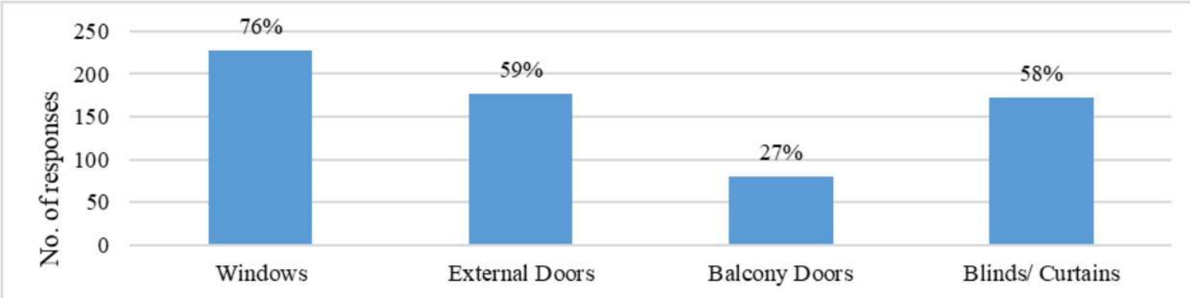

Figure 8 Natural Ventilation Controls Usage

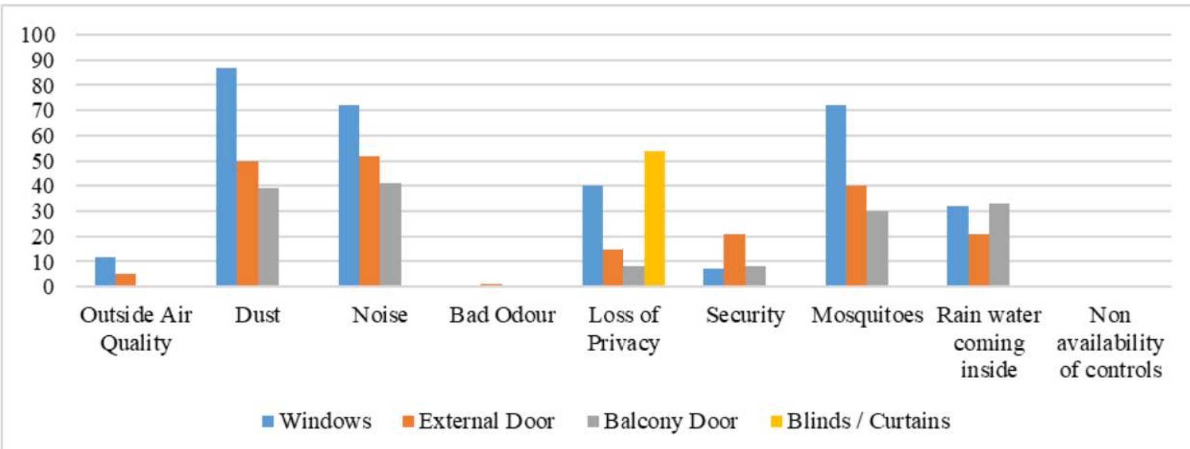

Figure 9 Barriers in the usage of Natural Ventilation Controls

Electro-mechanical devices usage analysis

About 90% of the all responses, subjects were reported using electro-mechanical devices such as ceiling fans, evaporative coolers, exhaust fans, room heating/cooling, lights. Of all the positive responses, 92% times ceiling fans were found in use followed by exhaust fans (15%), room cooling (10%) and only 2% evaporative coolers. 61% times lights were reported on at the time of the survey (Figure 10). None of the households reported using any Indoor Air Purification System. Ceiling fans are the favourite electro - mechanical devices over the evaporative coolers. A few subjects reported economic reason or non-availability of the controls as a barrier in using electro-mechanical devices. From Figure 8 and Figure 10, it is also observed that the total usage of various natural ventilation controls equals the overall usage of different electromechanical controls hinting equal affinity of the subjects towards both types of devices i.e. energy consuming and non-energy consuming.

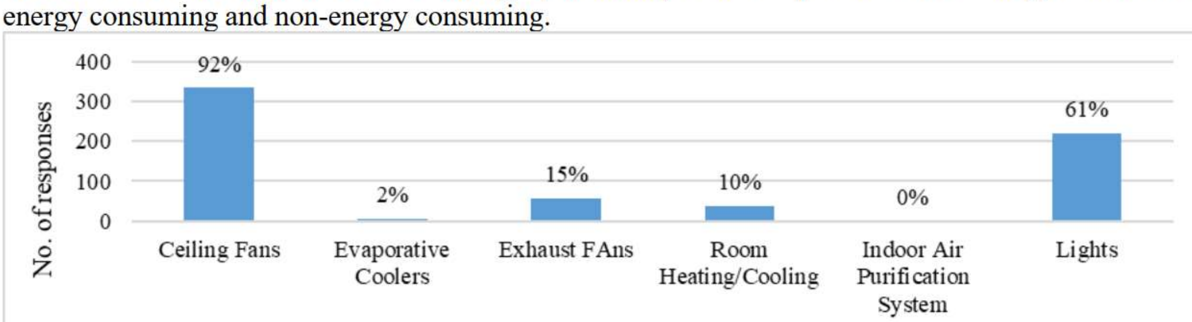

Figure 10 Electro Mechanical Devices Usage

CONCLUSIONS

The key findings of the field investigations in residential buildings of composite climatic region conducted using ASHRAE's class II protocols during the monsoon season are:

- Age, gender and education affects the thermal expectations of the users, however, the place of birth has a lesser role if users are acclimatised for more than a year.
- During the monsoon season in composite climate, most of the inhabitants are neutral for the thermal sensation but still prefer the cooler temperatures. The acceptance of the indoor temperature is also highly regarded.
- Though inhabitants vote neutral for the air velocity sensation, but they would still prefer a bit lower air velocity.
- Inhabitants were quite comfortable with the humidity levels.
- The overall acceptance vote correlates significantly with the thermal, humidity and air velocity acceptance votes.
- Clothing adaption of the study group depends on the prevalent outdoor environmental conditions and inhabitants exhibit a wide range of clothing ensembles.
- Metabolic activities of the users somewhat affect the thermal acceptability of the users but not the overall acceptability of the indoor environment.
- Sweating perception affects the thermal comfort subjective variables and hence the productivity of the respondents.
- Participants reveal a usage of varied adaptive actions wherein resting and drinking hot/cold beverages is a favourite action.
- Natural ventilation controls are being used as an advantage by the respondents in this particular study despite a lot or barrier being faced by them.
- Fans are the most commonly used electro-mechanical devices and evaporative coolers are least preferred.

This study hints that well acclimatised and adapted inhabitants can endure the thermal environment within acceptable limits in the monsoon season. However, further investigation and field studies from summer and winter seasons from same location are required to bring more insights into the thermal adaptation behaviour of the inhabitants of the residential units of this region.

FUNDING

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STUDY ON BEHAVIOURAL ADAPTATION FOR THERMAL COMFORT OF JAPANESE MIXED-MODE OFFICE BUILDINGS

Supriya Khadka[1], H.B. Rijal[2], Katsunori Amano[3], Teruyuki Saito[4], Hikaru Imagawa[5], Tomoko Uno[6], Kahori Genjo[7], Hiroshi Takata[8], Kazuyo Tsuzuki[9], Takashi Nakaya[10], Daisaku Nishina[11], Kenichi Hasegawa[12], Taro Mori[13]

[1] PhD Student, Tokyo City University, Japan, supriyakhadka1996@gmail.com
[2] Prof., Tokyo City University, Japan, rijal@tcu.ac.jp
[3] Master Student, Nagoya University, Japan, amano.katsunori.x1@s.mail.nagoya-u.ac.jp
[4] Assoc. Prof., Nagoya University, Japan, saito@nuac.nagoya-u.ac.jp
[5] Assist. Prof., Osaka Institute of Technology, Japan, hikaru.imagawa@oit.ac.jp
[6] Assoc. Prof., Mukogawa Women's University, Japan, uno_tomo@mukogawa-u.ac.jp
[7] Prof., Nagasaki University, Japan, genjo@nagasaki-u.ac.jp
[8] Assoc. Prof., Hiroshima University, Japan, takatah@hiroshima-u.ac.jp
[9] Prof., Kansai University, Japan, ktsuzuki@kansai-u.ac.jp
[10] Assist. Prof., Shinshu University, Japan, t-nakaya@shinshu-u.ac.jp
[11] Prof., Hiroshima University, Japan, nishina@hiroshima-u.ac.jp
[12] Prof., Akita Prefectural University, Japan, haseken@akita-pu.ac.jp
[13] Prof., Hokkaido University, Japan, mori.taro@eng.hokudai.ac.jp

ABSTRACT

This study focuses on the behavioural aspects of the occupants in Japanese office buildings. Occupants behavioural activities such as heating or cooling use, clothing adjustments are the essential contributors for the adaptive thermal comfort. Therefore, understanding the behavioural aspects of the office workers can lead to have the guidelines to explain the mechanism of the adaptive model. The main aim of this study is to identify the differences in behavioural adaptation of the occupants in Japanese office buildings. Environmental parameters such as air temperature, relative humidity, and so on were measured in five mixed-mode office buildings which is located in Aichi prefecture. Occupants behavioural survey were collected in these office buildings. The results suggest that the proportion of heating and cooling use is related to the outdoor air temperature. The proportion of 'clothing adjustment' is different for the different modes and are correlated to the outdoor air temperature. The findings of the occupant behaviours of these selected buildings will be fruitful in designing of the buildings with maximum thermal comfort in the future.

INTRODUCTION

Occupants tends to spend majority of their time indoor (Shaikh et al. 2014). With COVID-19, situations became so critical that people were bound to stay home, work/study from home. According to Humphreys and Nicol (1998) adaptation is physiological, behavioural, and psychological. Of these three types of adaptations, behavioural adjustments have the greatest opportunity for the occupants to play an active role in maintaining their own comfort (Nicol and Humphreys 1973; Humphreys 1994). When a person is uncomfortable, they adjust their clothing, posture or activity to make themselves comfortable (Nicol and Humphreys 1973). Adaptive principle states "if change occurs so as to produce discomfort, occupants react in ways which tend to restore their comfort" (Humphreys and Nicol 1998). It means that the occupant always tries to regain their level of comfort when there is any unpleasant change occurs. Rather than being unilaterally exposed to the thermal environment, humans adapt to the environment by working on their own to reduce discomfort. In fact, humans perform various thermal adjustments such as ventilation by opening windows, use of electric fans, clothes and increase or decrease of activities according to the indoor environment, and allow natural environment without relying on heating and cooling up to a certain thermal environment. Such human adaptability, so-called environmental adjustment behaviour, may not only reduce air-conditioning use, but can contribute in the reduction of COVID-19 infection from the aspect of ventilation, and expectations are rising. The range of adaptive thermal environment is said to be wider than in laboratory experiments where the degree of freedom is limited. It has been reported that in hot and cold environments, adaptation to the environment reduces the difference between the actual room temperature and the comfortable temperature, and accepts a wide range of temperature. About 80 % of the human spend their life indoor (Zhao et al. 2004). Due to this reason it is important that the temperature inside these office buildings is thermally comfortable. Despite the fact, workers always use different ways 'adaptive opportunities' to control their indoor thermal environment and ensure their thermal comfort (Rijal et al. 2019; Rijal et al. 2022a).

The Heating, Ventilation, and Air Conditioning (HVAC) system is well equipped in Japanese office buildings. The indoor temperature is adjusted using the air-conditioning systems to help in maintaining the thermal comfort. However, only adjustment of the indoor temperature cannot determine whether the occupants are thermally comfortable with the existing environment because any discomfort experienced by the occupants will induce to the behavioural changes in order to be comfortable (Rijal et al. 2022a). It is necessary to have a research on the behavioural adaptation in the Japanese office buildings. Thermal comfort and behavioural aspects of an occupants are closely related to each other. The previous studies on the adaptive behaviour in the office buildings such as Mustapa et al. (2016), Takasu et al. (2017), Thapa et al. (2018). Rijal et al. (2022a) have stated that adaptive behaviour (window opening, clothing insulation, proportion of heating and cooling use, etc.) are the main elements to affect thermal comfort of the occupants. This study aims to identify the differences in behavioural adaptation of the occupant in Japanese office buildings as the mechanisms of adaptive model and to investigate the relationship between the heating, cooling and clothing adaptation of the occupants to the outdoor air temperature.

METHODOLOGY

Investigated buildings

The field survey data is collected in five office buildings located in Aichi prefecture from July 2021 to March 2022 (Rijal et al. 2022b). The chosen office buildings were of change-over mixed-mode type. The change-over mixed-mode buildings have openable windows and doors, or can be air-conditioning mode depending on the seasons or time of the day (CBE 2021). Detailed information of the investigated office buildings can be found in Khadka et al. (2022b).

Thermal measurement survey

The study case focus on environmental factors, the occupant's characteristics, thermal measurement and the subjective thermal comfort surveys. With a digital equipment set up at 1.1 meters above the floor level and away from direct sunlight, we measured indoor environmental factors such air temperature, globe temperature, and relative humidity at ten-minute intervals. Table 1 shows the instrument details with its accuracy. The sensors accuracy was carefully checked before used in the field survey. The field survey method was as same as the survey conducted in Kanto region (Khadka et al. 2022a). Outdoor air temperature and relative humidity were obtained from the nearest meteorological station of the Aichi prefecture. The occupants were given questionnaire sheets with the brief explanation of the purpose of the survey. Additionally, an office building carried out the survey using excel spreadsheet on PC. Respondents conducted longitudinal survey using the digital instruments that has been installed at the office building for that periods of time. The use of heating and cooling were recorded as binary form (heating/cooling on = 1, and heating/cooling off = 0). Figure 1 shows survey questionnaire of the clothing insulation. We have collected 7120 votes from five mixed-mode office buildings.

Table 1. Details of the instruments used in the survey.

Parameter measured	Instruments name	Range	Accuracy
Air temperature	TR-76Ui TR-74Ui	0 to 55 °C	±0.5 °C
Relative humidity		10% to 95% RH	±5%RH

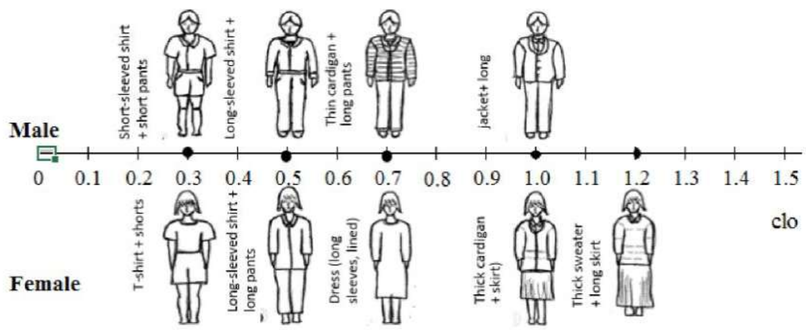


Figure 1. Questionnaire of clothing insulation survey

Estimating the occupant behaviour

To predict the occupant behaviours, we used logistic regression analysis. Nicol and Humphreys (2004) used logistic analysis and predicted the occupants behaviour in naturally ventilated buildings. In this study the relationship between the probability of heating or cooling use (P) and the outdoor air temperature are shown in the following equation:

$$logit\ (P) = log\left\{\frac{P}{1-P}\right\} = b\,T_{out} + c \qquad (1)$$

$$P = exp^{(b\,T_{out} + c)} / \{1 + exp^{(b\,T_{out} + c)}\} \qquad (2)$$

where exp (exponential function) is the base of the natural logarithm, b is the regression coefficient, T_{out} is the outdoor air temperature (°C) and c is the constant in the regression equation.

RESULTS AND DISCUSSION

Outdoor and indoor air temperature

During the voting, the mean outdoor air temperature was 16.3 °C, 9.2 °C, 27.9 °C for free running mode (FR), heating mode (HT), cooling mode (CL) respectively. While the mean indoor air temperature was 23.6 °C, 24.6 °C, 24.8 °C for FR, HT, CL modes respectively as shown in Figure 2. In 2005, Japanese government recommended indoor temperature of 20 °C in winter and 28 °C in summer. In this case, mean indoor temperatures during heating mode and cooling mode were different than the recommended values. This result is similar to the previous study in the Kanto region (Rijal et al. 2019).

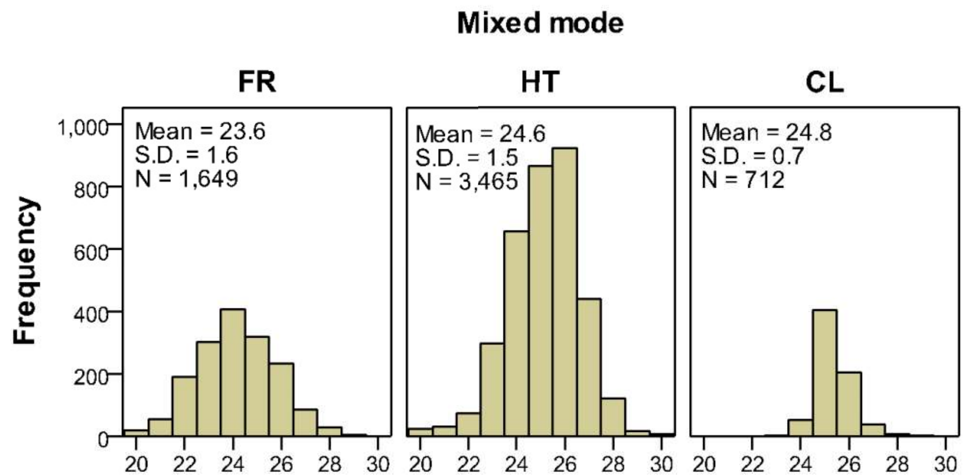


Figure 2. Distribution of indoor air temperature

The relationship between the indoor and outdoor air temperature for each mode is shown in Figure 3. Results obtained from the linear regression analysis are shown in Table 2. As chosen five office buildings are change-over mixed-mode type, the occupants use heating and cooling most of the time, and thus the regression slope is quite low in HT as well as in CL modes.

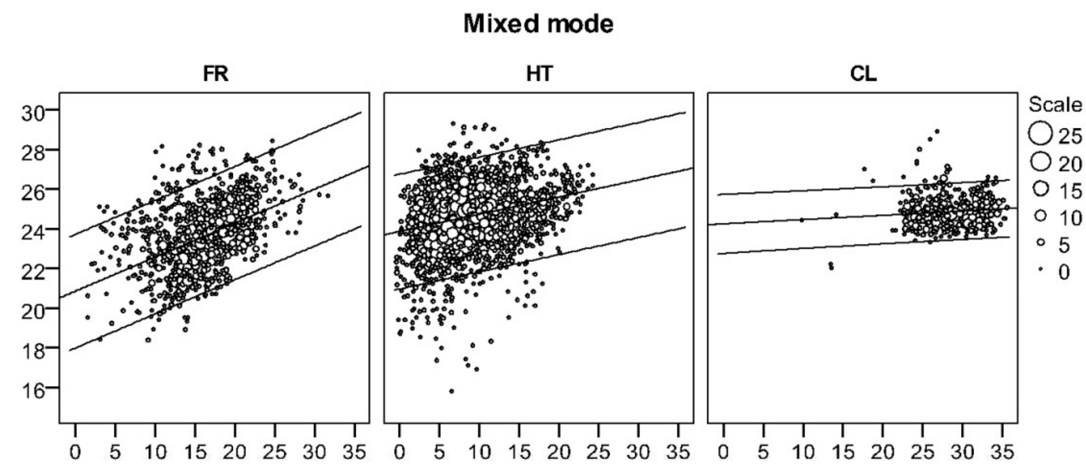


Figure 3. Relation between indoor and outdoor air temperature

Table 2: Regression equations of indoor and outdoor air temperature

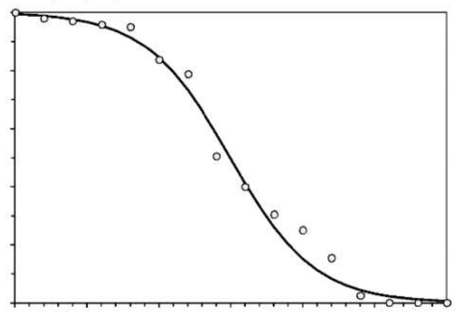
Mode	Equations	N	R^2	S.E.	p
FR	$T_i = 0.172\ T_{out} + 20.8$	1642	0.21	0.008	<0.001
HT	$T_i = 0.087\ T_{out} + 23.8$	3464	0.07	0.005	<0.001
CL	$T_i = 0.022\ T_{out} + 24.2$	712	0.01	0.007	0.004
All	$T_i = 0.027\ T_{out} + 24.0$	5818	0.02	0.003	<0.001

T_i: Indoor air temperature (°C), N: Number of the sample, R^2: Coefficient of determination, S.E.: Standard error of the regression coefficient and p: Significant level of regression coefficient.

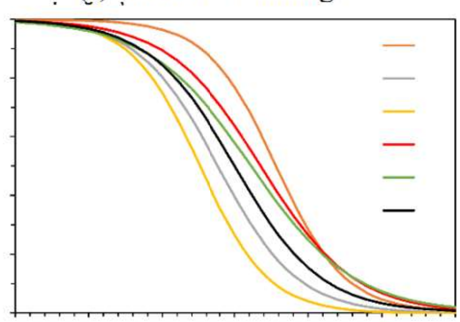
Occupant behaviour

Heating use

In this section, we analysed the heating use in the mixed mode office buildings. Equations obtained by logistic regression analysis are shown in Table 3. These equations are drawn in the Figure 4. We have also plotted the actual heating use which is binned at 2 °C interval of outdoor air temperature in Figure 4 (a). The results indicated that the logistic model is well fitted to the actual heating use data. The occupant starts using the heating when the outdoor air temperature starts dropping from 17 °C as found in previous studies of Kanto area (Rijal et al. 2022a). Trend of proportion of heating use for each building is similar to overall trend (Figure 4 (b)). Equations obtained from logistic regression analysis can be used to estimate and control the heating use in similar office buildings.



(a) All office buildings



(b) All and each office buildings

Figure 4. Proportion of heating use in relation to outdoor air temperature

Table 3: Regression equation for each and all buildings for heating use

Building code	Equation	N	R^{2*}	S.E.	p
N1	logit(P)= -0.427 T_{out} +7.6	2079	0.624	0.0194	<0.001
N2	logit(P)= -0.369 T_{out} +5.1	1866	0.454	0.017	<0.001
N4	logit(P)= -0.429 T_{out} +5.4	1463	0.432	0.022	<0.001
N5	logit(P)= -0.316 T_{out} +5.3	1325	0.284	0.019	<0.001

N7	logit(P)= -0.286 T_{out} +4.6	375	0.104	0.051	<0.001
All	logit(P)= -0.341 T_{out} +5.1	7108	0.470	0.008	<0.001

P: proportion of heating use, N: Number of the sample, R^{2*}: Cox and Snell R^2, S.E.: Standard error of the regression coefficient and p: Significant level of regression coefficient.

Cooling use

Like heating use in the buildings, we also predicted the cooling use in the offices. As most of the office buildings survey started from October, and only N1 office building had sufficient cooling use data for regression analysis. The following regression equation is obtained between the cooling use and outdoor air temperature for the N1 office building.

$$\text{logit(P)}= 0.727\ T_{out} -16.5\ (N=2078,\ R^2{*}= 0.67,\ S.E.= 0.044,\ p<0.001) \tag{3}$$

P: proportion of cooling use, N: Number of the sample, R^2*: Cox and Snell R^2, S.E.: Standard error of the regression coefficient and p: Significant level of regression coefficient.

The equation is drawn in the Figure 5. We have binned the actual cooling use at 1 °C interval of outdoor air temperature and plotted on the Figure 5. The result indicated that the logistic regression is well fitted to the actual cooling use data. The result showed that the proportion of cooling use increases with increase in outdoor air temperature. Rijal et al. (2022a) obtained similar results to this study.

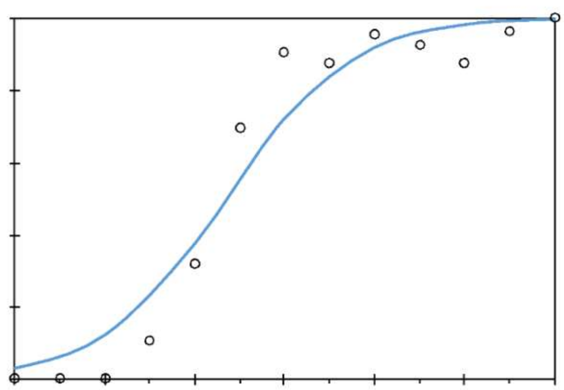


Figure 5. Proportion of cooling use in relation to outdoor air temperature in N1 office building

Clothing adjustment

The mean clothing insulation is 0.74 clo, 0.83 clo, 0.56 clo for FR, HT, CL modes, respectively indicating that the occupant chooses the clothing according to the modes. Figure 6 shows the error bar (mean ± 2 S.E.) of the clothing insulation by mode of the five office buildings.

A regression analysis of the clothing insulation and outdoor air temperature was carried out to estimate the clothing insulation. Figure 7 and Table 4 show the relation between the clothing insulation and the outdoor air temperature for raw and binned data. The data are binned at 1 °C interval of outdoor air temperature by applying weighted linear regression as done by Gautam et al. (2018), Rijal et al. (2019b), Rijal et al. (2022a) and Khadka et al. (2022b). We have obtained the equations as shown in Table 4 from regression analysis. There is a significant relationship between clothing insulation and outdoor air temperature, which is demonstrated by the binned data has significantly greater coefficient of determination than the raw data.

However, the slope of raw data and binned data are same. The regression coefficient is negative which clarify that the clothing insulation decreases when outdoor air temperature rises.

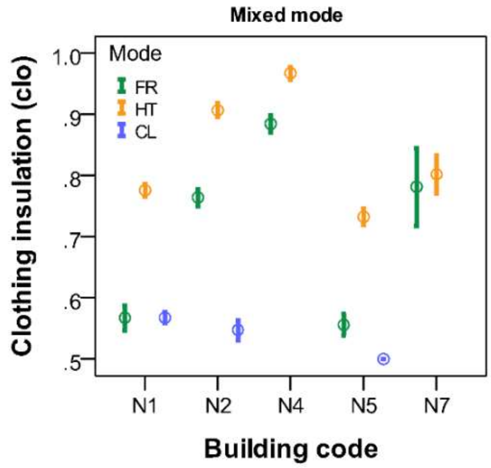
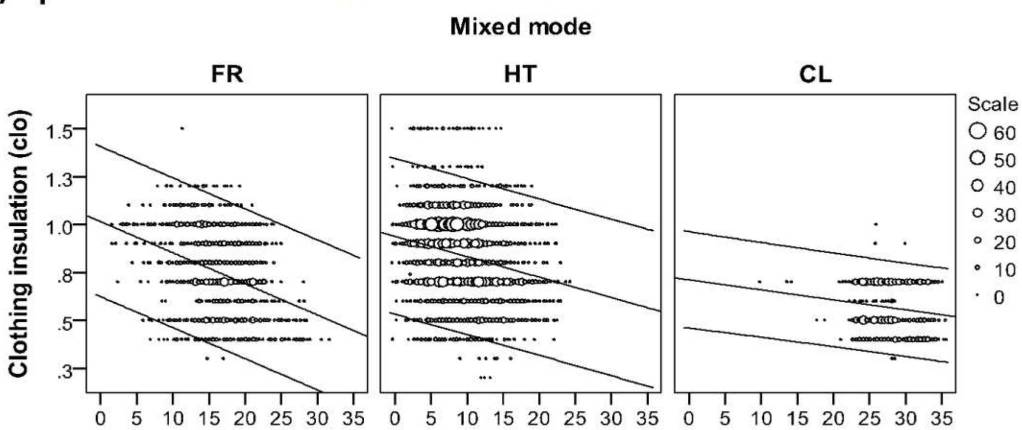
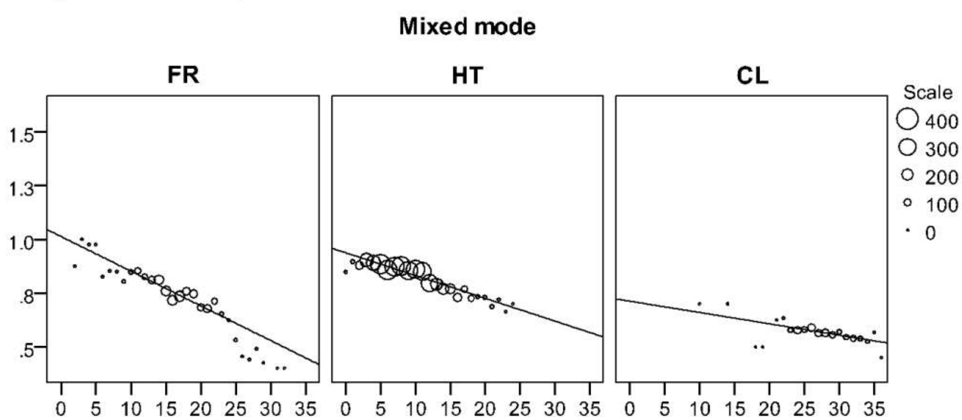


Figure 6. Clothing insulation according to office buildings with 95 % confidence interval (mean ± 2 S.E.)



(a)



(b)

Figure 7. Relationship between clothing insulation and outdoor air temperature (a) raw data (95% of the data points are within the band) and (b) binned data.

Table 4: Regression equation of clothing insulation and outdoor air temperature

Mode	Data	Equation	N	R^2	S.E.	p
FR	Raw	Icl= -0.016 Tout + 1.014	1752	0.12	0.001	<0.001
	Binned*	Icl= -0.016 Tout + 1.013	1752	0.83	0.001	<0.001
HT	Raw	Icl= -0.011 Tout + 0.937	4362	0.05	0.001	<0.001
	Binned*	Icl= -0.011 Tout + 0.938	4362	0.86	0.001	<0.001
CL	Raw	Icl= -0.005 Tout + 0.710	990	0.02	0.001	<0.001
	Binned*	Icl= -0.005 Tout + 0.712	990	0.70	0.001	<0.001

I_{cl} : Clothing insulation (clo), N: Number of the sample, R^2: Coefficient of determination, S.E.: Standard error of the regression coefficient p: Significant level of regression coefficient and *: Weighted regression analysis.

CONCLUSIONS

Having analysed the adaptive behaviours of the occupant in five mixed mode buildings in Aichi prefecture, the following conclusions are obtained.

The mean indoor air temperature during the survey was found 23.6 °C, 24.6 °C, 24.8 °C for FR, HT, CL modes respectively. The results showed that the heating and cooling temperature is different than recommended values: 20 °C for heating and 28 °C for cooling.

Occupants conducted the behavioural adaptation such as heating use, cooling use and clothing adjustments. The results show that these behaviours are related to outdoor air temperature. 80 % of occupants use the heating or cooling, when the outdoor air temperature is 11.0 °C or 24.5 °C respectively.

ACKNOWLEDGEMENTS

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GRIHA - INDIAN GREEN BUILDING RATING FOR A HOLISTIC SUSTAINABILITY EVALUATION OF BUILT ENVIRONMENT

Akash Deep[1]

[1] Area Convenor & Senior Program Manager, GRIHA Council, New Delhi, INDIA, akashdeep@grihaindia.org

ABSTRACT

GRIHA - Green Rating for Integrated Habitat Assessment rating developed by TERI (The Energy and Resources Institute) and adopted as national green building rating by MNRE (Ministry of New and Renewable Energy) is a tool to measure greenness of a project throughout the lifecycle of a building. Tool helps evaluates various sustainability measures adopted holistically in the build environment during the design, construction, operation and maintenance stages. GRIHA has been recognized by Government of India (GoI) as a tool for mitigation strategy to combat climate change in built environment. It demonstrates how Indian ancestral knowledge and modern technologies can be combined to achieve comfort in built environment without any added cost. It evaluates a project on various areas such as sustainable site planning, construction management, Energy efficiency, water efficiency, waste management, sustainable building materials, LCC, LCA, sustainable lifestyle and many more.

Due to growth in urban centers the resource consumption are rising exponentially. Implementing self-sufficiency through sustainability is the only hope for any future for human civilization. Through its recently launched de-carbonization program GRIHA has also created tools to assist GoI in its goal for achieving carbon neutral by 2070. The decarbonizing program targets individual resources and then helps corporates and projects evaluate their carbon footprint. The program also provides recommendation on no/low cost measure to help achieve carbon neutrality. GRIHA evaluates all types of built environment both existing and new construction. Through various projects (all typologies) across the country situated in various climate zone, it has been proven that creating and running a green building is economical as well as environment friendly. It helps it defeating the myth that "sustainability is costly".

The process of the rating has been developed as per the Indian construction industry practices. The process also facilitates hand holding for project teams to help them implement sustainability throughout the project timeline. The rating helps in making the whole process sustainable thereof making sure that the end result (buildings) are automatically sustainable. To address the ever evolving industry practices, GRIHA in all its variants keeps updating the requirement to push projects to follow various national and international standards. GRIHA has been developed as a single platform for meeting all regional and national statutory approvals making it easier for the developers to adopt and implement it. The rating adoption is currently voluntary so far the 1 or 2 % of the built environment impact is huge however if the adoption or green buildings is a mass movement the impact can be huge and life saving for the future generations.

INTRODUCTION

Climate change is the topic of discussion across the global platform. One of the major contributor's to the climate change is the building sector. Buildings while constructing and also during operational effect adversely on the local climate. It is one of the major resource consumers across the globe. However the history has taught us that buildings can be self sufficient and in harmony with the nature.

Indian ancient culture has always been in sync with the nature making it automatically sustainable including our lifestyles, food, cloths and even buildings. Figure 1 shows the diversity of various lifestyle habits across the country. Each of these have been suited and designed keeping in mind the local context of its whereabouts within the Indian sub-continent.

Figure 1. Depicting diversity in food, cloths and building as per the regional climate and availability of resources.

The eating habits were as per the climate of the region hot and spicy food in rajasthan making sure we sweat a lot, which intern helps to keep the body colder in hot and dry winds, similarly white color cloths from rajasthan and woollen cloths from northeast. Also the buildings and cities, the blue city, sloped roof in coastal regions, high roof in Uttar Pradesh region and many more. The Indian culture always preached waking up with sun and sleeping with sun i.e. optimal use of daylighting and no requirement of artificial lighting. Similarly recycle and reuse is there in our DNA use books and cloths of our elders by young in family. Having cyclic use of material rather than the current linear approach. An apparel first worn by many and at the end of its life as apparel converted and used as hand bag, purse, duster or even mop. These all cultural habits indicate the sustainability was embedded in our DNA. However the modern approach has pushed us away from this culture towards unsustainability.

Buildings are one such very evident example. The modern glass box aped from the west is in true nature inappropriate to the Indian context. The majority climate in the country is of hot and dry and warm and humid. Making these glass box one of the worse options if not designed optimally and intelligently. These buildings fail to even achieve the four basic comforts (refer figure 2) thermal, visual, acoustical and indoor air quality. First we create problem and then look for solutions. However there is still hope, the ancient knowledge with modern technology gives us the edge to target sustainability in true sense.

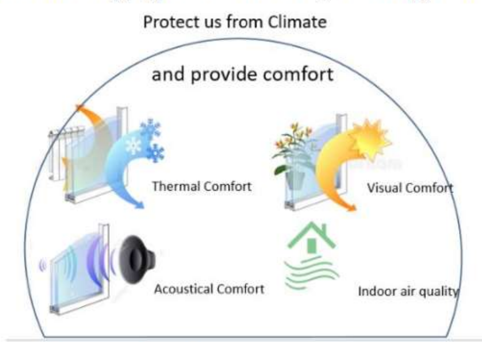

Figure 2. The comfort parameters

GRIHA – INDIA'S OWN GREEN BUILDING RATING

GRIHA is a part of mitigation strategy for combating climate change in India's "Nationally Determined Contributions" submitted to UNFCCC by the Ministry of Environment, Forests & Climate Change, Government of India, and has been recognized as India's National Green Building Rating. The rating has been developed with the Indian ethos and culture embedded in its principles.

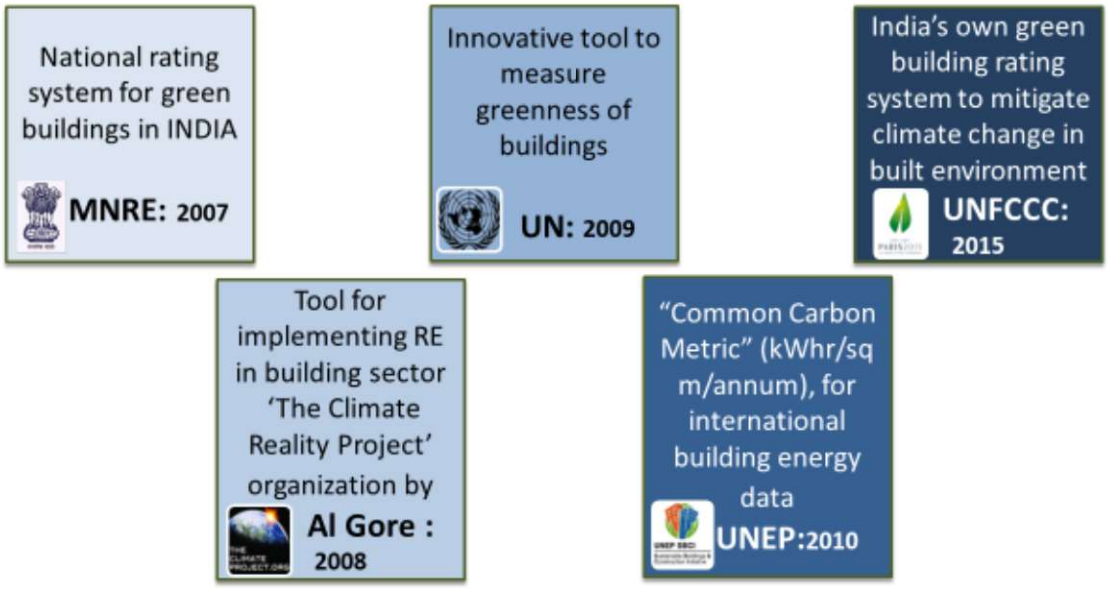

Figure 3. National and international endorsement

In 2005, TERI (The Energy and Resources Institute) released an indigenous green building rating system called TERI GRIHA in accordance with the Indian climate. On 1st November 2007, an MoU was signed between MNRE and GRIHA to develop and operationalize GRIHA for Green Buildings by MNRE and TERI. In 2007, GRIHA was adopted as the National Green Rating System for green buildings in India, by MNRE (Ministry of New and Renewable Energy). In the subsequent years, GRIHA has been recognized as a tool for "implementing Renewable Energy in the building sector" by the Climate Reality Project founded by Mr. Al Gore; and an "Innovative Tool" for sustainable development by the United Nations. Additionally, GRIHA has been instrumental in collecting international building energy data for the development of "Common Carbon Metric (kWhr/sq. m/annum)" by UNEP-SBCI. Figure 3 illustrates the various national and international endorsements received by GRIHA chronologically.

Rating Variants

GRIHA rating variants have been designed keeping in mind the complexities of building typologies however making it simpler for user to choose a relevant variant. The built environment have been classified under two broad categories i.e. new buildings and existing buildings. Further the variants have been designed keeping in mind the size of the projects. As sustainable solutions vary significantly due to the size of projects. So if a project is small in size a different set of strategies can be implemented while if it is a very large campus the philosophy and strategies changes.

Figure 4. Various rating variants under GRIHA
Source: GRIHA Council, Manuals, www.grihaindia.org, 10Th May 2022.

GRIHA Council evaluates and rates a vast variety of buildings including newly constructed buildings, existing buildings, cities and resource efficiency. Figure 4 provides a list of rating variants covering all built environment.

New Buildings

SVA-GRIHA (Simple Versatile Affordable) – This rating variant was conceived to introduce the concept of green buildings and sustainability to small-scale stakeholders, that is, owners of projects such as bungalows and small offices etc, with built up area 200 sq. m. $\leq x \leq$ 2500 sq. m. It was developed as a simple guidance-cum-rating tool to ramp up its adoption by general masses and further minimize the GHG emissions caused by small-scale constructions.

GRIHA – All new construction projects with built up area more than 2500 sq. m. (excluding parking, service areas, and typical buildings) are eligible for certification under GRIHA.

GRIHA LD – Large developments serve as crucial units that make up cities, neighbourhoods, and townships. GRIHA for Large Developments was developed to assess the environmental performance of developments with site area $\geq$ 50 hectares.

GRIHA AH – Considering the incremental growth in urban population and the need for urban housing, GOI (Government of India) has taken several steps like the PMAY(Pradhanmantri Awas Yojana) scheme, AMRUT etc. GRIHA for Affordable Housing was developed for all projects under PMAY and in compliance with the Reserve Bank of India's "Master Directions – Priority Sector Lending (PSL) – Targets and Classification".

Existing Buildings

GRIHA EB – All operational buildings having a built-up area greater than 200 sq. m. are eligible for certification under GRIHA for Existing Buildings rating. The typology of buildings includes offices, retail spaces, institutional buildings, hotels, hospital buildings, healthcare facilities, residences, and multi-family high-rise buildings.

JAN GRIHA – Jan Awas Nirman GRIHA is a newly launched rating catering to smallest built form for residences less than 200 sqm. The aim of the rating is to take sustainability to the masses.
GRIHA for Existing Day Schools – GRIHA for EDS was developed with an aim to develop a proactive attitude amongst the students and teachers to reduce their environmental footprint and adopt a greener lifestyle, by means of learning through play activities, thereby converging towards the national targets.

Cities
GRIHA for Cities (Civic bodies governing Town, Industries, Existing & new Settlements) – The GRIHA for CITIES rating has been structured as a framework for sustainable development of a city, to be achieved by measuring 'greenness' of existing as well as proposed cities. The rating sets performance benchmarks for key resources such as energy, water, and waste; and evaluates the project's performance in areas such as smart governance, social wellbeing, and transportation.

Resource Efficiency
GRIHA Water Positive Certificate – To address the on-going water crisis in the country, GRIHA Council has released India's first Water Positive Certification. The process involves water audit to quantify the impact of water efficient solutions adopted and implemented by the project/organization to reduce the water footprint.

Zero Waste – GRIHA Council developed a zero waste certification to audit solid waste management in buildings, by means of quantification and management of waste through the adoption of the 3 R principle of reduce, reuse and recycle.

Decarbonizing program – GRIHA Council released this certification to assess the holistic environmental performance of a building throughout its lifecycle. The certification analyses carbon emissions from transportation, energy, water and fuel consumption; and waste generation in a building.

However for simplicity and better understanding of the system this paper only covers GRIHA V. 2019 (new buildings) covering the major portfolio of projects in India i.e. built up area more than 2500 sqm. This version of the GRIHA variant is the 5th version since its launch in 2005. All rating variants undergo periodical technical revisions based on in-depth research to enhance ease of implementation and adoption, incorporate national and international building standards, market feedback, user experience and technological advancements.

RATING PROCESS GRIHA V. 2019

The rating process has been designed in sync with the project life for better and wide spread adoption. It also has been especially tailor-made to suit the Indian construction industry. The rating process (refer figure 5) has been divided in 3 different stages covering the life cycle of a project. It is also very important to understand that each of these stages play a very crucial role in making a project sustainable. Missing a single step makes sustainability costly.

Design Stage
This includes the registration and orientation workshop for the project. The registration of the project the initial step is the most crucial one and best suited if done during the design stage. Any further delay in process means there might be chances of cost escalation, as in this instance sustainability then is as an added thought. The orientation workshop is the first step to bring the project team together and discussing with them each project in detail in terms of increasing the sustainability of the project. This also provides a sense of responsibility of the various teams involve in the process such as architects, contracts, project client and the consultants.

Construction Stage
This stage includes two mandatory site visits followed by documentation submission and evaluation of construction linked criteria. This stage caters to the sustainability during the construction stages emphasizing on minimized damage to the ecology. The site visits are part of handholding process to guide project through this crucial stages. The first site visit is done during the initial stages of the project making sure that the sustainable construction practices are implemented on site since the beginning. It's always easy to carry forward processes from start while it is most difficult to alter process in between.

The second site visit happens when the project structural work is nearing completion and all high end equipment and interior material and systems are about to be ordered. The visit helps projects firstly identify green products and system available in the market. Secondly it also helps project teams to ask for right documents from the product or system vendor to ascertain the sustainability factor in the product. As the market is abandoned in various choices of products, however very few can check the sustainability parameters in the same. Hence this visit becomes crucial before ordering high cost equipment on site, to check their compliance through specification or technical brochures. Both the site visits also play a crucial role in making sure the health and safety of labours on construction site. Once the construction process is complete the project can submit construction linked documents for evaluation.

Operation and Maintenance Stage
This stage is the longest span in the life of building i.e. the user phase. Whatever strategies have been implemented by design and construction teams is set to test by multiple user and their own phycology. Project teams submits all remaining criteria documentation to claim points during this stage. Post documentation evaluation by 3rd party specialists the site is visited for the final time to make sure the claims made in documentation is being implemented as designed. Also to make sure that the project has not missed documenting any strategy which they have implemented. Post site verification an documentation evaluation the project is awarded the rating. However this is not he end of rating process as the building is still there for almost 60 – 80 years. So for projects who have committed to sustainability, it becomes a life time commitment keeping a building run sustainably. It is required to renew the rating after every 5 years either by submitted audited data as per consumption or to convert project under GRIHA EB rating evaluations.

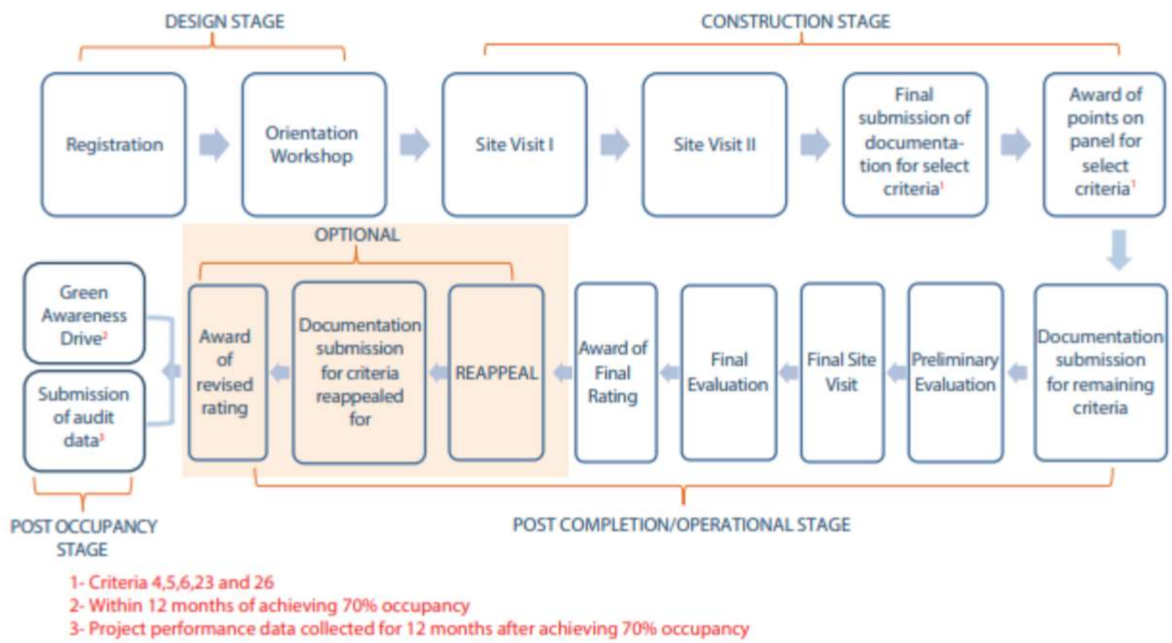

Figure 5. GRIHA V. 2019 rating process.
Source: GRIHA V 2019 manual, Volume 1, 2022

SECTIONS AND CRITERIA UNDER GRIHA V. 2019

The sections and criteria have been designed as per the rating variant relevance to the applicable built environment. Keeping the new construction practices in the country this rating variant evaluates the project throughout the life cycle i.e. design, construction, operation and maintenance. This makes sure that the process of making a building itself becomes sustainable making the end result automatically sustainable. The 11 sections have been developed keeping in mind the sustainability of the project throughout the life cycle of building covering all aspects holistically. A total of 30 criteria under these sections have then been developed for various typologies of built divided under 7 categories aiming all building groups and types (refer figure 6).

There are 3 types of criteria:

Mandatory – As the rating has been design as per Indian aspects. The base requirements automatically becomes the local standards and norms. There are multiple local standards and norms. GRIHA brings these standards on single platter making it easier for the projects to meet the local norms and this creates the foundation of sustainability from the start. Some of the requirements criteria as a whole or partly have been made mandatory which are allotted zero points. These appraisals if are non-compliant the rating for the project is denied.

Optional – Once a projects achieves the mandatory clauses it can aim to enhance its performance in various areas by improving the above the basic standards. Therefore if projects showcases better performance more optional points can be claimed and can target a better rating.

Applicable – The rating has been designed keeping mind the diverse nature of all construction sites. Some criteria clauses have option for non-applicability. So technically if something does not make sense in a project due to some site constrains the appraisal becomes non-applicable. The points allotted for the clause is subtracted from the denominator without effecting the overall percentile of the project.

Healthcare Facility	Hospitality	Institutional	Office	Residential	Retail	Transit Terminal
Hospitals	Hotels	Universities	Core & shell buildings	Multi-dwelling unit	Shopping complexes	Airports
Clinics	Guest houses	Schools	IT buildings/ data centres	Hostels	Banquets/ wedding halls	Heliports
Medical colleges	Service apartments	Colleges	Owner-occupied buildings	Bungalows	Restaurants	Bus stands
Dispensaries	Community/ Visitors centre	Libraries	Co-working spaces	Villas	Food courts	Railway stations
		Institutes	Industries	Mansions	Cafeterias	Metro stations
		Sports complexes	Court	Military barracks	Multiplexes	
		Research and development buildings			Gallery/ Museum	
		Place of worship			Sports and leisure facilities	
					Auditorium/ Theatre	

Figure 6 – Various typologies covered under GRIAH v 2019
Source: GRIHA V 2019 manual, Volume 1, 2022

CASE STUDIES
Govardhan Ecovillage , Thane

Location: Galtare, Wada, Thane, Maharashtra
Site Area: 70 acres
Built up Area: 2400.65 sqm
Non AC Area: 2400.65 sqm
Energy Reduction: 57%
EPI: 42 KWh/ sqm/year
Renewable Energy: 30KWp
GRIHA rating: 5 Stars
Year of completion: 2012

Optimum Window openings
Light and reflective floor for light diffusion
Soft landscape giving no reflected glare
Shaded walls and openings

Buildings placed such that minimal trees are cut and agriculture is not impacted.
Buildings on hard ground to save on foundation cost.
Layout based on hydrogeological survey's inputs so that development does not have a negative impact the recharge and discharge zones of water.

Use of Precast arch panels for roofs.
Use of stabilized soil cement blocks on walls and maintaining the same un-plastered exterior.
Double tile roofing for final roof finish.

CESB based construction has an embodied energy of 1% the regular construction (0.275 MJ/kg energy in CESB and 72.3 MJ/kg in conventional concrete structure).
Use of quarry dust to replace sand

IMPACT

The GRIHA parameters have been developed to strike a balance between established practices and emerging concepts, between divergent ideas and strategies, in its approach toward evaluating the environmental performance of buildings and enabling its holistic convergence over their entire life cycles into a sustainable development. The principle for the evaluation parameters has been 'what gets measured, gets managed', it attempts to quantify aspects such as energy consumption and indoor comfort conditions to optimize efficiency and resource consumption while ensuring that buildings continue to perform at desired levels of safety and liveability.

On a broader scale, the current work process is designed to benefit the community at large through a reduction in emissions, the enhancement of productivity and the mitigation of resource scarcity. GRIHA Council currently has over 2280 registered projects across the country with a combined footprint spanning 630 million square feet. Of these, more than 700 buildings that have already been rated have 533 MWp of renewable energy systems installed and are responsible for saving 2,97,38,818 MWh of energy and preventing 83,93,046 tons of carbon dioxide from being released into the atmosphere every year. GRIHA rated projects have contributed to water savings of 10,36,11,250 kL/annum, 2,66,770 newly planted trees and 28,000 preserved trees (refer figure 7). Over the years, GRIHA Council has enlisted more than 3,000 products, and trained more than 20,000 students and professionals across India. During the evaluation process, GRIHA Council provides active guidance to project teams, scrutinizes documentation, and validates execution on site in order to ensure compliance.

The Prime Minister's call for an Atmanirbhar India, resonates deeply with GRIHA's fundamentals which are based on adapting worldwide research and technological advancements to meet local requirements. GRIHA Council, as a torch bearer for green development in the country has conceived and implemented several local and long-term policy and regulatory mechanisms for building climatic resilience and will continue to lead the nation as it makes the all – important shift towards sustainable environment and climate mitigation.

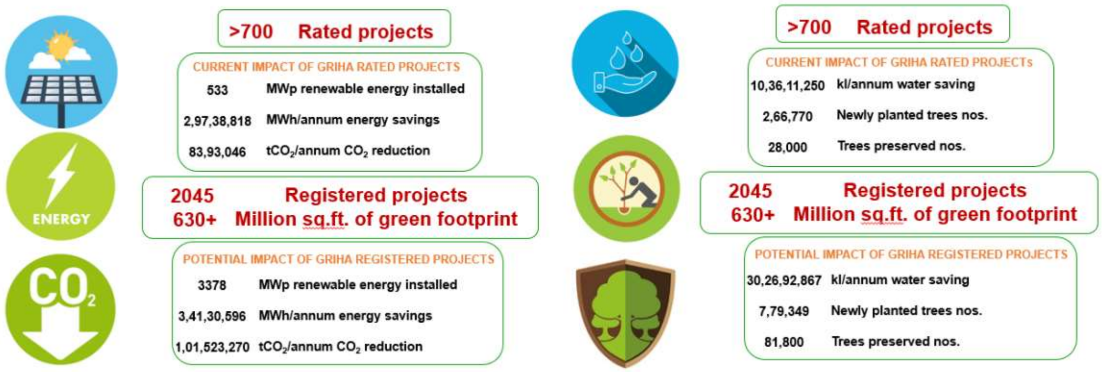

Figure 7. Current and projects impact of implimentation by GRIHA

CONCLUSION

Currently in the building industry sustainability is referred as an added feature, however until it becomes part of the process, the basic requirement carrying it forward through buildings life time will always be looked as an added cost and effort. The myth that sustainable buildings cost more is only due to ill time decisions and non-contextual building design. One of the easiest and cost effective way to make building climate resilient and self-sufficient is through climate responsive design.

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COMPARATIVE VISIBILITY ANALYSIS TO EVALUATE THE SUCCESS OF OPEN SPACES IN HOUSING LAYOUTS

Ophylia Vinodhini G[1], Shabitha P[2] , Murugesan O[3], Santhanapriya AS[4]

[1] Associate Professor, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. ophylia.vinodhini@care.ac.in
[2] Professor, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. pshabitha@care.ac.in
[3] Assistant Professor, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. omurugesan@care.ac.in
[4] Undergraduate Student, C.A.R.E School of Architecture, Tiruchirappalli, TN, IN. santhanapriya.as@care.ac.in

ABSTRACT

Open spaces are an integral part of residences and residential neighbourhoods. They play an important role in lower-income group housing and tropical climate regions. This is due to the relatively smaller area of the houses in the lower-income groups, requiring flexible spill over space that can accommodate multiple activities. Similarly, open spaces help create a microclimate and offer solace from the heat and humidity. They are also associated with the culture of a place. Hence it is important to design appropriate open spaces, especially in a country like India where a large part of the housing demand is from the lower-income group. Residential open spaces serve different purposes and hence demand different spatial characteristics such as scale, location, visual and physical connectivity, enclosure, etc depending on the activity. The ability to create open spaces that can cater to varied purposes like public, semi-public, semi-private, and private activities, reflecting qualities such as a sense of identity, belonging, security, etc determines the success of open spaces in residential built environments. Open spaces in traditional and organically evolved housing inherently possess these characteristics and hence have been relevant and thriving over decades and sometimes even centuries. This research paper intends to compare the quality of open spaces in organically evolved housing and planned social housing in Trichy. Isovist is used as a tool to assess the spatial characteristics of residential open space, by comparing and comprehending organically evolved and planned housing layouts to understand the visibility areas. Isovist analysis of Depthmap x.70 is used to generate 64 isovist maps from multiple viewpoints of each layout. The research findings are the listing of design criteria for open spaces in future housing projects. Effective planning of open spaces is instrumental in increasing the social and economic sustainability of the neighbourhoods.

INTRODUCTION

Housing for the low-income group located in the urban setting faces the biggest challenge of limited space. A large population of people is to be housed in places with limited and expensive land resources. Open spaces become very critical in such scenarios since they compensate as flexible spaces into which various activities of the residents can spill over and support. Open spaces become the haven in dense urban residential environments. They serve tangible and intangible purposes. Building regulations and standards prescribe guidelines to assure the presence of sufficient open space. However, the way these open spaces are distributed and designed can largely affect their effective use. When implemented negligently, building regulations tend to address the objective purposes of open spaces only, ignoring the intangible aspects of open spaces. This often can result in the underutilization or misuse of open spaces. The problem of limited carpet area in lower-income housing is further exacerbated when open spaces do not perform their intended role. This paper aims to understand the efficiency of open spaces in terms of quality rather than quantity in low-income neighbourhoods. Organically evolved housing and planned social housing for the lower-income group differ in their design approach though the user group is the same in both. The fundamental difference is the planned social housing design is an accumulation of solids in a largely unmanipulated void while organically evolved housing is the accumulation of voids in a largely unmanipulated solid (Fred Koetter and Colin Rowe, 1979). This difference reflects in the physical environment and the way the open space is used. Hence an understanding of the qualities of open space that make it efficient is critical in creating good residential neighbourhoods. More awareness of strong socio-cultural factors in domestic space would seem to be required if guidance is not to lead to insensitive standardised design. Hanson and Hillier (1982).

OPEN SPACES

Open spaces play a significant role in creating conducive residential environments, especially for the LIG (Low-income group) in densely packed urban settlements of India. Open spaces derive their meaning from the multitude of functions it serves. These include three major categories namely utilitarian functions such as light and ventilation, access to areas, parking, etc., social functions such as interaction, recreation, domestic activities, etc, and perceptual functions of aesthetic satisfaction, identity, etc. (Vastu Shilpa Foundation, Residential open spaces - A behavioural analysis, 1988) Since the utilitarian functions are the most apparent they are always considered while designing housing. The standards and building codes also predominantly address utilitarian functions in the form of the percentage of open space, setbacks, and space between buildings. This ensures sufficient lighting and ventilation to the indoor spaces, sufficient space for access and safety concerns, and provision of greenery and play spaces for the residents. The social functions of extension of domestic activity like cooking, sleeping, studying, etc into the open spaces, interaction amongst residents, recreational activities, and small commercial activities serve as activity generators in keeping the neighbourhood vibrant and safe apart from compensating for the small carpet area of the individual houses in LIG housing. The perceptual functions such as identity are determined by the physical built environment and social functions carried out in the open space. However, the intangible nature of social and perceptual functions makes it ambiguous to comprehend, and difficult to incorporate as an integral part of design consideration or to implement in the form of standards and codes. To make open spaces truly function a scientific understanding of the intangible aspects of open spaces is necessary.

The activities that happen in a residential open space can be either private, semi-private, semi-public, or public in nature. Hence the open spaces should also correspond with the nature of the activity. A semi-private activity-like interaction among neighbours can happen only when appropriate spaces are created. The characteristics of the private, semi-private or semi-public domain of the open spaces are determined by their physical characteristics of the location, size, visual connectivity, access, and enclosure. The open spaces meant for more private activities are smaller in size, have a greater sense of enclosure and hence lesser visibility, lesser visual and physical accessibility from the public domain, and are located within the domain of the residence. The open spaces meant for more public activities are located with easier access from the other public and semi-public spaces, are larger in size, and are visually more porous. The incongruity between the type of activity and the characteristics of the physical environment can result in underutilization and undesirable utilisation of such open spaces.

Good open spaces are characterised by an appropriate physical setting conducive to the kind of activity intended, flexibility and adaptability in accommodating various functions, activities that generate medium to high intensity of use throughout the day, inclusivity and variety of user groups, sense of security through natural surveillance, clear definition of individual and collective domains with a well-established sense of territoriality and ownership, ability to provide a climatically favourable outdoor environment through most of the day and year. The qualities of the built environment such as location and visibility play an important role in determining the effectiveness of good open spaces.

OPEN SPACES; SUSTAINABILITY AND VISIBILITY

Open spaces for sustainability

Numerous studies have documented and analysed the presence of open spaces concerning the social and economic sustainability of communities. Any improvement in these areas brings a wide range of health benefits for all age groups (Engemann, K., et.al. 2019., Appolloni, L., et.al. 2019.). Derya Oktay mentions that the logics of sustainability and physical components of open spaces are influential in increasing the satisfaction rates of people (Oktay, D., 2004.). These satisfactory rates also depend on ownership of housing (Kowaltowski, D.C., et.al. 2006). Social interaction among the communities is higher when the dwelling units are planned around an open space where the location at the precinct level is more successful (Karuppannan, S. and Sivam, A., 2011.). Better place quality contributes to the long-term benefits inclusive of health thereby providing social, economic, and environmental outcomes (Carmona, M., 2019.). The environmental context is more crucial in the evaluation of these open spaces concerning adaptability to living conditions (D'alessandro, D., 2020.).

Visibility and Sustainability

Research is limited in the areas of visibility and sustainability. People's emotions and feelings are influenced by the paths, and visual connections with adjacent spaces are linked with the spatial structure of enclosures in their vicinity Shulin, S.H.I., et al.,(2014.). They discuss the unused potential of public open spaces in housing layouts resulting in illegal parking, and household waste disposal thereby creating spaces that are neglected, unsafe and unattractive spaces (Bogdanović Protić, I., et al. (2020.).

Visibility of open spaces and ISOVIST measures in housing

Table1. Studies on visibility of open spaces

S.No	Area of Study/ Case Studies	Findings	Researchers
1	use of open spaces in the City of London	bound to the visibility field or isovist properties of space	Bill Hillier, 1996
2	Interaction of visual fields, linear properties, and socio-spatial boundaries with the structure of open spaces in the city of Athens	proved the principle with syntactic and isovist analysis. People converge on the areas of the greater visual field.	Trova et al. 1999
3	to study the main activities of people in open spaces	tools and approaches to be able to see, hear, and experience people functioning in different situations.	Bada, 2012
4	"Life between buildings: Using public space"	The presence of people is the key feature in the use of public open spaces.	Gehl, 1987
5	Importance of visual factor	The main activity for people is to look for other people. Visibility increases a sense of security.	Whyte 1980
6	Eyes on the street	More visibility of more people in the street increases safety in neighbourhoods	Jacobs 1992

STUDY CONTEXT

The study was conducted at 4 residential areas in the city of Trichy, two of them were social housing projects (at Sengulam colony and sub-jail road) while 2 were organically evolved housing (at Alwarthoppu and Iruthayapuram). The open spaces in these four neighbourhoods were documented and analysed. The user groups in all four housing belonged to economically weaker sections and low-income groups. The open spaces in the organically evolved housing were well defined and lesser in the area while those in the social housing projects were as per the building regulations, larger in the area and loosely defined between buildings.

METHODOLOGY AND PARAMETERS FOR ANALYSIS

The characteristics and purpose of open spaces were derived from earlier research and literature (Bill Hillier, 1996; Gehl, 1987, Whyte 1980 etc) as mentioned in **table 1** in the previous section. 4 housing projects, 2 organically evolved and 2 planned social housing projects were selected in the city of Tiruchirappalli. All four housing projects belonged to the low-income group of users. The open spaces in these four housings were documented. The intensity and type of use of the open spaces in each housing project were noted based on observations (through observations of people using the space and markers of under or misuse like bad maintenance, antisocial activities, etc) and interviews with the residents. Based on this the open spaces were classified into well-used and neglected open spaces. An ISOVIST mapping and analysis of the open spaces was conducted. The results of the observation mapping and ISOVIST analysis were compared.

OBSERVATION STUDY AND ACTIVITY MAPPING

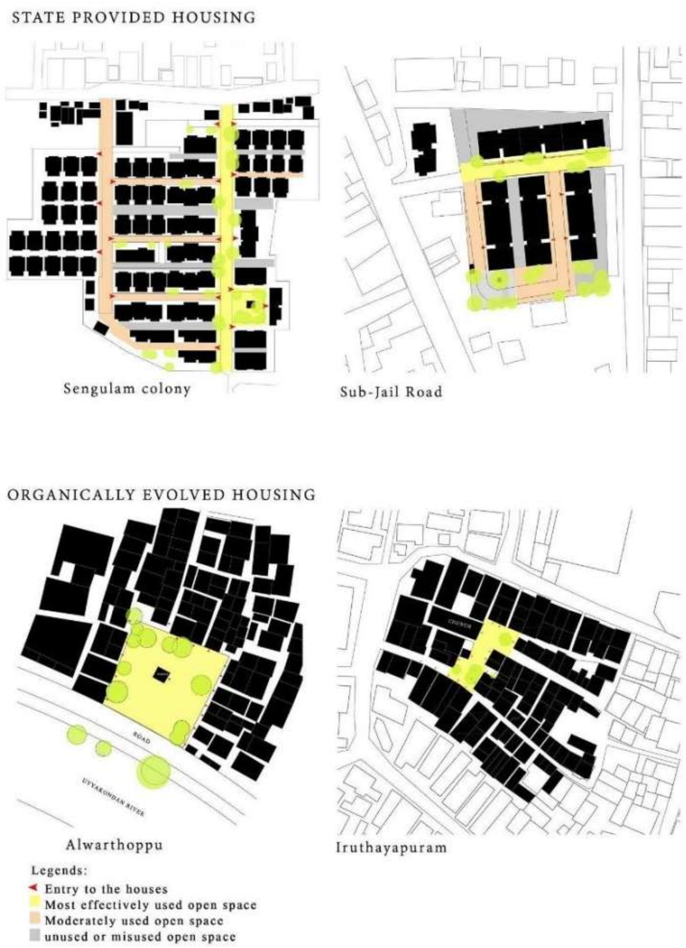

Figure 1. Nolli's map with activities in the identified open spaces in a) Sengulum Colony b)Sub-jail road c)Alwarthoppu and d)Iruthayapuram

The user activity and upkeep of the open spaces in the four housing were observed and documented (Figure 1). In Alwarthoppu a single large open space located adjacent to the main access road is the hub of all activities of the neighbourhood. The edge of the open space is defined by houses with entrances and a row of trees that create a smooth transition from the private to the public realm and from enclosed to semi-open to open space. All streets of the neighbourhood branch out from this open space. A small temple located at the centre acts as the reference point. The open space caters to multiple activities. Most of the residents are involved in making papads as an alternate source of income. During the day the entire area is used for drying papads and in the evening the space is used for social interaction and as a children's play space.

In Iruthayapuram, the main open space is located at the junction of 7 streets, 2 of which connect the neighbourhood with the main access road. Several houses, a church, a government office, and a shop define its edge. A water supply tap and tree providing shade are also present. This space was also well used and characterised by multiple activities taking place due to the presence of entries to houses, commercial, religious, social, and household activities. In the social housing on the sub-jail road, the main street connecting the sub-jail road and Madurai road is the most vibrant open space. It is defined by the entries to the housing blocks, several petty shops, and hawkers. 3 linear open spaces branch out from this main street, two of them are streets that have entries to the housing blocks and one rear open space between blocks. The streets were fairly well used for storage, parking, and some social interaction. However, the rear open space between buildings was badly maintained, and used for garbage dumping. Open space adjacent to a small temple is located at the southwest corner at the junction of the secondary street and the setback in the south. This open space despite having entrances to housing blocks was misused due to its remote location lacking visibility from the streets.

In the social housing at Sengulam colony, there are two main streets running north-south, of which one connects the main access road to the site and a smaller road to the surrounding neighbourhoods. The main street. This street is the most well-used space due to its connectivity, shade created by trees, small shops, hawkers on its edge, and the entries of housing blocks opening into it. A small open space adjacent to this street with a temple is also efficiently used (Figure 2). The other main street and the streets containing the entries to the housing blocks running perpendicularly between the two main streets are fairly well used. However, the rear open spaces between housing blocks are not used.

Figure 2. Character Sketches of the Housing and open spaces

ISOVIST MAPPING AND ANALYSIS

Visibility access to open space is the key to developing functional spaces. Four housing projects identified for the study are analysed with their open spaces. Depthmap x. 0.70 is the software used to assess the visibility and quantify the viewshed areas of these sites. The presence of these spaces is also assessed concerning the conceptual distance and their relationship with the adjoining spaces. At the onset, the housing projects are of similar occupancy and scale, thereby leading to a fair comparison of visibility parameters.

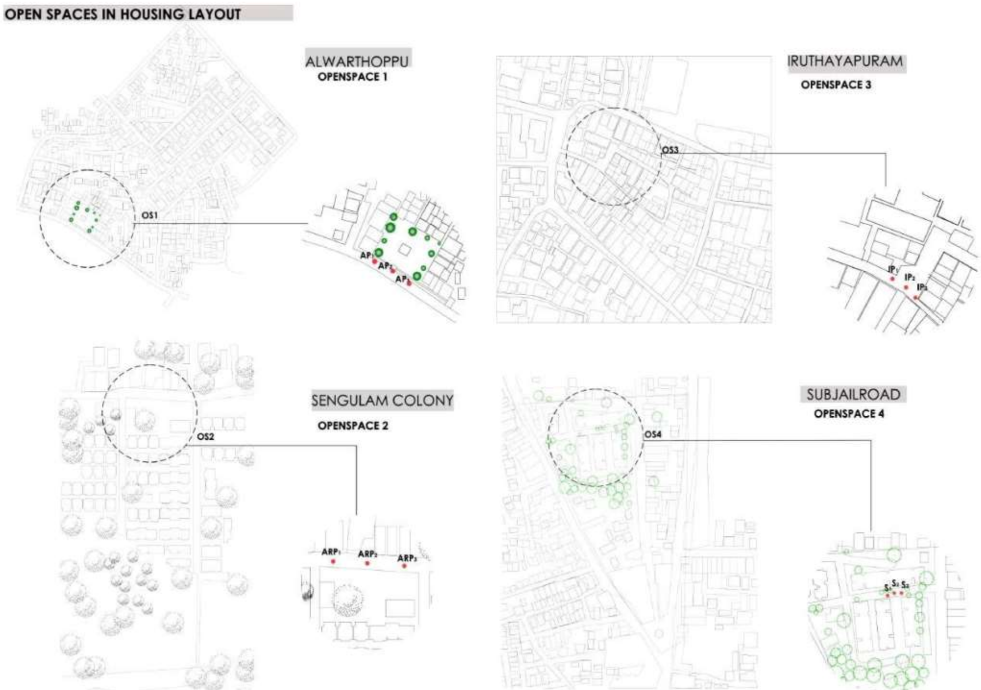

Figure 3. Locations of identified open spaces in 4 Housing projects.

Three points (Figure 3) of observation on the left, centre, and right of the road abutting the open spaces are taken for the study. 96 maps are generated for the four open spaces identified in the four housing projects respectively. 24 maps are generated for each open space. 12 Isovist maps are generated with standard points (at the same point of view) and 12 maps with dragged points (view along the movement of the perceiver). The relevance of these points is significant to understand the importance of open spaces at a static point of view and along movement. The four angles of Isovist used for the study are 90°, 120°, 180°, and 360°. The relevance of Isovist angles is generated from the viewer's perception of the open space with respect to choice of user and sequence of movement. 360° is one such angle of visibility that a user may sometimes choose when they want to turn around and view the entire open space. Figure 4 below shows the sequence of maps generated concerning the angles and points of observation. The discussions of the results follow in the further subsections.

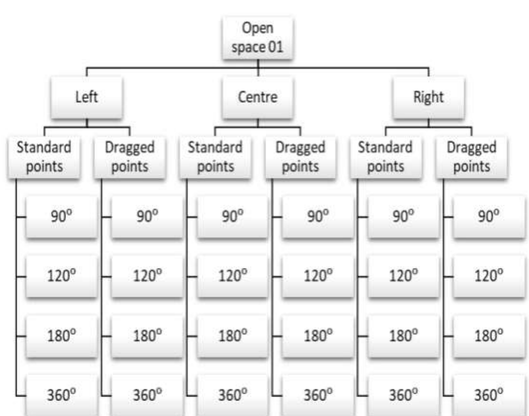

Figure 4: Sequence of generated ISOVIST maps for analysis of the open spaces

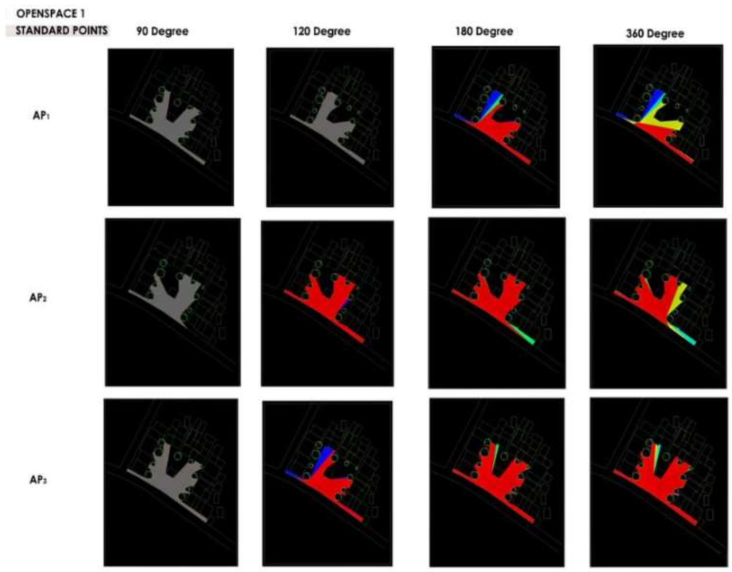

Figure 5: ISOVIST maps generated with standard points for open space1 at Alwarthoppu, Tiruchirappalli, *(Legend: Grey – minimal Isovist area; red – reflected; yellow – spectral; cyan – visible; blue - accessible)*

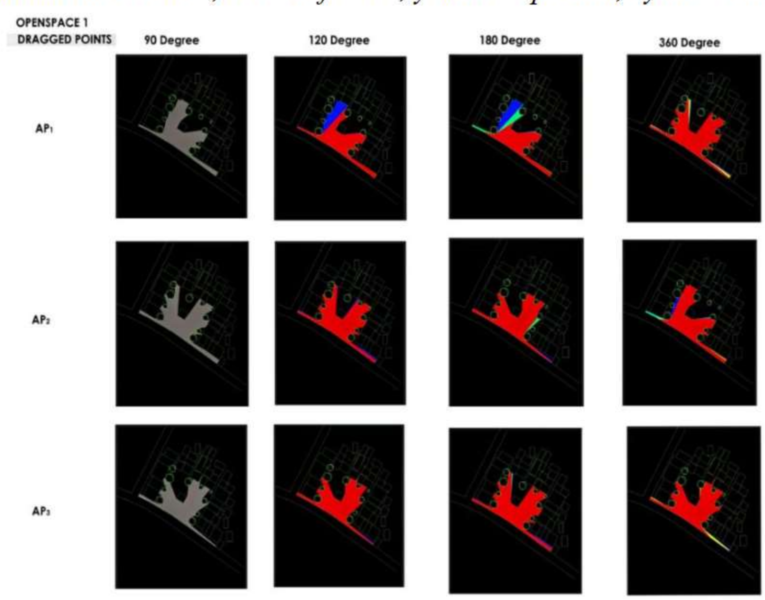

Figure 6: ISOVIST maps generated with Dragged points for open space1 at Alwarthoppu, Tiruchirappalli, *(Legend: Grey – minimal Isovist area; red – reflected; yellow – spectral; cyan – visible; blue - accessible)*

Figures 5, 6, and 7 depict the isovist maps generated for the four identified open spaces. The samples are validated with photographs and physical observations on site. Table 2. below provides the comparison of Isovist areas based on visibility angles for the four identified open spaces.

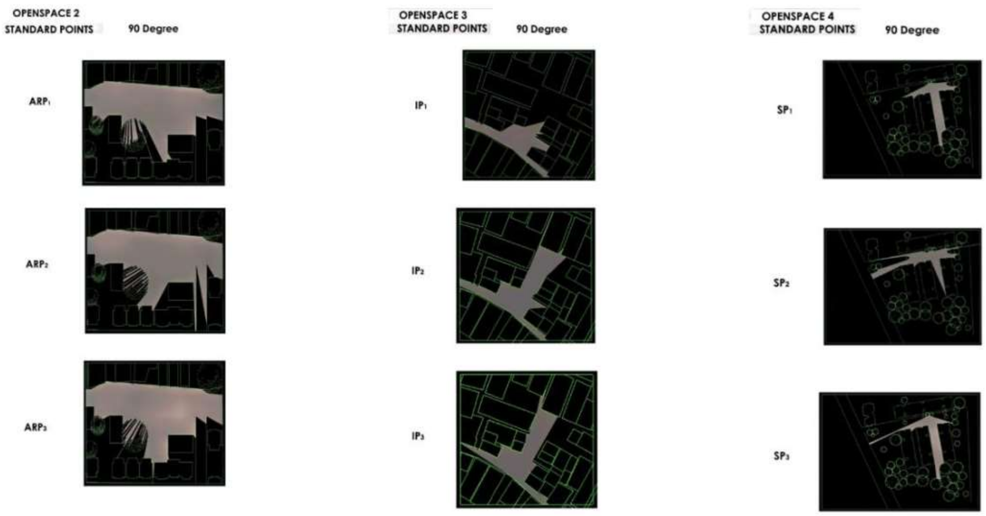

Figure 7: ISOVIST maps generated with open spaces 2, 3 and 4
(Legend: Grey – minimal Isovist area)

Sl.No	DEGREES OF ISOVISIT	SITE DEGREES	ALWARTHOPPU (sq.m)	SENGULAM COLONY (sq.m)	IRUTHAYA PURAM (sq.m)	SUBJAIL ROAD (sq.m)	TOTAL (VIEWSHED BASED) (sq.m)
1	90 Degree (standard point)	SSP1	1024.87	12810.09	811.351	3662.61	18303.921
2	90 Degree (dragged point)	SDP1	1064.006	12670.19	853.902	4311.45	18881.548
3	120 Degree (standard point)	SSP2	1011.979	12799.65	892.091	5662.562	20366.582
4	120 Degree (dragged point)	SDP2	1046.573	13080.23	818.035	4273.83	19218.668
5	180 Degree (standard point)	SSP3	994.366	12842.02	903.659	3011.551	17751.596
6	180 Degree (dragged point)	SDP3	978.975	12988.66	843.265	4279.94	19106.231
7	360 Degree (standard point)	SSP4	941.841	12905.08	803.199	3252.299	17902.419
8	360 Degree (dragged point)	SDP4	984.079	12999.42	844.476	4189.23	19017.205
	TOTAL (site based sq.m)		8046.689	103095.34	6769.978	32643.472	

Table 2. Isovist areas: Comparison of four identified open spaces

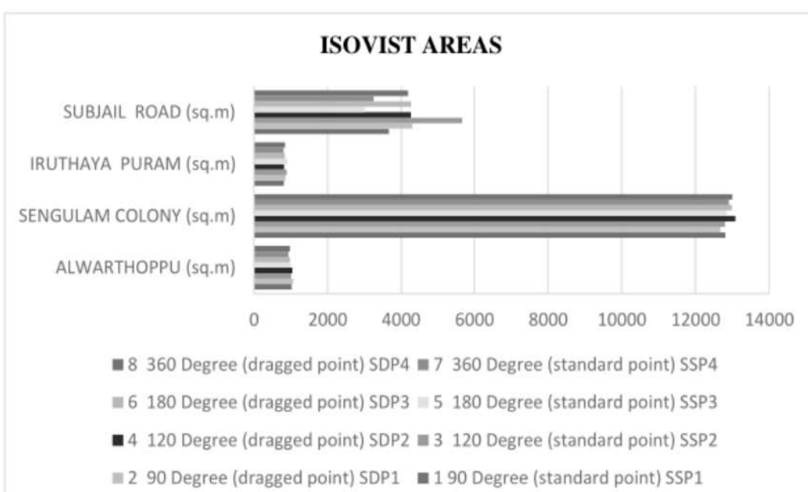

Figure 8: Comparative graph of viewshed areas of the four identified open spaces

Figure 8. and Table 3. provides the comparison of Isovist areas based on open spaces for the four visibility angles.

Table 3. Viewshed areas of the four open spaces in housing layouts.

OPEN SPACES			DEGREES OF ISOVIST							
			90 Degree (standard)	90 Degree (dragged)	120 Degree (standard)	120 Degree (dragged)	180 Degree (standard)	180 Degree (dragged)	360Degree (standard)	360 Degree (dragged)
OPEN SPACE1	AP1	MIN	330.61	335.962	330.61	335.962	330.61	222.15	330.61	222.15
		MAX	330.61	335.962	330.61	335.962	330.61	335.962	330.61	335.962
	AP2	MIN	376.703	382.349	376.703	368.573	376.703	368.573	376.703	357.886
		MAX	376.703	382.349	385.902	382.349	385.902	382.349	385.902	382.349
	AP3	MIN	317.552	337.896	317.552	345.755	317.552	330.69	317.552	337.896
		MAX	317.552	337.896	346.809	337.896	346.809	337.896	346.809	337.896
OPEN SPACE2	ARP1	MIN	4058.47	4099.78	4058.93	4075.86	4058.93	4070.99	4058.93	4069.52
		MAX	4058.47	4102.99	4068.47	4102.99	4072.07	4102.99	4073.78	4102.99
	ARP2	MIN	4289.48	4297.69	4289.48	4297.69	4289.48	4297.69	4289.48	4293.6
		MAX	4289.48	4305.29	4306.14	4305.29	4306.14	4305.29	4306.14	4305.29
	ARP3	MIN	4424.13	4272.72	4424.13	4668.16	4424.13	4431.2	4424.13	4431.2
		MAX	4452.14	4709.87	4452.14	4709.87	4560.91	4709.87	4452.14	4727.68
OPEN SPACE3	IP1	MIN	187.369	190.949	187.369	190.949	187.369	190.949	187.369	190.949
		MAX	206.5454	216.565	206.5454	216.565	213.392	216.565	213.392	216.565
	IP2	MIN	303.219	320.136	303.219	320.136	303.219	315.006	303.219	315.006
		MAX	324.48	328.944	313.678	328.944	326.717	328.944	326.717	328.944
	I3	MIN	275.368	320.91	275.368	306.997	275.368	306.997	275.368	306.997
		MAX	304.366	320.91	304.366	320.91	304.366	320.91	304.366	320.91
OPEN SPACE4	SP1	MIN	1077.97	1536.22	1077.97	1467.3	1077.97	1440.47	1077.97	1349.98
		MAX	1077.97	1536.22	1085.31	1536.22	1085.31	1536.22	1133.4	1536.22
	SP2	MIN	1285.13	1479.11	1285.13	1367.87	1285.13	1449.06	1285.13	1276.67
		MAX	1285.13	1486.71	1339.24	1486.71	1339.24	1486.71	1339.24	1486.71
	SP3	MIN	1379.51	1296.12	1379.51	1296.12	1379.51	1296.12	1379.51	1296.12
		MAX	1379.51	1296.12	1379.51	1296.12	1367.28	1296.12	1396.82	1296.12

MINIMUM STANDARD VALUES AT EACH POINT OF ALL THE ISOVIST DEGREES ARE SAME

MAXIMUM DRAGGED VALUES AT EACH POINT OF ALL THE ISOVIST DEGREES ARE SAME

RESULTS AND DISCUSSIONS

The Sengulam colony site has a larger open space compared to the other 3 sites. The sub-jail road has the second-largest area. Being planned with proportionate areas of open spaces, the areas are provided with more than the required spaces, which are sometimes underused or misused by people as garbage dumping spaces. The open spaces in Iruthayapuram and Alwarthoppu are less in area, yet comprehensible on the human scale. These spaces are maintained with hygiene and used effectively by people. Smaller open spaces immediately abutting entries to houses are more effective than larger spaces without direct access and lesser usage. In both organically evolved housing, the largest and often only open space was located at the junction of major circulation paths, and its edge was well defined by entrances to various units. The open spaces serve multi-functions like social, household, recreational, economic, and religious activities. Both open spaces had a religious structure located in the open space. The open spaces in the organically evolved housing were voids amongst a dense closed packed built environment. In contrast, in the social housing projects, the buildings were solids placed in an uninterrupted void, thus creating several open spaces scattered throughout the site. Some of these spaces are located in areas remote from the circulation network or in places that are not connected to the entries of the housing. The open spaces adjacent to the circulation spine catered to social, recreational, and economic activities whereas the open spaces that did not have building entries or were away from the circulation network were underused or misused which was evident from the bad upkeep and lack of security.

The findings of the observation study demonstrates that the open space in Iruthayapuram was most effectively used followed by open spaces in Alwarthopu and Sub jail road, while Sengulam colony has the least effective open space. The ISOVIST analysis shows that Iruthayapuram had least ISOVIST are followed by open space in Alwarthopu and Subjail road, and open space in Sengulam colony had most ISOVIST area (figure 8). Thus, the results of the observation study and ISOVIST analysis corelate. The building typology in housing also has an influence on the use of open spaces negatively correlating to the increase in the number of stories. The study shows that a more substantial influence on visibility occurs in sites with greater ISOVIST areas. In general, open spaces with good visibility with less ISOVIST area were used well due to their better visual surveillance. Spaces with less ISOVIST areas tend to be more comprehensible and relatable to human scale. Hence these spaces were observed to reflect good communal behaviour among the people of the place. Whereas open spaces with greater ISOVIST areas had blurred visibility due to the vastness of the space that is unrelatable to human scale. The size and enclosure of open spaces when designed with consideration of human scale promote communal betterment.

CONCLUSIONS

This study reflects that the use of open spaces in housing depends on the comprehensibility of human scale, visibility, location, access to other buildings from the open space, and the presence of shade and multiple activity generators. Hence the quality of function of open spaces needs to be considered concerning the above-mentioned design criteria rather than just providing the open spaces as per standards. Providing open spaces without considering this often results in underuse and misuse of valuable open spaces in urban areas.

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GENDER SENSITIVE URBANISM : (RECLAIMING OF URBAN SPACE THROUGH UNGENDERING THE CITY).

Namrata Pulsay[1]

[1] Associate Professor, VTU, Brindavan College of Architecture, Yelahanka, Bangalore, namratapulsay@gmail.com

ABSTRACT

Cities were planned either as a "World Class City" that takes into account wishes of elite and planned for the needs of men.The vulnerable section -the poor,and especially the women , children, and aged are marginalized and pushed to corners.By focus on the needs and concerns of women which are common to all addresses the needs and concerns of elders and children.Gender sensitive urban-ism is to design cities and built environment focusing on gender. According to the U N Sustainable Development Goals (5), UN : 2030 agenda, which aims to achieve “Gender Equality”and the New Urban Agenda(2016) which aims women right to the city .The objectives of this paper include :-(a)Historical reasoning of transition from traditional society to modern society as gender through time and scale. (b) Gender intersection in Urban Spaces and issues faced by women (c) To understand the role and issues faced by the selected women sample, at Madiwal market and Siddharthnagar, Bangalore.(d) Connecting issues to larger urban network and these aim to revive and intervene the area for gender equality.

Keywords: Urban space, Gender, Vulnerable, Sustainability.

INTRODUCTION

Urban planners and designers create our surroundings, which has an impact on way we move, live, work, play, and sleep.The urban planning process has direct relationship with built forms and behaviour that define our society, frequently reflecting gender inequality inside. Cities, on average, benefit males more than women,gender minorities and differently able people. Gender sensitive urban ism is to design cities and built environment focusing on gender.By focus on the needs and concerns of women which are common to all addresses the needs and concerns of elders and children. Women have particular needs and concerns like safety,mobility,accessibility in the urban public spaces,the facilities of rest rooms,lack of lighting in public areas and many such gender blind existing situations that serve as a entry point and initiate an enquiry into the gender-ed nature of built environment. Later,the gender issues of the underprivileged sections of the society can be focused on, such as the needs and concerns of working class woman as they get access to the elite discipline of planning.In order to make the entire cityscape more inclusive and accessible, urban design must take this into account.

LITERATURE REVIEW

Globalization and transformation

Globalization has generated various social processes across the world. The essential role that women play in international economic processes is one such example that Saskia Sassen examines in her study. As she demonstrates, the feminization of the work force has had both beneficial and bad consequences. (Sassen, 2002).Process offshore has increased, leading to an increase in the engagement of urban women participation in the economy in emerging nations. This transition is a sign of empowerment,giving urban women in India the opportunity for independence and security, where gender inequality has long been a concern.Because of the skills that these off shored professions require in developing nations, notably India, urban women are being pushed to work and support their families. This shift in gender dynamics is transforming city dynamics, in addition to the economic and social revolutions that Indian cities are experiencing.'Gender relations and gender roles are central to the allocation of resources, facilities and opportunities in a city, which in turn is essential to the structuring of the urban space.' (England, 1991).Gender relations in cities are being affected by feminization of the labour force, and vice versa. As a result, the changing women's place in society, as well as their growing participation in the labour, the way the city runs should be affected. But the urban structure of Indian cities has yet to experience this social transformation.

Underpriviledged sections of society and gender

The needs and concerns of working-class women when they get access to the elite discipline of planning can be focused on.The needs of women must be taken into consideration, especially those who reside in underdeveloped areas and slums.Women living in slums are engaged in informal economic generating activities like bidi making , agarbathi ,embroidery,tailoring etc.

If we look at the scenarios and efforts in India. Self-Employed Women's Association (SEWA) India is taking initiative to improve and sustain the economic condition of women within the unorganized sector.This association along with creating jobs for women in the form of informal economy which is carried at house hold level ,it is also providing access to other requirements like school and health care centre,housing and clean water. JNNURM (Jawaharlal Nehru National Urban Renewal Mission) taking initiatives in the form of policy reforms to provide basic services by understanding the urban gender concerns.

In Kozhikode, Kerala is preparing to open India's first International Women's Trade Centre, in accordance with the United Nations Sustainable Development Goals. This project intends to increase female entrepreneurship and achieve gender parity by providing a safe environment away from home for women to establish new enterprises, set up or develop existing firms, and promote their goods abroad.
Within the property, there will be women's startup and incubation centres, retail fashion and technology outlets, health and wellness centres, business centres and offices, conference/convention/exhibition spaces, a performing arts centre, residential suites, and day care for the elderly and children.

Global agendas for women rights

According to the U N Sustainable Development Goals (5), UN : 2030 agenda, which aims to achieve "Gender Equality"and the New Urban Agenda(2016) which aims women right to the city.The 2030 Agenda, adopted in September 2015, outlines the importance of cities for human development and how cities and gender equality interact.SDG 11 aims to "Make cities and human settlements inclusive, safe, resilient, and sustainable" for the first time. Gender equality is a cross-cutting goal in the majority of SDG objectives and indicators, according to the Agenda.The 2030 Agenda and the New Urban Agenda serve as a framework for agreements made by UN member states and pledged by governments of global metropolises.

HISTORICAL REASONING OF TRANSITION FROM TRADITIONAL SOCIETY TO MODERN SOCIETY AS GENDER THROUGH TIME AND SCALE.

There is a direct relationship between space and social structure.In a society belief, culture, perception ,time, context impact discrimination and social segregation. The built form expresses ideals and realities concerning the interaction between men and women at various levels, from the city to the neighbourhood, from institutions to the house. The culturally acquired and accepted patterns of behaviour in private and public areas represent a way of life. The use of space is governed by culture rules that are frequently internalized, and code governs gender-ed behaviour. Women's educational and economic potential are hampered by this behaviour, which is accepted as normal. Caste, community, class, religion, ethnicity, and other factors all have an impact on spatial arrangement, with women being the main focus. As a result, the spatiality of public and private areas, as well as their interactions, must be considered.

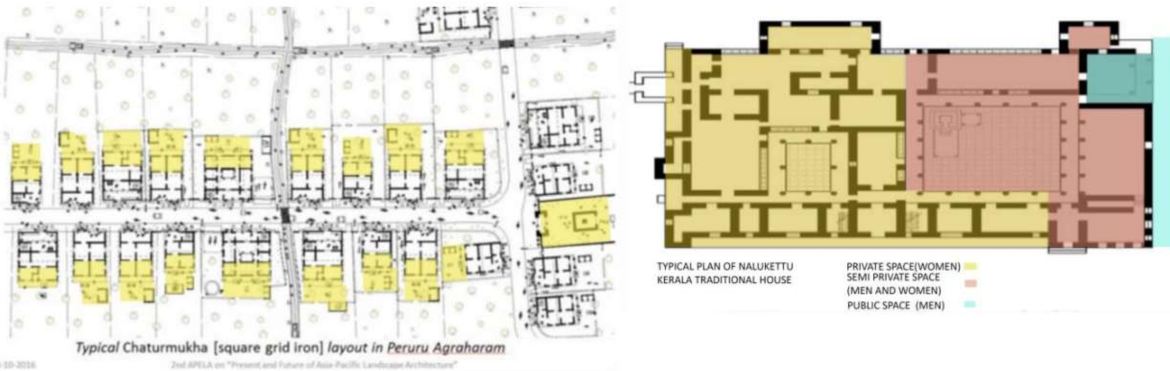

Figure 1:Space used by Men and Women
Source : author

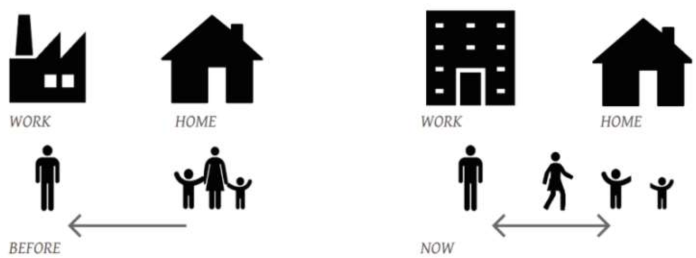

Figure 2: Women and Work
Source : author

"Women's isolation in the home and confinement to domestic life is the basic cause of their unequal position in society" (Hayden, 1982). Before industrial revolution, most productive work during these years took place within or close to the home alongside reproductive work (Arendt, 1958),thus the development of cities was mostly influenced by private interests and business.The Industrial Revolution, on the other hand, saw the migration of economic activity from the house to factories, culminating in the establishment of dense urban slums. Urban planners and designers created urban settings that used the neutral city user who works and is a man, whether consciously or unwittingly. Men were allowed full access to the public sphere, property, and dwellings, but women were relegated to the domestic world and denied land assets.

Migrants to the city in the early nineteenth century left their families behind, but women began to move as well, not just as social migrants but also as economic migrants.The proximity of the worker's residence to the work place is a good illustration of how beneficial it would be for women to have access to the workplace for a significant number of women working in the city.Their engagement in the industry has not yet resulted in a full withdrawal from the domestic sphere. These physical and social realities of women are in direct opposition to international town planning standards, namely zoning laws based on the separation of public and private spaces, which are in turn based on male experiences. Isolated zones result from precise land use planning that divides work and life in cities, limiting flexible accessibility across the urban system.

Women's ambition for economic independence and social equality highlighted a fundamental concern about men, women, and children's relationships in industrial society. It was then that the idea of bringing women out into urban space and including them in the creation of a city became a reality. The need for a physical space was integrated into the design process, which included kitchen less households, day-

care facilities, public kitchens, and community dining halls. Ebenezer Howard, Rudolph Schindler, and Lewis Mumford were among the many progressive architects and planners who promoted the reorganization of housing and neighborhoods around the needs of employed women (Hayden, 1982).
Over the next two decades, several developments in urban planning and design theory helped to shed light on gender discrepancies in the built environment.

Why woman?
By focus on the needs and concerns of women which are common to all addresses the needs and concerns of elders and children.This eventually benefits men also.Gender sensitive urban-ism is to design cities and built environment focusing on gender.

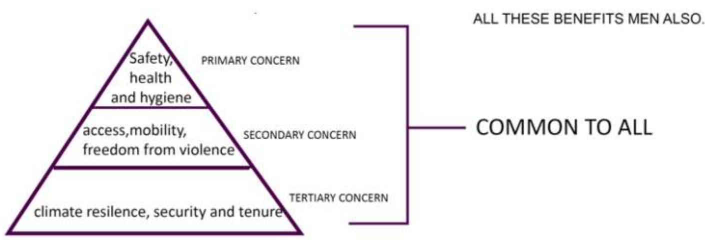

Figure 3 :common to all (women,children,elders)
Source : author

GENDER INTERSECTION IN URBAN SPACES AND ISSUES FACED BY WOMEN

When it comes to developing cities, gender is still an under-discussed subject in both theory and practise. Everyday life rights are negotiated or exercised. Recognizing the role of gender in everyday experience allows planners and policymakers to implement more inclusive solutions. W omen's experiences and spatial strategies are more directly drawn upon in developing frameworks, which leads to finer understandings. As a result, there are approaches to support gender ed and grounded everyday rights notions. Learning from city inhabitants will support sense of belonging.Gender-ed rights may become more fully realised in daily life if the many uses of space are once again taken into consideration within a framework that is sensitive to diversity.

Women's requirements, such as accessibility, safety, and mobility, are not addressed.A fuller grasp of how women assert their rights to urban space and exercise is inherently gender ed stems from a more in-depth engagement with everyday spatial activities.It is critical to comprehend the various methods in which women may enter the city, as well as the function of planning in facilitating these processes. Focusing on ordinary experiences allows us to better comprehend the spatial restrictions that women face as a result of the city's layout. Therefore learning from the past and present can help us understand the needs of women and help in the role of planning for gender equality.Gender ed experiences differ between countries, situations, and political regimes.The city is gender ed as a result of the acts and experiences of its residents. As a result of national laws and shifting social norms, gender is continually being formed at various scales, providing a range of complexity levels for coherent interpretation.

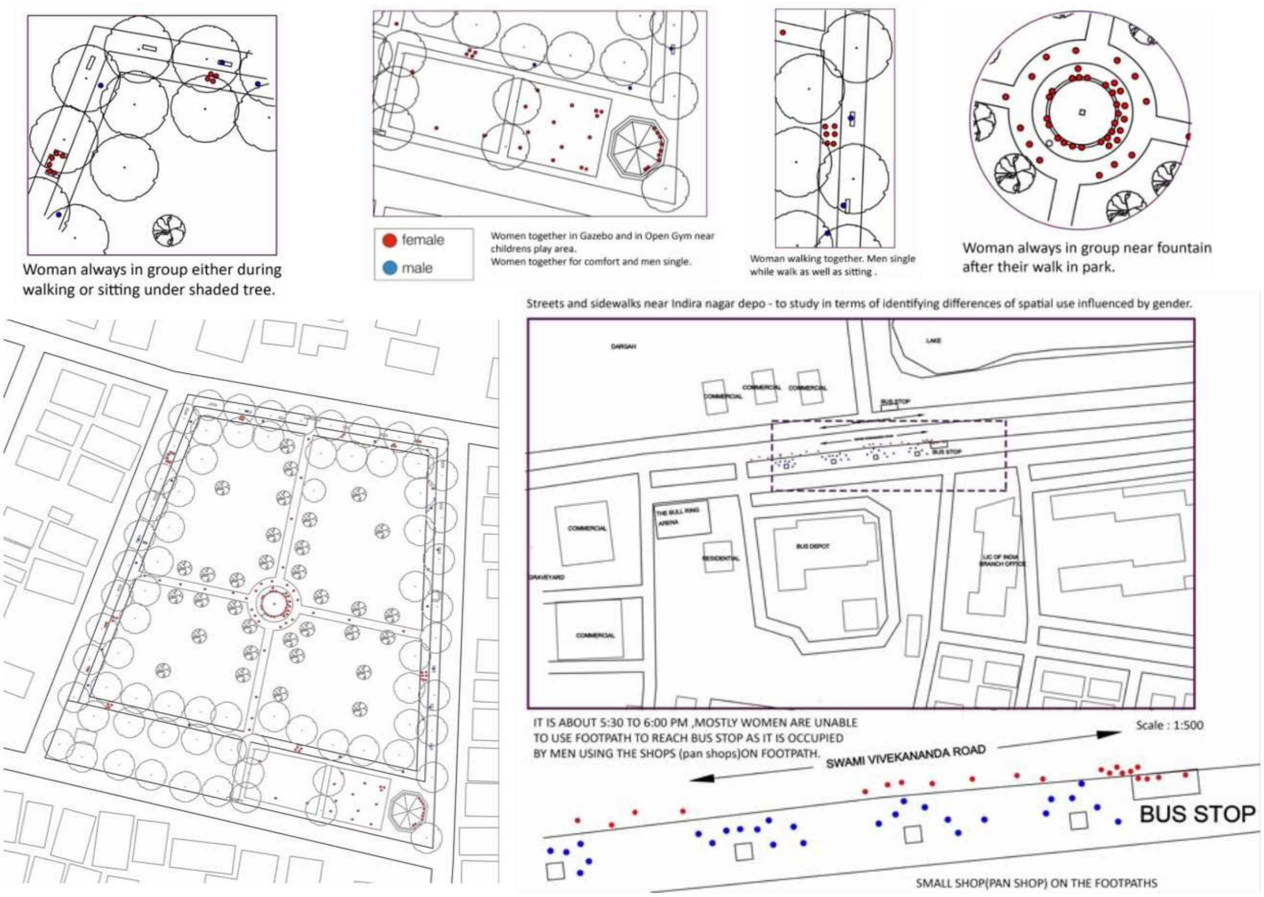

Figure 4 : Neighbourhood park | **Figure 5 :** Streets and sidewalks near Indira Nagar.
Source : author

Neighbourhood park :1.women are found always in group , for comfort and leisure .2.Men always in single. 3. Women always in motion on streets. 4.Men stationary on sidewalks. 5.women always with a purpose while using public space.6. women care taker of elders,children,so accompany kids in parks. Streets and side walks: mostly women are unable to use footpath to reach bus stop as it is occupied by men using the pan shops on footpath as shown in figure 5. Understanding such behaviour and issues faced by women in everyday experience will help the urban designers and planners to design cities considering the needs of women.

TO UNDERSTAND THE ROLE AND ISSUES FACED BY THE SELECTED WOMEN SAMPLE,AT MADIWAL MARKET AND SIDDHARTHNAGAR,BANGALORE.

Madiwal market place has a history .At present it has informal economy and informal settlement.The total percentage of women working in Madiwal market is up to 75% compared to men.There is a work and live kind of atmosphere as the settlements(sidharth colony) are very close to work area(Madiwal market).Madiwal lake area as a public space is very close to this public space. Sidharth colony is a strong community and women centrist or workforce area.

History

Madiwal market was located in this place 60 years ago in the place of present Total Mall.Later on shifted towards the service road,occupying the service road and median because of the development of Mall in place of the market.Madiwal in Kannada means washer man.The locality was home to a community of washermen and washerwomen and the place was named after them.Dates back to 890 AD ,encompassing a busy area between Madiwal and Begur,that flourished among red sandalwood trees.Someshwara temple at madiwala built during Chola dynasty exist even today.Farmers get vegetables from Anekal,Chandapur,Sarjapur,Hoskote,Kolar,Bagalur,Masti,Hathibeli,Tamilnadu,KRpura,Malur,Sulgeri,Vellore,Vagotti.Vegetable vendor buy vegetable from an agent early in the morning at 4:00 am and works up to 8:00pm.Women vendors live in very close area , old Madiwal , Siddharth colony,Tavarkere,BTM 1st stage ,Entapur , Jakkasandra.

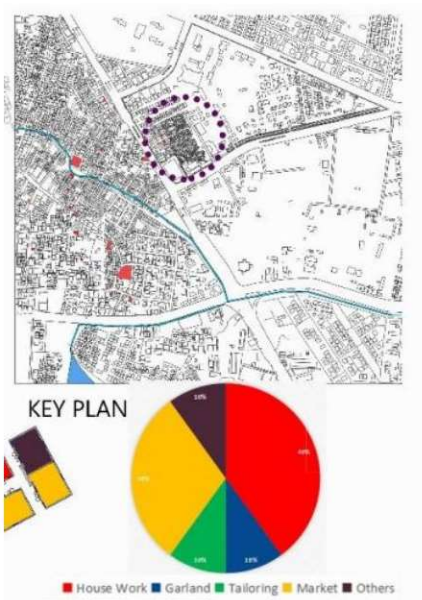

Figure 6: Economic activity of women in Settlements of Siddharth colony.
Figure 7: Key plan showing Siddharth colony and Madiwal market.
Source: author

Role and issues faced by the women

Multiple jobs and the economic ecosystem that the women in informal sectors are involved in.Women in Sidharth nagar engaged in work like House help, pourkarmikas ,garment workers,garland making,cook,idli shop,house keeping,vegetable vendors,woman mason and other formal and informal employment. Gender Sensitive issues at Market area and Siddharth colony according to the parameters are no transparency or permeability,longer blocks, no eyes on streets,no street lights,nodes near market not pedestrian friendly and not to human scale,aesthetically not pleasing,not climate resilient as structures in dilapidated condition,no facilities like toilet,day care and lunch room, health and hygiene issues,no security of tenure,presence of unfriendly activities,no lung space, community space and children's play area,poor housing and infrastructure,no connection to formal city,no facilities like community hall,health care centre and workshop space.

The market from outside is seen as a series of large openings which will lead to interior streets of the market. These large openings merely look like voids,which most people do not see or know about that these voids or large openings leads to distinct functions or land uses behind the market.

Figure 8: Sidharth colony settlement and Key plan showing market stretch and siddharth colony
Source :author

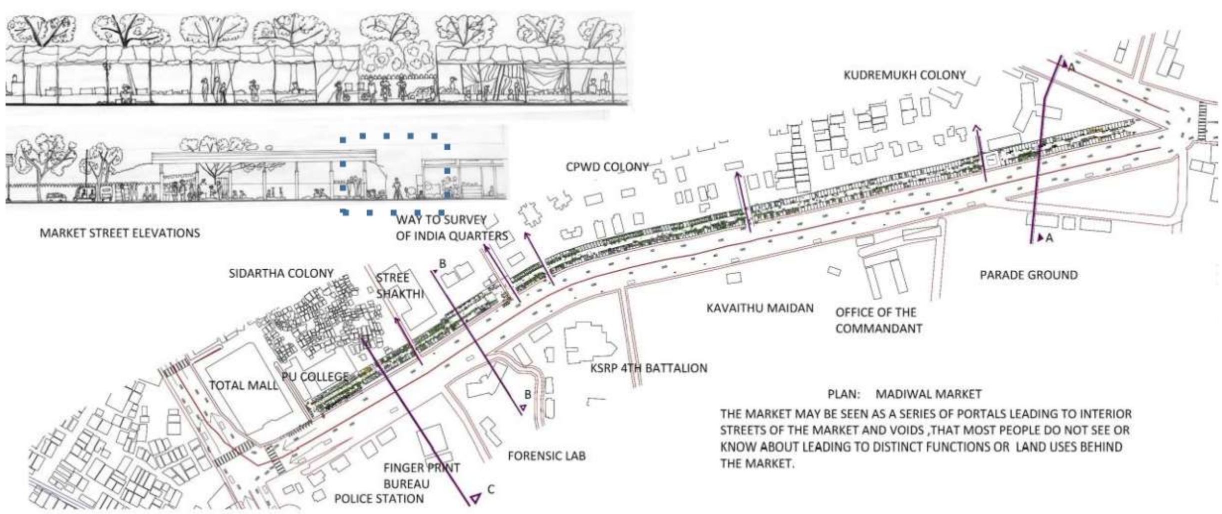

Figure 8 : Sidharth colony and Madiwal market stretch
Source :author

CONNECTING ISSUES TO LARGER URBAN NETWORK AND THESE AIMS TO REVIVE AND INTERVENE THE AREA FOR GENDER EQUALITY

Pattern of women in Siddarth colony and Madiwal market with respect to space,time and activity were analyzed. Women's everyday spaces were mapped ,analyzed, and understood the issues faced by women.Points of conflicts were mapped. By connecting issues of gender to larger urban frame work ,role of selected women sample in the urban network ,what role they play was analyzed. Through classification of spaces with respect to women like economic,sociocultural,political,recreational,mobility the role of the women in these classified spaces were analyzed .A thorough analysis of there economic activity area like production network,consumption network and distribution network were analyzed through mapping their activities,which gave a clear idea of issues in spaces as well as to identify gaps.

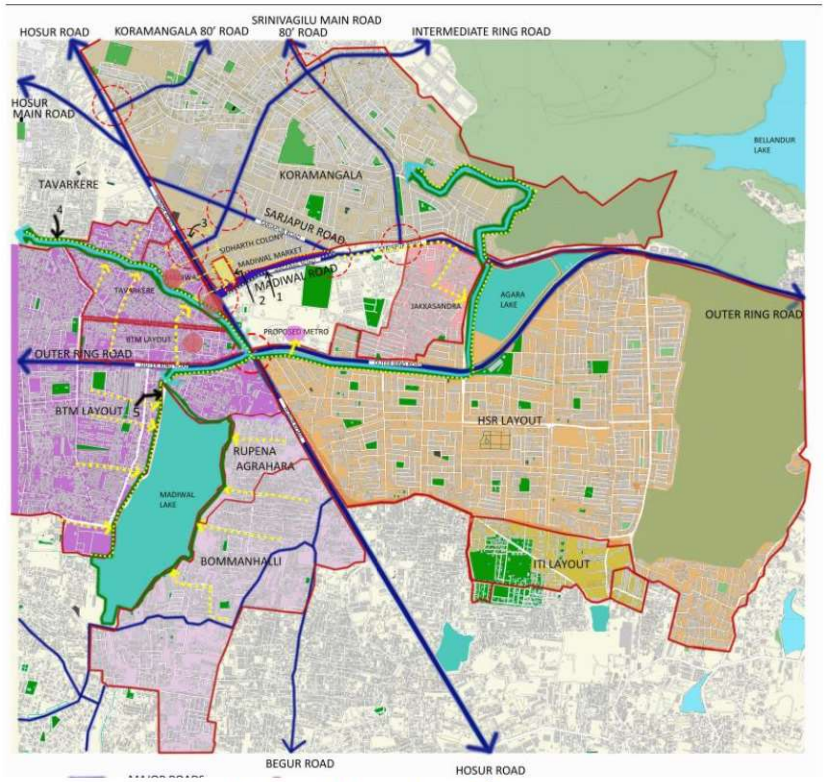

Figure 9: Structure Plan
Source : author

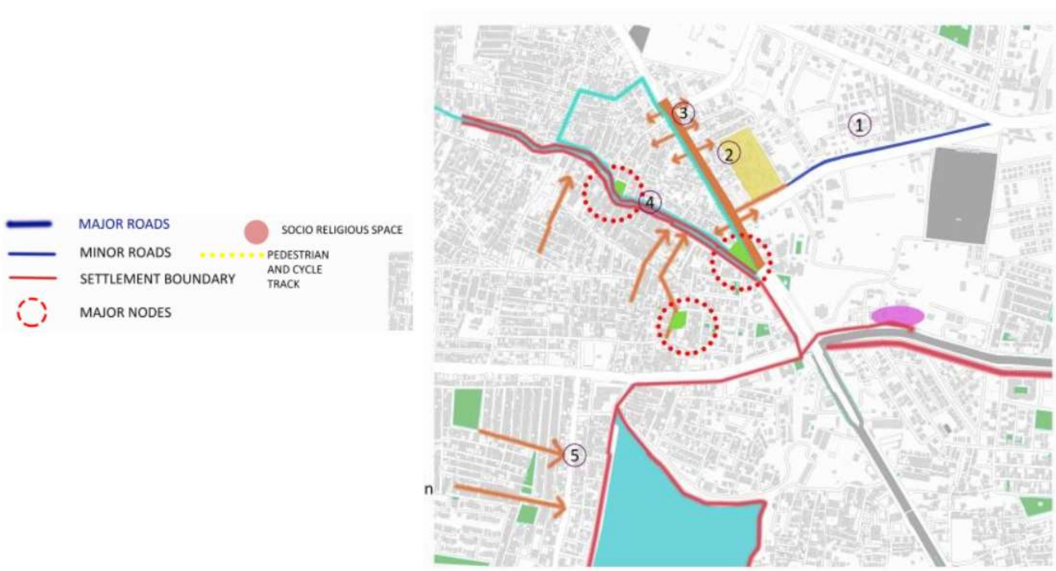

Figure10: Strategy plan
Source : author

STRATEGIES TO REVIVE AND INTERVENE THE AREA FOR GENDER SENSITIVE URBANISM

Redevelopment of Madiwal market stretch ,this intervention will help to achieve SDG goal of gender sensitive urbanism ,by providing a safe environment and a revived platform for women working in Madiwal market as well as for visitors it may be men,women,children,elderly,differently abled people.It will solve the problems mentioned above and provide, transparency or permeability,shorter blocks,eyes on streets, street lights, making nodes near market pedestrian friendly and to human scale,aesthetically pleasing,climate resilient with climate responsive materials and providing facilities like toilet,lunch room space, etc

Redevelopment of Sidharth nagar slum area,the neighborhood is an informal settlement tucked away behind the market streets of "MADIWALA" ,located in Koramangala ,Bangalore.It is a 6 acre land ,home to over 600 families approximately 3000 individuals and living in 6 Sq m . Total number of families existing is 600.Intervening this area will provide proper housing and infrastructure facilities and solve all the problems mentioned above by providing workshop space,lung space,day care,health care,community hall ,security of tenure,presence of friendly activities,community space,children play area.This intervention will help to achieve the goal of SDG i e Gender equality ,as work place and live place are in proximity to each other, which will help the women to achieve their economic potential fully. Issue of accessibility,the highway was dividing the Madiwal village and market, women faced problem in connecting .The solutions were side walks,crosswalks and street lights.Thus connecting the two areas and stitching them .

Strategy to connect the social religious spaces to community and thus creating public realm.Social religious spaces to be used to engage the community .The buffer zone of Nala very close to these religious space to be developed as public realm and giving a sponge effect for sustainability.Generating interest of the community by giving incentives,creating sense of belongingness by incentivising the use of commons by the community(by building parks etc).By building a sense of belongingness and dependence on the urban commons,also achieving the effect of "eyes on street". Providing pedestrian and cycle track along nala edge and lake edge to connect to the lake which is a public realm and to the metro station.

Figure11&12 : Proposed intervention at Siddharth Colony & Madiwal Market
Source : author

CONCLUSION

It is necessary to understand the role of women in history and in present day.With this analysis we understand the changing role of women in present scenario.This changing roles of women gives us further reason to understand the needs and aspirations of women,how they navigate and negotiate everyday spaces and the issues faced by women.For gender sensitive urban-ism,it is necessary to take evolving gender roles into account.There are different issues related to gender at different contexts. Those different issues need to be addressed for un gendering the city. Therefore through tactile interventions and through integrated approach in design as many aspects of the city affect gender differently ,SDG goal of Gender Equality can be achieved. There is further scope to investigate the city from gender perspective.Women are engaged in economic, social and recreational activities,the public spaces and infrastructure design need to be considered through gender Perspective by Urban planners and designers.

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ECOLOGY-CENTRIC DEVELOPMENT CHALLENGES AROUND URBAN LAKES: CASE OF PUTTENAHALLI AND HEBBAL LAKE

Aruna Gopal[1], Sudha Kumari G[2], Surekha Ramineni[3]

[1] Faculty, Ramaiah Institute of Technology, MSRIT Post, MSR Nagar, Bengaluru, arunagopal@msrit.edu
[2] Faculty, Ramaiah Institute of Technology, MSRIT Post, MSR Nagar, Bengaluru, sudhakumari@msrit.edu
[3] Faculty, Ramaiah Institute of Technology, MSRIT Post, MSR Nagar, Bengaluru, surekha.ramineni@msrit.edu

ABSTRACT

Urbanization is a boon to the economic growth of a city, but its impact on the lake ecosystem has led to significant deterioration and ultimately loss of many lakes in the recent past. At the same time, it adds tremendous stress on the environment and existing resources, especially the water quality in the lakes due to anthropogenic activities leading to eutrophication that results in adverse effects on human health. Well maintained water bodies with good standards of Water Quality (WQ) mitigates the urban climate and significantly improves the aesthetic quality of the urban ecosystem. This paper aims to study and analyze the quality of water in two lakes - Puttenahalli and Hebbal Lake in Urban Bangalore, further analyzed for pH, Conductivity, Turbidity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Hardness, Chloride, Total Alkalinity, Nitrate, Phosphate as PO_4, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Sodium, Potassium and Sulfates with standard methods. The paper further discusses the findings for prospective sustainable development and protection of lakes and their ecosystem by suggesting strategies for mitigating anthropogenic factors for sustainable development.

Keywords: Sustainability, Anthropogenic factors, Eutrophication, Water Quality, Bangalore lakes

INTRODUCTION

Planning and developing a resilient ecosystem mainly depend on the basic resources to be in good condition. (Surendra *et al.*, 2018) The lake ecosystem is one such resource that is vital for the health of the urban environment as they regulate the microclimate of the region. Urban lakes perform numerous functions replenishing the ground water, supporting biodiversity, as catchment area and buffer against floods, as source for drinking water, agricultural needs, recreation and tourist attractions. They are also associated with cultural and historic values thus closely interacting with human society. In the past lake and community users had a close bond and this relationship helped in having well sustained water bodies. But with passing generations the lakes have been mismanaged, encroached, deteriorated or some of them have totally disappeared, fragmenting the human-lake relationship. Urban development has been influenced by the relation between urban planning and water bodies in the past and will continue to do so in future too. For instance, urban development has led to 19 lakes transforming to Bus stands in Bangalore. Urbanization often leads to conflicts in ownership of lands and changing landscape over time. (Unnikrishnan, 2016) Land use changes due to rapid increase in population puts further stress on water bodies. (Guo *et al.*, 2010) A significant bulge in population during the last century put developmental pressures on the lakes transforming them into sinks for contaminants resulting in their degradation or complete disappearance. (Ravikumar, Mehmood and Somashekar, 2013).

To reduce environmental degradation of lake ecosystems it is important to acknowledge the link between poor water quality and human activities associated with lakes. Interactions of anthropogenic factors with physical and chemical components of the lake ecosystem determine the health of the lake. (Ramachandra, 2007). The water bodies were selected based on their use and locations. The lakes belong to two different catchment areas, while Hebbal lake belongs to Hebbal valley, Puttenhalli lake belongs to Chellaghatta valley. As both the lakes have been revived in the past from eutrophication condition, it was intended to observe the developments, management and status of the lake after revival till date to assess the extent of impact by anthropogenic activity. The locations of both urban lakes have different types of user interactions, management strategies and different challenges, hence comparative analysis of development and management of the two lakes provide an interesting perspective of lake survival in urban conditions.

BACKGROUND

History of Bengaluru and its Lakes

Bengaluru, the capital city of Karnataka is the fifth-most populous agglomeration of India making it a megacity. With a population over ten million, this southern city is located on the Deccan plateau at an elevation of 900m from mean sea level. This cosmopolitan city was once popular as 'Pensioner's paradise' and 'Garden city'. Kempe Gowda, a medieval chieftain founded 'Benda Kaalu Ooru'(Bengaluru) in the mid-sixteenth century. According to the author (Unnikrishnan, Sen and Nagendra, 2017), the settlements date back further to stone age as derived from a megalithic stone tomb and epigraphical inscriptions. Absence of perennial river flowing in this region created the need to build lakes bunding the natural ridges and valleys that suited well to form the water bodies. These lakes would serve the settlements with drinking water, livelihood needs like fishing and water for irrigation, cattle etc. The system was maintained by the local residents and was well managed by interlinking the lakes so that the lake water has a cascading effect thus removing possibilities of flooding. The lakes depended on the rainwater harvested. This helped the recharge of the ground water too that was abundantly available by wells and reservoirs. Over the years with the advent of piped connections bringing river Kaveri water from long distances to the households, people neglected the lakes and the growing cosmopolitan population no longer connected to these water bodies. Urbanization and Information Technology (IT) boosted the economic growth of the city, at the same time, the city failed to handle the exploding population of job-seeking migrants, the city's failing sewerage system and ill-maintained solid waste management caused tremendous stress on the water bodies. Sadly, out of 262 lakes from the 1960s to only a few handful ones are in good working condition, the scenario calls for urgent change in our attitude to nature and the city.

Attribute of Urban Lake Degradation

The various factors which affect the quality of water in urban lakes are mainly due to anthropogenic activities such as change of landuse, idol immersions during festivals, unhygienic activities and open defecation. (Peters, Meybeck and Chapman, 2005) have elaborately studied the various human interventions that impact ecological properties. Deforestation leads to increased runoff, increases soil erosion that leads to agriculture runoff with inorganic fertilizers getting into the streams, depletion in ground water level, leached pesticide and herbicides in water affecting the quality. Increase in invasive exotic plants alters the food web. Presence of pathogenic bacteria in freshwater bodies is detrimental to humans. (Huang *et al.*, 2013) suggests through their study that the built-up land was positively related to the indicators of water quality whereas forest land and grass land were negatively related to water quality. Another interesting observation is that diversity in landscape reduces the pollution in water quality. (Gorain and Paul, 2019) enumerates the fluctuations in the biochemical properties of the lake water during the religious festivities with idol immersions. Rise in BOD and COD levels in the post immersion period can be attributed to the dilution of biodegradable matter in the water which may be due to decomposition of flowers, leaves and other organic matter used in rituals. The authors recorded an increase in heavy metal concentration after the immersion period due to varying solubility rates. Increase in public awareness about the damage caused to aquatic ecosystems due to idol immersion is vital to combat the issue.

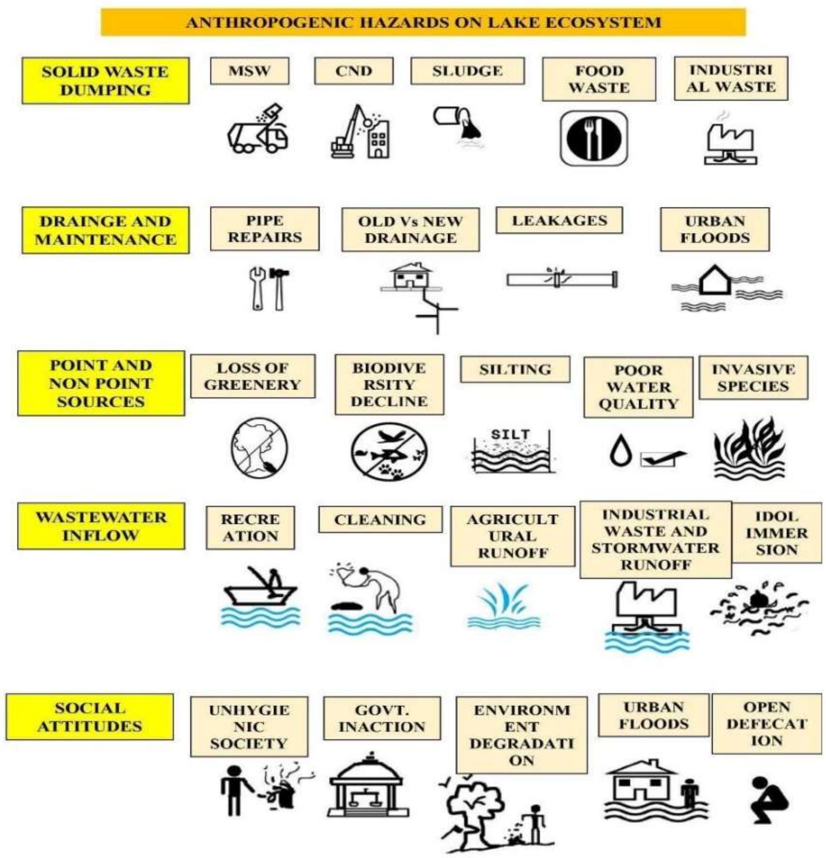

Figure 1: Anthropogenic hazards on lake ecosystem
Source: Author

Significance of Water Quality Testing

Quality of water is a significant indicator of ecosystem resources available and the biota in the region and also the suitability of water for human use. (LIANTHUAMLUAIA, ASHA T. LANDGE, C. S. PURUSHOTHAMAN, 2013) Water quality is determined by a large number of physio-chemical parameters along with biological parameters. Hence it becomes essential to identify the sources of the contaminants to provide scientific remedies for improvement in city planning around urban water bodies and recommendations for efficient lake management. (Rao, Jeevan and Jayashankar, 2010) have studied the biochemical parameters of four polluted lakes of Bangalore of which Puttenahalli lake is one of them. As the samples were collected during algal blooms in the lake which also had fish kills, high values of pH and turbidity were noticed. This study was undertaken in 2010. PNLIT had reported sewage leak into the lake by storm water drain from March 2018 again. (http://plog.puttenahallilake.in/) Trophic state index was calculated using the average Secchi depth, average Chl-a and average total dissolved P concentration that indicated Puttenahalli in bloom conditions to be in hypereutrophic state. Influx of sewage and runoff caused bicarbonate production from microbial activity along with N and P pollution caused the algal growths. We understand from this study that Puttenahalli lake is subjected to extreme stress from anthropogenic factors summarized in Figure 2. (Ramakrishna, 2014) investigates the significant role of Abiotic factors in the trophic dynamics. The DO levels in water are an indicator of water quality. The presence of fish and invertebrates are bio indicators of water quality. The water parameters correlation with Benthic fauna showed positive results. Abundant vegetation and aquatic plants support organic matter to thrive in water. The report indicates moderately polluted Hebbal lake which was tested in 2013 to 2014.

METHODOLOGY OF LAKE RESTORATION

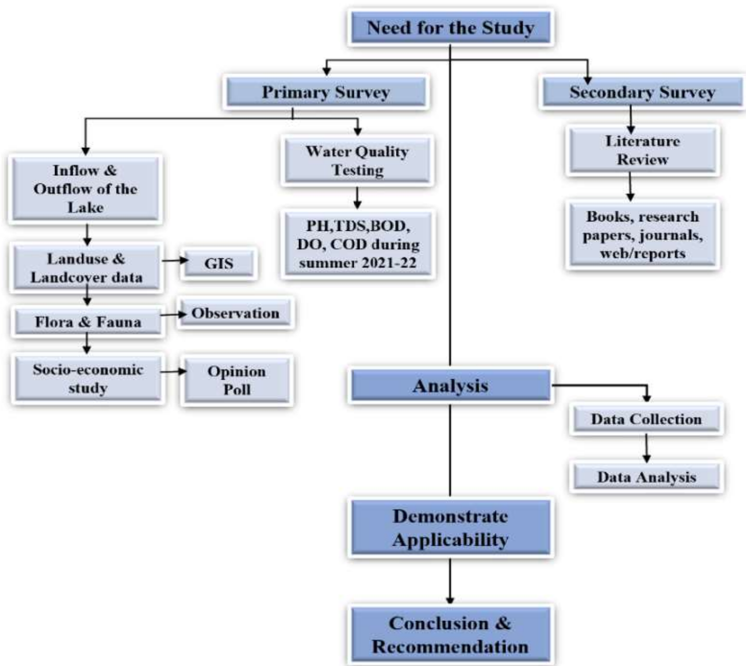

Figure 2: Methodology of study
Source: Author

STUDY AREA

The Hebbal lake is located at 13.0466° N, 77.5856° E occupying an area of 192.48 acres belonging to Hebbal valley. It was created in 1537 by the founder of Bengaluru, the chieftain Kempegowda, by building bunds around the natural valleys facilitating the accumulation of water through rainwater. This lake has been home to exotic birds and aquatic life but at the same time there have been incidences of fish kills and sewage inflow that prompted restoration of the lake in 1998. Hebbal lake has been under the aegis of Lake Development Authority (LDA) since 2002 and has been recently taken over by the Ministry of Environment and Forests (MoEF).

Puttenahalli Lake at J.P Nagar is the smallest of the three lakes- Jarganahalli, Chunchaghatta, Puttenahalli. It is located at 12.8904° N, 77.5872° E with an area of 13.25 acres. PNLIT (Puttenahalli Neighborhood Lake Improvement Trust), a citizen group and Bruhath Bengaluru Mahanagara Palike (BBMP) had spearheaded the lake revival from 2008. The successful revival of the lake was maintained until 2018 when its water was threatened by two most dreaded reasons: sewage seeping in from Under Ground Drain (UGD) and encroachment of land. Restoration works are underway and the lake is getting back its past glory.

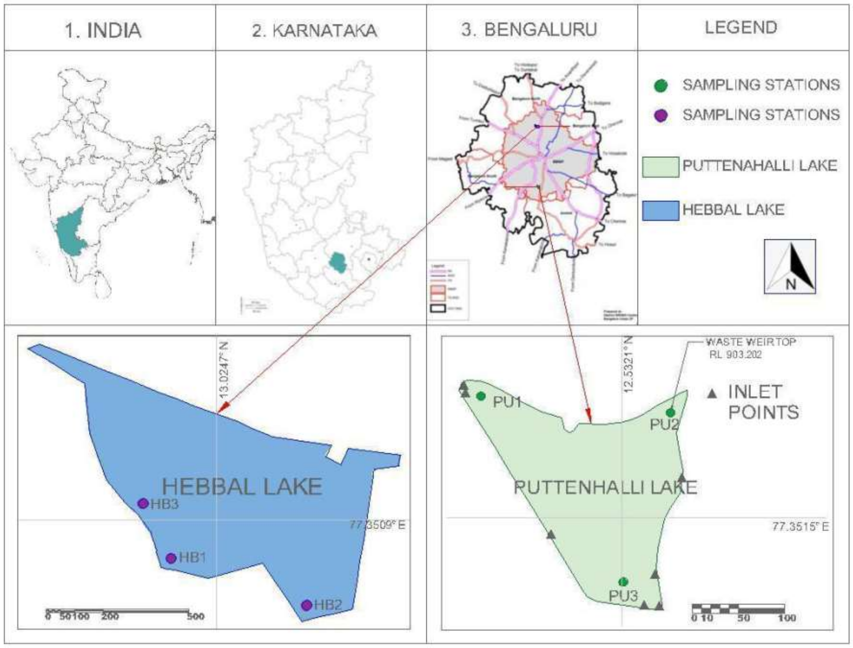

Figure 3: Study area map
Source: Author

LITERATURE STUDY

As per the BBMP records on lakes, out of the 210 lakes that exist in Bengaluru urban, BBMP has 167 lakes under its custody, 33 lakes are under Bengaluru Development Authority (BDA), 5 lakes are under Karnataka Forest department custody, 4 each under Lake Development Authority (LDA) and Metro/BMRCL. Under Article 51-A (g), it is the fundamental duty of every citizen of India "to protect and improve the natural environment, including forests, lakes, rivers and wildlife, and to have compassion for living creatures". Some of the Acts and regulations that provide a legal framework to protect the lakes are National Environment Policy, 2004, The Environment (Protection) Act, 1986 (EPA), The Forest (Conservation) Act Of 1980, The Water (Prevention and Control of Pollution) Cess Act of 1977. In 2020, the High Court passed a judgment that the State Government will not execute any MOU with the local lake groups, this would include BBMP not having to link with any local lake groups for its maintenance or upkeep. This judgment came as a huge blow to the private partnerships of the citizen's group who took BBMP's help in maintenance which was a huge financial load otherwise.

Table 1: Socio-economic and environmental factors of Hebbal and Puttenahalli lake
Source: Author

Factor	Hebbal Lake	Puttenahalli Lake
Social	No walking paths, recreational sports or facility at the premises Entrance fee was collected Presently closed to public Once existing lake goddess spot is not accessible to public No public participation in lake management. Access denied to the public creates room for spurious activities.	Newly laid pavement for walking. Public participation in cultural and recreational activities organized on lake premises Environment awareness-based activities organized have participants from corporate offices, institutions and experts on various disciplines. Commercial fishing is practiced

	Has aesthetic appeal and cooling effect	Lake water and greenery around it enhances the climate
Economic	Pisciculture activities generates income Poorly maintained pathways and lack of recreational facilities make it unwelcome to public use Income to washermen using the lake Income from cattle feed.	Fund crunch in maintenance of the lake by BBMP and PNLIT Active community and citizen group participation in management of the lake ensures its survival Generates income to people involved in lake maintenance
Environmental	Abundant resource of flora and fauna Known for migratory birds visiting the lake Threatened by privatization of lake Proximity to National highway adds to traffic related issues during rains and in runoff characteristics.	Constantly threatened by malfunctioning underground drainage system and land encroachment that contaminates the water Home to exotic flora and fauna, well documented by community participation Citizen groups activities oriented to environmental awareness and conservation.

URBAN TRANSFORMATION: HEBBAL AND PUTTENAHALLI LAKE

The man-made lakes in Bengaluru have undergone tremendous transformation with respect to the size, water quality, flora & fauna which in turn attracts migratory birds and the melody of birds/hustle of leaves has declined over the years. In case of Puttenhalli and Hebbal lake if we observe the satellite images for the year 2000 & 2022 in the Figure 4, we can see the economic growth of Bengaluru city with increase in urban infrastructure but certainly decline in green cover resulting in environmental degradation. The urban infrastructure occupied the catchment areas around lake and inflow of solid waste resulted in the decline of ground water. The identification of the extent of boundary of catchment area was not clear hence we could observe in the pictures of garbage dumping and encroachment by buildings and squatter settlements. The land use around is mostly residential because of the encroachment and change in the land-use from agricultural land to others, instead of parks and waterfront development. The physical infrastructure mainly around Hebbal lake national highway and outer ring road with a junction/ node along the catchment line restricts the activities of protection of lake like increase in green cover/lakefront development.

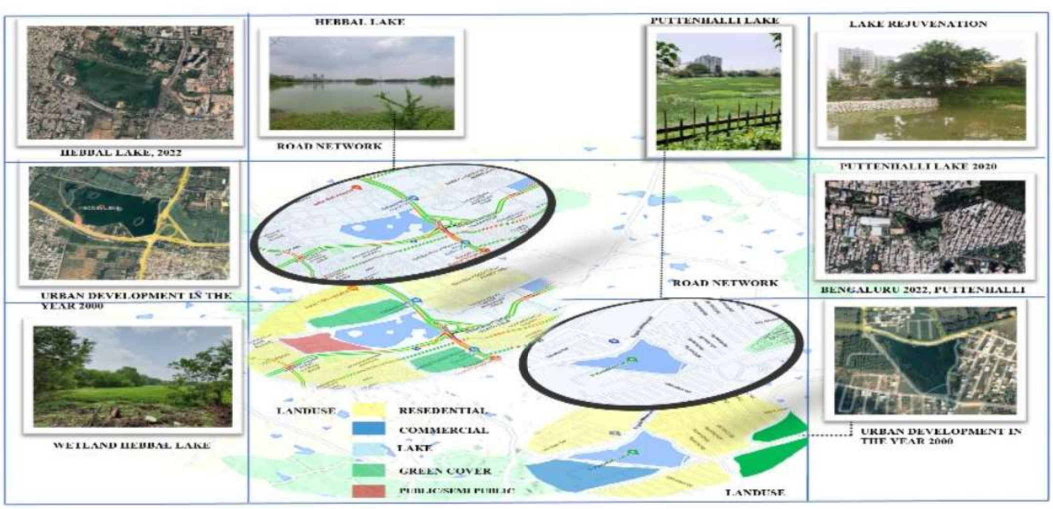

Figure 4: Chronology, Land-use and Road Network of Hebbal and Puttenahalli lake
Source: Author

PRIMARY SURVEY: HEBBAL AND PUTTENAHALLI LAKE

Water Quality Testing

Samples were collected from the lake as per standard procedures during early summer in March 2021and a year later in summer of April 2022. During sampling at Puttenahalli lake in 2021, the lake was undergoing rejuvenation works like dredging and dewatering on site and hence closed for public use. Hebbal lake was under LDA and was open to the public for a limited time. One year later in summer of 2022, Puttenahalli lake had been restored by BBMP and PNLIT. Hebbal lake was taken over by MoEF and the public was not allowed to use the lake premises except in the morning hours for a limited time. It is observed that both the lakes are only rain fed and do not have any other inlet of water other than runoff from road at certain points along the lake. One-liter sterilized plastic bottle was used for sample collection and then water was collected without entrapping any air bubbles by plunging in with the neck down. (Surendra *et al.*, 2018) The sampling points were near inlet points of runoff in Hebbal lake and at Puttenahalli lake it was collected near slum encroached area, near waste weir and near STP treated water discharge point. pH, temperature, turbidity and DO were immediately tested as they can change over time. Samples were refrigerated at 4°C for testing other physio-chemical parameters (Conductivity, TDS, TSS, Total hardness, Chloride, Total Alkalinity, Nitrate, Phosphate, BOD, COD, Sodium, Potassium, Sulphates) in laboratory as per standard methods (Ravikumar, Mehmood and Somashekar, 2013). Applying the framework to provide sustainable urban ecosystem (Keeler *et al.*, 2012). The WQ parameters evidently point to the differences in the status of the lakes during the time it was sampled. While Hebbal lake has pristine water with minimal human interventions, Puttenahalli lake is just recovering from consequences of raw sewage inflow into the lake. The lake is filled with weeds and the sediments are being dredged and contaminated water is being dewatered. The stress induced by incompetent storm water drains and encroachment issues on the lake water body significantly alters the chemical composition of the water and ultimately the biodiversity of the lake is also severely impacted. This can be seen in the variations of the WQ parameters between the two lakes.

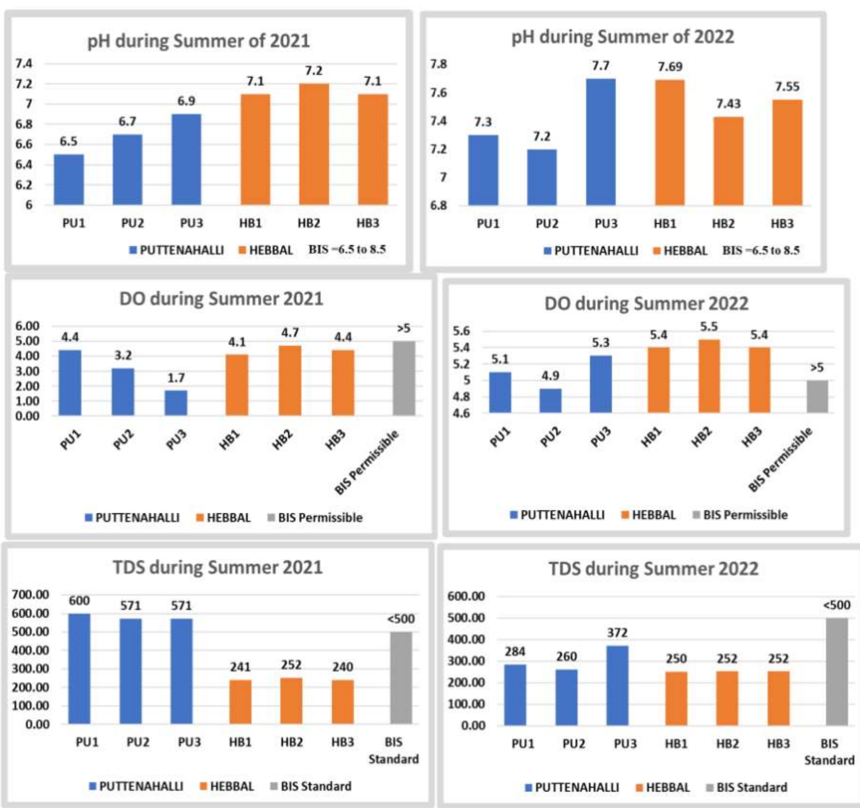

Figure 5: Graphical representation of WQ parameters of pH, DO, TDS in Summer of 2021 and 2022
Source: Author

RESULTS AND DISCUSSIONS

The pH values of Puttenahalli lake are on an average 6.6 and that of Hebbal has an average of 7.1. Level of DO is important for survival of fish and other aquatic plants (Ramachandra, 2007) and its level is maintained by photosynthetic activity. The lower level of DO of 1.3 in Puttenahalli Lake is due to its eutrophication condition. Hebbal lake shows an average of 4.5. BOD and COD are important parameters indicating contamination with organic waste, typically disposal of domestic or industrial waste. BOD should not be above 6 mg/lit for drinking water. The BOD values for Puttenahalli lake shows above standards due to aquatic plants on site. The COD test indicates the toxic state of the lake. High COD indicates increased anthropogenic stress and high organic matter. (Ravikumar, Mehmood and Somashekar, 2013) COD of HB lake ranges between 8 and 16. A high TSS means presence of metals, pesticides and nutrients. TDS is a measure of the organic and inorganic content. TDS is a leading cause of turbidity in water. Electric conductivity is the ability of a solution to carry electric current. It has a direct relation to TDS and temperature. The high conductivity in PU lake confirms the presence of overload of nutrients. Nitrates accelerate the growth of algae and macrophytes. Its presence indicates human activities like agriculture, food industry, effluents from industries. Hardness is caused by the dissolved carbonates and bicarbonates of Calcium and Magnesium. The sample point PU3 is having high values as it is the inlet point of waste water from STP. Large quantities of detergents inflow into the lake from residential dwellings also contribute to high hardness values. Excess Chloride is detrimental to aquatic life as it reduces the DO content. It remains in the sewage even after treatment and its level may vary during different seasons. A significant improvement in water quality parameters is observed in Puttenahalli lake in the summer of 2022 as the lake was restored. Improvement in DO was observed which related to increased activity of birds, fishes etc. indicating the good health of the lake.

Opinion Poll

A survey of how the public in general was aware and participating in the present scenario was essential to be understood to justify the need to conserve natural resources in urban context, hence opinion poll was conducted through lake group member, people living in the vicinity of the 3 lakes selected Hebbal lake, Sankey tank and Puttenahalli JP Nagar lake. 37.6% felt the lake maintenance was average, as these lakes had fenced boundary, 35.4% were sure there were no encroachments, Negligence of governing bodies and insensitivity of general public to environmental issues were cited as the main reasons for pollution in the lake by more than 56%. Nearly 54.2% agreed to the decline in ecological factors like trees, bird and fish population. Less than 50% wanted to participate in lake conservation activities. The above opinion poll bares the fact that people fail to take responsibility for the public issues that need government attention. Mere agreement to the burning issues does not help in resolving them.

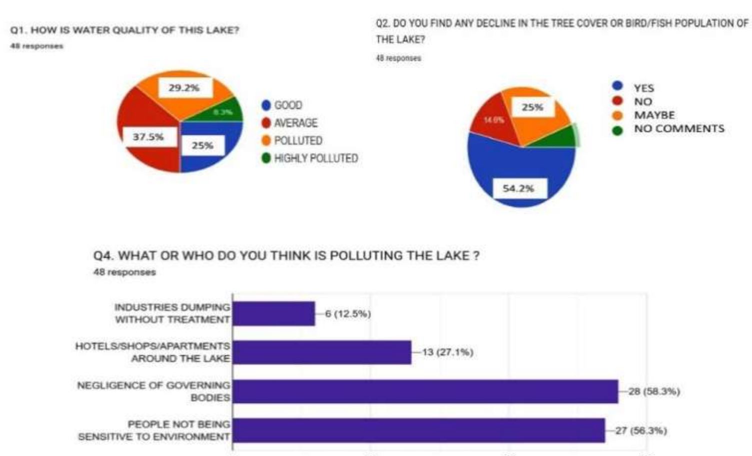

Figure 6: Opinion poll result
Source: Author

CONCLUSION

The above study and analysis of the two lakes w.r.t water quality and urban transformation gives us an understanding to look into the details of site level activities like inflow/outflow of the lake, water pollution & anthropogenic factors, in case of the Puttenahalli lake that was on the path to rejuvenation had parameters that needed immediate action to address the issue of lake weeds, cleaning and drainage system upgradation of the area. The anthropogenic stress is high on the lakes that interact with people on a daily basis. Hence these lakes must maintain the records of water quality in all months and seasons as it provides a clear picture of the type of contamination and its possible solutions. The significant improvement in water quality parameters like the TDS, TSS, DO indicates the effect of restoration practice. The scope to interpret these chemical parameters further to predict the possible level of contamination in future and the relationship with land use can be researched in depth. Apart from the site level activities, a macro level study, decisions made by the competent authorities in terms of landuse, landcover and physical infrastructure laws to be strictly enforced with rigorous punishment and a participatory approach with government and the public with regular interaction and awareness campaign can regulate the environmental pollution and contribute in the better quality of life of an individual.

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SOCIO-SPATIAL PLANNING FOR WELL-BEING IN TOWNSHIPS

Supritha M Y[1], Dr. Mahavir[2], Deepak D G[3]

[1] Research Scholar, School of Planning and Architecture, New Delhi, Assistant Professor, BMS School of Architecture, Bengaluru, suprithamy@bmssa.ac.in
[2]Professor, School of Planning and Architecture, New Delhi,
[3]Assistant Professor, BMS School of Architecture, Bengaluru, deepakdg@bmssa.ac.in

ABSTRACT

Well-being is the condition of a person or group. A high level of well-being means that the condition of the individual or group is positive in a sense. It is an experience of physical health, social life, and economic growth. This includes psychological health, high life satisfaction, meaning or purpose, and the ability to manage stress. According to International Sociological Association, Various Indices have been formed to rank different countries. Good country index, Human Development Index, World Happiness Report, and Social Progress Index are a few Indexes that the International Sociological Association takes into consideration. Each of these Indices has identified indicators to measure the country's social development.

One of the concepts that are rapidly changing the country's real estate economy is Integrated townships. The exponential growth of urban dwellers leads to the growing demand for housing and urban infrastructure. The housing sector is also changing more urban dwellers from independent homes to gated communities and integrated townships. Increase in township development as more people are moving towards investing in the townships.

Socio-Spatial Planning promotes knowledge of how to modify the built environment with its users. The emergence of self-organizing civic collectives is a crucial change in today's social search for sustainable places and the future. It highlights citizens' role in creating places. Spatial justice is one of the main principles of designing future cities. This paper deals with identifying the different indicators of well-being for townships.

INTRODUCTION

During the 20th century, population and urbanization patterns has increased rapidly in most towns and cities. As per the United Nations (UN) estimates, the proportion of the world's urban population is expected to increase from 55% in 2018 to 68% by 2050 (UN DESA 2018). The projections show that urbanization on, gradual shift of population from villages to cities, combined with the overall growth of the global population could add 2.5 billion people in urban areas by 50. A meta-analysis of 326 satellite data-based studies between 1970 and 2000 shows a minimum global expansion in urban land area of 58,000 km2 i.e. about 9% of the 2000 levels (Seto et al. 2011). At current urbanization rates, a doubling of the urban population during next three decades will require a tripling of built-up areas (Angel et al. 2010). This rapid urban growth could reduce per capita social-economic amenities which in turn exemplified in decreasing wellbeing in different aspect. Problems such as lack of jobs, homelessness, expansion of squatter settlements, inadequate services and infrastructure, poor health and education services and the deteriorating environment are among the factors that hinder the well-being of citizens. The problem would be unquestionably acute in residential neighbourhoods that occupy a significant portion of any sizeable town or a city.

Concepts such as Transit Oriented Development, Liveable Communities, Smart Growth, Form-Based Code, New Urbanism, and others. try to tackle these issues through holistic planning for living, working, recreation and movement. Most Indian cities are already under tremendous pressure due to a lack of land for urban expansion and traffic congestion. Population increase and urbanization growth rates are higher than infrastructure development. This has led to serious urban problems such as vehicle and population congestion, urban sprawl, slums, pollution, pressure on available infrastructure and services, and environmental and health problems

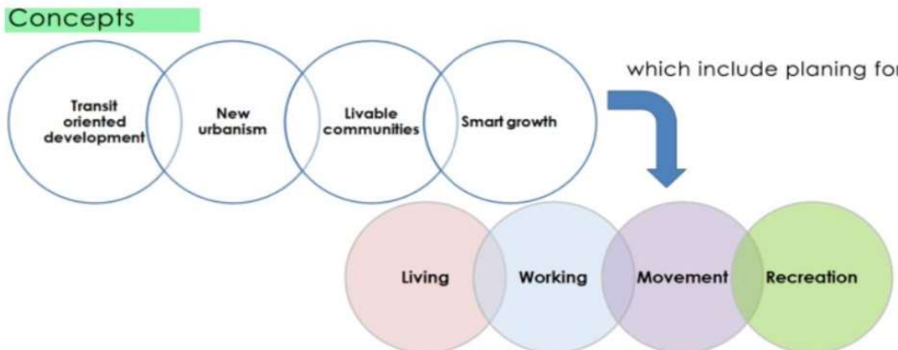
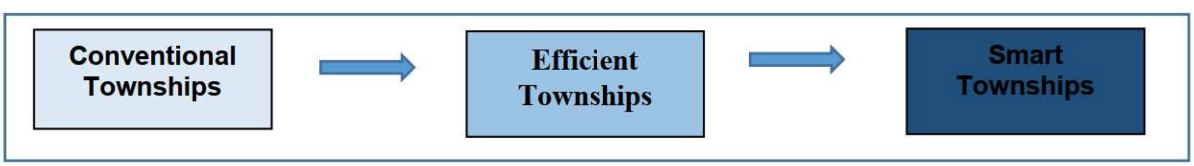


Figure 1. Concepts of urban development

There is a lack of infrastructure and a housing shortage which could be categorized under the sustainable neighborhood category, including all the amenities required to meet the country's current needs. When it comes to urban development, townships are a new format for the future. Townships are a potential solution as urban areas become more crowded. The Integrated townships which are mainly focused on work, play, and live concepts are the potential townships. However, the development of the township has been taking place for more than 20 years under various models. This has been quite evolutionary. The township's initial development was around the city boundary is slightly less organized but linked to the central city. Then came the integrated townships that are self-sustained to accommodate the populations through plotted developments and housing units.

Evolution of Township models in India



Township development then took the turn to efficiency and environmental protection. Due to physical aspects and varying social composition, every neighbourhood has a unique sense of place. There will be a mutual effect between the old and new housing developments built adjacent to each other.

Figure 2: Townships in different locations in India

WELLBEING

Well-being is the condition of a person or group. If the condition of the individual or group of people is positive, it indicates a high level of well-being. it is an experience of physical health, social life, and economic growth. The level of satisfaction with people's living conditions is essential for well-being. Well-being is assessed based on subjective and objective well-being. The subjective components deal with quality of life and objective components deals with the standard of living. Well-being is a combined measure of physical, social, mental, and economic well-being experienced by each individual and group of people. According to Diener, 1984 Subjective well-being is often conceived of as three different metrics: Life satisfaction, positive affect, and negative affect. Subjective well-being can also be distinguished by: Life evaluation, Hedonic wellbeing and Eudaemonic wellbeing.

Happiness cannot be measured directly; it is associated with the emotional condition of the people and is a time-based aspect we need to consider for well-being. People's expectations and past experiences also play in a major role in evaluation. These factors get affected by various factors that affect day to day living and lifestyle of the people. Such as household size, education qualification, health conditions, property assets, leisure time, and also personal satisfaction and self-esteem. People residing in a commonly administered community are likely to be more affected by the concept of well-being than people living in individual properties.

THE LINKAGE BETWEEN RESIDENTIAL ENVIRONMENT (IN TOWNSHIPS) AND PERSONAL WELLBEING.

The residential environment provides the backdrop to the lifestyle we adopt and impacts our community life and emotional attachment toward society. One's participation in physical activities and general well-being are also linked to the surrounding environment.

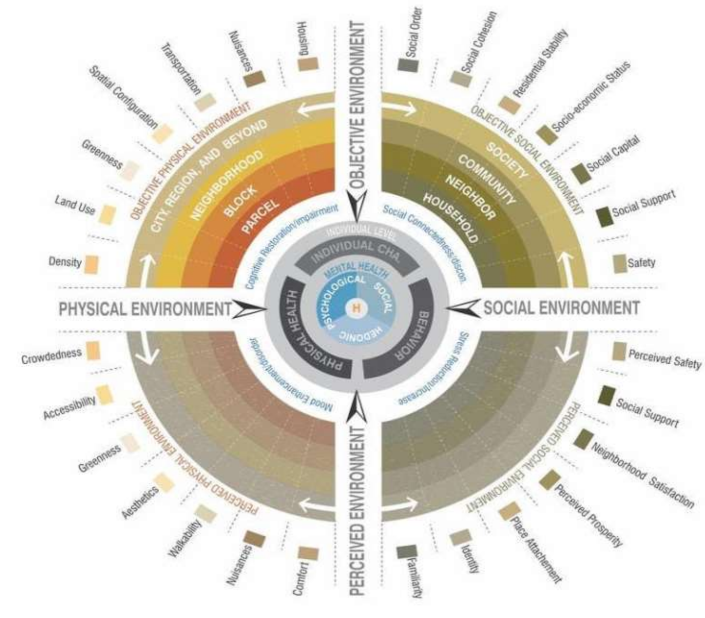


Figure 3: Relationship between built environment and wellbeing

Factors such as open space, built form, mobility network and socio-economic environment are likely to have a greater impact on well-being. According to Pacione "There is a relationship between people and their daily environment that associates socio-economic status with geographical location causing social-spatial variation in QoL".

THEORETICAL REVIEW OF WELLBEING ASSESSMENT TOOLS/ INDICES BASED ON LITERATURE REVIEW

This examines and understands the different methods and techniques being used in wellbeing tools/ indices around the globe. It derives six basic research criteria that could generally characterize the functioning of an effective model of assessing well-being. The chapter further presents a comprehensive review of parameters/ indicators and analytical techniques used worldwide by numerous indices/ tools and relevant studies developed for wellbeing assessment at the city and sub-city level to put forward a conceptual framework for wellbeing assessment at the neighborhood level. The framework essentially covers three crucial dimensions namely; physical, social, and economic. Under the identified parameters, specific indicators are based on the benchmarks set by public agencies in the form of norms or standards useful in assessing the current well-being levels. The framework further identifies the analysis technique to be adopted to draw results and findings.

Table 1: Fundamental study criteria

Wellbeing Type	Category of wellbeing	Coverage area	Approach	Technique	Result
Objective or subjective	Physical, Social, Economical	Neighbourhood / District / State/ Country	Top Bottom or Bottom Top	Statistical, Geographical analysis, or a combination of both	Ranking / Policy / Governance / General application

Table 2: Literature study based on the fundamental study criteria

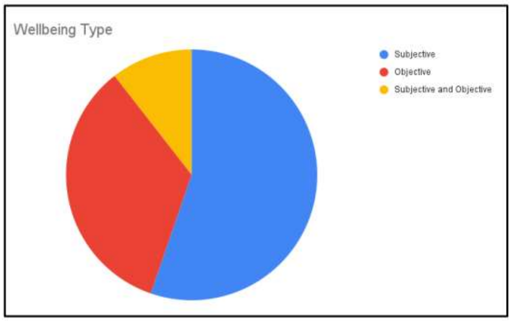
Sl no	Paper	Wellbeing Type	Category of wellbeing	Coverage area	Approach	Technique	Result
1	Determinants of wellbeing in a South African township	Subjective	Social,Economical	Township	Bottom top	Combination of both	policy
2	Subjective wellbeing, health, and ageing	Subjective	Social	Country	Top Bottom	Statistical	Governance
3	The challenge of defining wellbeing	Subjective	Physical	Country	Bottom top	Statistical	policy
4	A Multicriteria Approach for Well-Being Assessment in Rural Areas	Objective	Social,Economical	District	Bottom top	Statistical	policy
5	The Choice of priciple variables for computing some measures of human well being.	Objective	Social	City	Top Bottom	Geographical analysis	policy
6	Evolution of townships	Objective	Economical	City	Bottom top	Geographical analysis	policy

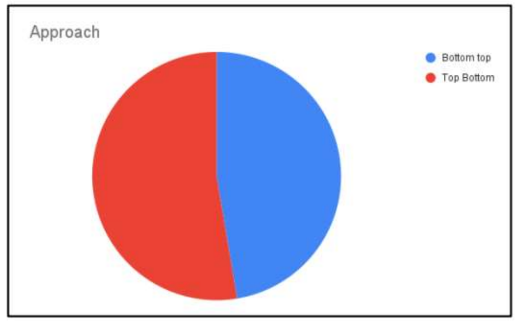
7	Determinants of wellbeing in a south african township.	Objective	Social,Economical	Township	Bottom top	Statistical	Governance
8	Neighborhood Predictors of Life Domain Satisfaction and Subjective Wellbeing in Rural and Urban Groups: Implications for Health Policy	Subjective	Social	Neighbourhood	Bottom top	Geographical analysis	policy
9	Time Perspectives and Wellbeing in Chile	Subjective	Social	Neighbourhood	Bottom top	Geographical analysis	policy
10	Subjective well-being: a general overview	Subjective	Social,Economical	Country	Top Bottom	Geographical analysis	Governance
11	Subjective Well-Being Around the World: Trends and Predictors Across the Life Span	Subjective	Social	Country	Bottom top	Statistical	General application
12	The science of happiness and life satisfaction	Subjective	Social	Country	Bottom top	Statistical	General application
13	The concept of well being in relation to health and quality of life	Subjective	Social,Economical	Country	Top Bottom	Geographical analysis	Governance
14	Optimizing mental health benefits of exercise: The influence of the exercise environment on acute stress levels and wellbeing	Subjective	Social	District	Bottom top	Statistical	policy
15	Sustainable Urbanisation and Community Well-Being in Suburban Neighbourhoods in Beijing, China	Objective	Social,Economical	Neighbourhood	Bottom top	Statistical	Governance
16	Coolangatta: A Portrait of Community Well-being	Subjective	Social	District	Bottom top	Statistical	General application
17	Environmental surroundings and	Subjective	Social	District	Bottom top	Statistical	policy

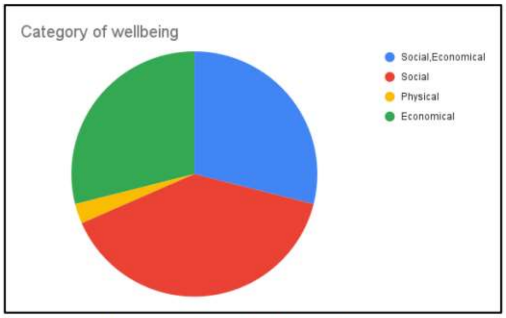
	personal well being in urban china						
18	Conceptualizing a Community Well-Being and Theory Construct	Objective	Social,Economical	Neighbourhood	Bottom top	Geographical analysis	Governance
19	A Review of the Literature and an Assessment of Conceptual and Methodologicul Issues	Subjective	Social,Economical	Neighbourhood	Top Bottom	Geographical analysis	policy
20	Sources of Happiness: A Qualitative Approach	Subjective	Social	Neighbourhood	Bottom top	Geographical analysis	General application
21	A Happiness and Objective Well-being Index for Living and Working in the State of Illinois,	Subjective and Objective	Economical	Neighbourhood	Bottom top	Statistical	policy
22	Townships for sustainable cities	Subjective	Social	City	Bottom top	Geographical analysis	General application
23	Healthy living, well-being and the sustainable development goals	Objective	Economical	Country	Bottom top	Geographical analysis	Governance
24	Indices of Social Development	Objective	Social	Neighbourhood	Bottom top	Geographical analysis	Governance
25	Satisfaction with life scale	Subjective	Economical	Country	Bottom top	Geographical analysis	Governance
26	Well-Being Across the U.S.	Subjective	Economical	Country	Top Bottom	Statistical	policy
27	The global analysis of wellbeing report 2018	Subjective	Economical	Country	Top Bottom	Geographical analysis	policy
28	2019 Wellbeing Report	Objective	Economical	Country	Bottom top	Statistical	policy
29	The Well-being of Nations	Objective	Social	Country	Top Bottom	Geographical analysis	Governance
30	Wellbeing in developing countries: conceptual foundations of the WeD :	Subjective	Social,Economical	Country	Bottom top	Bottom top	Governance

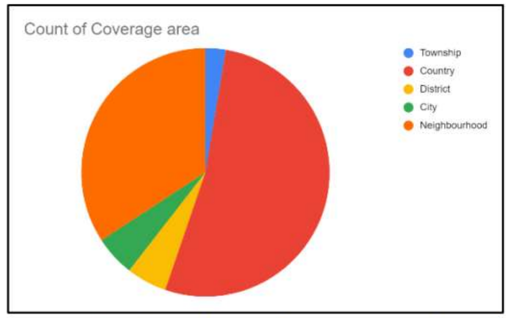
31	Impact assessment of the COVID-19 outbreak on wellbeing of children and families in Armenia, June 2020	Objective	Social	Country	Top Bottom	Statistical	Governance
32	Urban and regional development pland formalation and implantationn	Subjective	Social,Economical	neighbourhood	Top Bottom	Geographical analysis	policy
33	The International Wellbeing Group	Subjective	Social	Country	Bottom top	Geographical analysis	policy
34	Understanding Scores on the Satisfaction with Life Scale Ed Diener	Subjective	Economical	neighbourhood	Top Bottom	Geographical analysis	policy
35	COVID-19 AND HUMAN DEVELOPMENT: Assessing the Crisis, Envisioning the Recovery	Objective	Economical	Country	Top Bottom	Statistical	Governance
36	Healthy living, well-being and the sustainable development goals	Subjective	Economical	Country	Top Bottom	Geographical analysis	Governance
37	Subjective wellbeing, health, and ageing	Subjective	Social,Economical	Country	Top Bottom	Statistical	Governance
38	Mental Health Issues and Challenges in India: A Review	Objective	Social	Country	Top Bottom	Geographical analysis	Governance
39	Economic well-being	Subjective	Economical	Country	Bottom top	Statistical	policy
40	Spatial nature of urban well-being	Subjective and Objective	Social,Economical	neighbourhood	Top Bottom	Geographical analysis	Governance
41	Moves to measure wellbeing must support a social model of health	Objective	Social	Country	Bottom top	Statistical	policy
42	How do spatial characteristics influence well-being and mental health? Comparing the effect of objective and subjective characteristics at	Subjective and Objective	Social,Economical	neighbourhood	Top Bottom	Geographical analysis	Governance

	different spatial scales						
43	Manual for the well-being inventory(WBI) A multidimensional tool for assessing key components of well-being	Subjective and Objective	Social,Economical	neighbourhood	Top Bottom	Geographical analysis	Governance
44	Geographies to human well being	Subjective	Economical	Country	Top Bottom	Statistical	Governance
45	The Impact of the Built Environment on Mental Wellness	Subjective	Social	neighbourhood	Top Bottom	Geographical analysis	policy
46	The effects of changes to the built environment on the mental health and well-being of adults: Systematic review	Objective	Social	neighbourhood	Top Bottom	Statistical	policy
47	Exploring wellbeing in human settlements - A spatial planning perspective	Subjective	Economical	neighbourhood	Bottom top	Geographical analysis	policy
48	The impact of the physical and urban environment on mental well-being	Subjective	Physical,social	neighbourhood	Bottom top	Statistical	Governance
49	Subjective happiness scale	Subjective	Social	neighbourhood	Bottom top	Statistical	Governance
50	System Dynamics Model for the Improvement Planning of School Building Conditions	Objective	Social,Economical	neighbourhood	Bottom top	Statistical	policy
51	The concept of wellbeing in relation to health and quality of life	Subjective and Objective	Social	Country	Top Bottom	Geographical analysis	policy









Based on the above-identified study criteria for the Literature study of articles and reports the data derives:

Metric/ Indicator of Wellbeing

Expert survey for the identification of Indicators of Well-being based on the 3 identified dimensions: Physical, Social, and economic dimensions have been conducted. The Experts approached for the Survey are sociologists, psychologists, economists, Urban Planners, and Urban Designers. Based on the suggestions from the expert panel, the indicators for each dimension have been listed below to get a clear understanding of well-being.

Table 3: Indicators/ Metrics of Wellbeing

Sl No	Dimensions	Subjective Indicators	Objective Indicators
Physical Dimensions			
1	Density	Satisfaction with Habitat	Average household size
		Crowding	Dwelling units/acre
2	Housing conditions	Conditions of the housing – satisfaction level	Pacca houses (%)
3	Water Supply	Service satisfaction with water supply	water supply connection and water supply quantity
4	Sewerage system	Rating of cleanliness	sewage network services
5	Solid Waste Management	Satisfaction with cleanliness	Household level coverage of SWM services
6	Public Transport	Adequacy of reaching the township	Frequency of reaching the township
7	NMT	Provisions within the township	
8	Physically disabled	Provision	Universal Design

9	Street Design	Accessibility and ease of walking and cycling	
Economic Dimensions			
9	Affordability	Pricing of the housing units	Rent/ Lease/ purchase price of the housing units
10	Category of Housing		EWS, LIG, MIG, HIG
Social Dimension			
10	Neighborhood facility	Satisfaction with a school and colleges facility	Primary school, Secondary school
11		Satisfaction with health facility	Hospital facilities
12		Satisfaction with Sports	No sports facilities
13		Satisfaction with Recreation	Proportions of green spaces
14		Satisfaction with Art and Culture	No art and cultural spaces
15		Community spaces	No and type of community spaces
16		Rating of Safety	
17	Social Environment	Social Inclusive	-
18		Liveable built environment	-
19		Suitability of local community	-
20		Neighborhood support	-

CONCLUSION

This paper ends with the proposed indicators to make well-being an important aspect in planning for the betterment of society and community, that can be adopted at several levels, from residential units to city planning. The identified indicators would help in accessing the case study areas in the future process of my research and planning interventions for the city.

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DEVELOPING LOCALISED ADAPTIVE THERMAL COMFORT MODEL FOR NATURALLY VENTILATED RESIDENCES IN WARM AND HUMID CLIMATE OF MUMBAI, INDIA

Anand Achari[1], Trupti Mishra[2], Bakul Rao[2]

[1] VES College of Architecture, India (anandachari@gmail.com)
[2] IIT Bombay, India

ABSTRACT

Urban residencies in Indian cities are adopting use of air conditioner very rapidly. Naturally ventilated (NV) and thermally comfortable habitat are needed to be developed to avoid energy use and associated emissions. Appropriate local standards of thermal comfort in naturally ventilated spaces will aid in sustainable development.

The climatological and cultural diversity is vast in India, but it is not reflected in the current thermal comfort standards. It is important to use local climate based thermal comfort range but single common model is suggested by the National Building Code of India (NBC) for all naturally ventilated (NV) buildings in India.

Field surveys were conducted in residential buildings of Mumbai in naturally ventilated condition to derive adaptive thermal comfort temperature range applicable to warm and humid climatic zone. Acclimatised adult occupants were surveyed (class II survey) NV apartments during morning, afternoon and evening each in summer, winter and monsoon to observe holistically. Physical, psychological, physiological and behavioral factors affecting thermal comfort were included in this study. The Localised adaptive thermal comfort (LATC) model was developed, which is applicable to NV midrise residential buildings of warm and humid climate of India.

Keywords: Residence, Adaptive comfort model, Field Survey, Warm and humid, India

INTRODUCTION

Rising global temperatures in future will stress the thermal performance of new and existing residential buildings, which will be primarily due to thermal discomfort in existing naturally ventilated residences, and rising dependence on air-conditioning.

It is evident that residential segment in the building sector is having higher energy consumption currently and also might double by 2030 as compared to the commercial segment. There will be higher energy consumption in the residential building sector, mainly due to higher capacity and more frequent use of air-conditioning, as the indoor thermal comfort would not meet due to higher outdoor climatic conditions due to the global warming scenario. As thermal control becomes the largest consumer of energy, achieving this thermal comfort in natural ventilation would make the user avoid the air conditioning which shall lead to reduction in energy consumption (Friedman C., Becker N. & Erell E., 2014). It is extremely necessary in today's context to study thermal comfort, where there is an energy crisis in India and around the world (Charles K. E., 2003).

Naturally ventilated buildings often use lesser than 50 50% energy as compared to air-conditioned buildings. And these naturally ventilated buildings can provide thermal comfort all year (Kumar P., 2014). During the rapid urbanization process, many uncertainties still exist around residents' adaptive thermal comfort in terms of its adaptation process and underlying adaptively comfortable thermal boundaries which will contribute to housing energy conservation. This study addresses the above problems through investigation in residential buildings using the case of Mumbai, a typical city in the Warm and Humid climatic zone of India, and within Equatorial Monsoonal climatic zone as per updated Köppen-Geiger climate classification (Kottek M. et al, 2006). Mumbai city is the capital city of Maharashtra state, and financial capital of India. As per census records of 2011, Mumbai city is also one of the highly populated cities of India.

Adaptive thermal comfort:

Thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation." (ASHRAE, 2017). ASHRAE 55 is one of the highly referred thermal comfort standard as it provides permutations of indoor thermal conditions and human factors which will result in thermal environmental conditions that 80% or more occupants of the space consider acceptable (Kumar P., 2014). According to adaptive thermal comfort model (ATC), a person adapts either psychologically, physiologically or behaviorally, to restore his comfort whenever there is a discomforting change in thermal environment around him (Kumar P., 2014).

Thermal comfort model developed earlier in 1970's by Fanger focussed solely on the human body heat balance model. Adaptive model of thermal comfort defined in ASHRAE 55, 2004 standards consider to some extent the behaviour of human for example clothing, regulating air speed or changing metabolic activity. Diverse factors of human such as expectation of indoor environment in various building types, user's cultural background, and behavioural patterns diversly influence the thermal sensation and acceptability of the occupant of a space. Building design that avails their occupants the opportunities to control personal mobility, opening windows, using balcony, clothing and metabolic activity, improve the thermal experience of the occupants. Such opportunities are observed typically in NV buildings. The occupants of such buildings have wider range of comfort band as compared to ASHRAE 55, as they can easily respond to variations in thermal environment due to climatic and seasonal changes (Kumar P., 2014; Ozarisoy & Altan, 2021; Altan & Ozarisoy, 2022). The field survey data is conducted to find the suitable adaptive approach about the thermal environment along with subject's thermal response, taken in form of comfort vote. Interactions between building or another environment and its occupants influence the comfort temperature (Nicol J. F. & Humphreys M. A., 2002). Thinking from the adaptation and operating approach, adaptations are classified into three categories: behavioural, physiological and psychological adjustments. All of these adaptations are considered while conducting a field study with adaptive approach (Dear & Brager, 1998).

Thermal comfort standards:

Fanger and colleagues developed the Predicted Mean Vote (PMV) model and a model of local discomfort from draught. Since static PMV over-predicts thermal sensation on warmer side, some researchers question their validity (Charles K.E., 2003; Manu S. et al, 2016). The global reference standards for thermal comfort (ASHRAE 55) defines the range of thermal conditions acceptable to most of the occupants of naturally ventilated or air-conditioned spaces. The ASHRAE 55 2017 standards have also considered effect of elevated air velocity for aiding thermal comfort in humid conditions. These standards are called as adaptive thermal comfort standatds (DeDear R., Brager G. & Cooper D., 1997). However, these studies focus on different climatic zones and different type (use) of buildings. The NBC of India (BIS, 2016) proposes India model for adaptive comfort (IMAC) for any type of building in any of the five climatic zones. But is developed by only studying office buildings (Manu S., et al, 2016).

A generalised thermal comfort equation for the entire country or world is not feasible without consideration to variable factors like different types of climates, buildings, user (occupancy, age, gender) and their cultural and economic contexts (Indraganti M. & Rao K.D., 2010). Many buildings are designed to function as air-conditioned building which as relevant thermal comfort standards exist, however proper thermal comfort standards for NV buildings are absent (Kumar P., 2014). As a result, use of NV design in buildings is not encouraged, which in some extreme climates compels users to use energy guzzling devices for achieving thermal comfort (Indraganti M. & Rao K.D., 2010).

Thermal comfort studies in India:

Very few research study thermal comfort in residential buildings in Indian context which are naturally ventilated, that too are based on the composite climate of India (Table 1). Other Indian studies did not focus on residential buildings.

Table 1: Indian studies focusing on thermal comfort in naturally ventilated buildings.
Source: Author

Author	Location / Climate	Building Type Studied
Sharma & Ali (1986) (NBC 2005)	Roorkee (Composite)	Institutional Building
Indraganti M. (2010)	Hyderabad (Composite)	Residential buildings
Kumar P. (2014)	Mruthal (Composite)	Students' Accommodation
Dhaka S. et al. (2015)	Jaipur (Composite)	Residential and office buildings
Kumar S. et al. (2016)	Jaipur (Composite)	Students' accommodation
Manu S. (2016) (NBC 2016)	Ahmedabad, Bangalore, Chennai, Delhi, Shimla (all indian climatic zones)	Office Buildings

There is no evidence of research on the adaptive thermal comfort in NV residential buildings in warm and humid climatic zone in India as per the ASHRAE global thermal comfort database II. Hence this research studied the thermal comfort neutrality of the residential apartments in the warm and humid climate in India through class II field survey.

Region localised ATC model is developed in this study which represents the thermal adaptation of local occupants better as compared to national or global standards. The typology of households, lifestyle and population density of the residential area is considered to develop the thermal comfort model applicable specifically to residential areas. Field surveys and associated statistical analysis were employed as the main research methods for this study. The survey investigated urban households to characterize their daily thermal behaviours and thermal requirements through questionnaires. Sets of thermal comfort data drawn from households (in naturally ventilated buildings) reported residents' real thermal perception corresponding to the climate.

METHODOLOGY

The field study database collected by Achari et.al. (2021) was used to perform meta-analysis methods adopted from the approach of ASHRAE RP-884, and Xiong et.al. (2010). This database was collected from residential apartment buildings in warm and humid climate of Mumbai at three different times of the day (Morning, Afternoon and Evening) and in three seasons of the year (Monsoon, Winter, Summer). These surveys were carried in naturally ventilated apartment buildings of low-rise medium density region in two locations of Mumbai namely Vileparle and Vashi. "Right-here-right-now" approach of thermal comfort surveys resulted in the database which included occupant's thermal sensation, preference, acceptability, air movement preference, clothing, metabolic rate, and indoor climatic parameters such as relative humidity, globe temperature, air temperature, and air velocity. The study was focused on the low rise-mid density residential development in and around Mumbai. Vileparle (Mumbai) and Vashi (Navi-Mumbai) area were identified as the suitable areas for study. All studied buildings were two to 4 stories tall (walk up apartment buildings) with R.C.C. flat roof and floors, one brick thick external cement plastered walls. The study was conducted in the living room of the occupant's house which were naturally ventilated.

Respondents in that study were required to be healthy adults (age 18 to 70 years) and they should have been acclimatised to the present city and house for more than a year. The house must be naturally ventilated and belong to a medium income group family. The respondent must have relaxed or performed sedentary activity for at least 30 minutes before the survey. The occupants should be in a good health (not having fever or cold at the time of survey) and should be capable of expressing their thermal response properly. Questionnaire used in this investigation covered categories of information such as permission for survey of respondent, Building / House Information, Respondent's Information and Behaviour, Resident's instantaneous thermal perception, sensation, acceptance, and preference, Environmental and Thermal measurement. The respondents were required to answer the questionnaire by carefully observing personal sensation and condition.

Present field study was a Class II category investigation as per ASHRAE RP-884. The thermal condition parameters mentioned earlier were recorded at 3 heights (0.1m, 0.6m, 1.1m) during each sample survey as per class II protocol of ASHRAE standards. Dry bulb temperature and humidity was measured using portable electronic thermal hygrometer Testo605i (resolution 0.1% RH and 0.1 °C temperature), globe temperature was recorded by using the same device with its sensor covered with 40mm diameter black painted ping-pong ball. Air velocities were recorded by portable hot wire thermal anemometer Testo 405i (Resolution 0.01 m/s).

The surveys were conducted with each respondent thrice a day, and thrice each in a year to observe the respondents in wide range of thermal conditions. Each survey was conducted with prior appointment and the detailed procedure was explained to the respondent by trained investigator in the first survey. The respondents were requested to remain in their habitual clothing, sit on their habitual seat, keep the ceiling fan & other mechanical ventilation devices switched off, and all the windows were kept open during the survey. While the respondents gave their thermal perception votes, the investigator measured the indoor thermal condition using digital sensors which were stabilised for 5 at least minutes before the actual measurements. The surveys were conducted only in daytime (7 am to 9 pm) and that too only in living room of the occupant's apartment due to limited permission and privacy concerns.

The data collected from the entire field study were carefully tabulated in the form of a large spread sheet with each sample data in one row and each variable data in a separate column. Further, the measurements of 3 heights were averaged and used for calculating thermal comfort indices such as operative temperature, new effective temperature, standard effective temperature and PMV using thermal comfort index calculator developed by R.De.Dear.

Analytically developing the adaptive model

A two-stage analytical approach was implemented to develop the ATC models. Thermal neutrality was derived in first stage by analysing the relation of thermal sensation with indoor thermal environment. ATC model was developed in second stage by finding the dependence of thermal neutrality on outdoor thermal characteristics. Data aggregates are prepared in this study which became the primary units of analysis. For aggregating the data, entire field study database was segregated at the level of 2 surveyed locations. Further the data of each location was pooled at the level of each surveyed month of the year. This 'Location + Month' became the appropriate aggregate for further analysis. Analysis results from these aggregates were further categorised for meta-analysis.

Weighted linear regression of indoor ET* & ASHRAE's thermal sensation scale (7 point) was performed for each aggregate to derive thermal neutrality. And further their relation was found with the outdoor 30 day running mean air temperature through weighted linear regression. The resulting model is termed as the ATC model. The flow diagram for the entire methodology is given in figure 1.

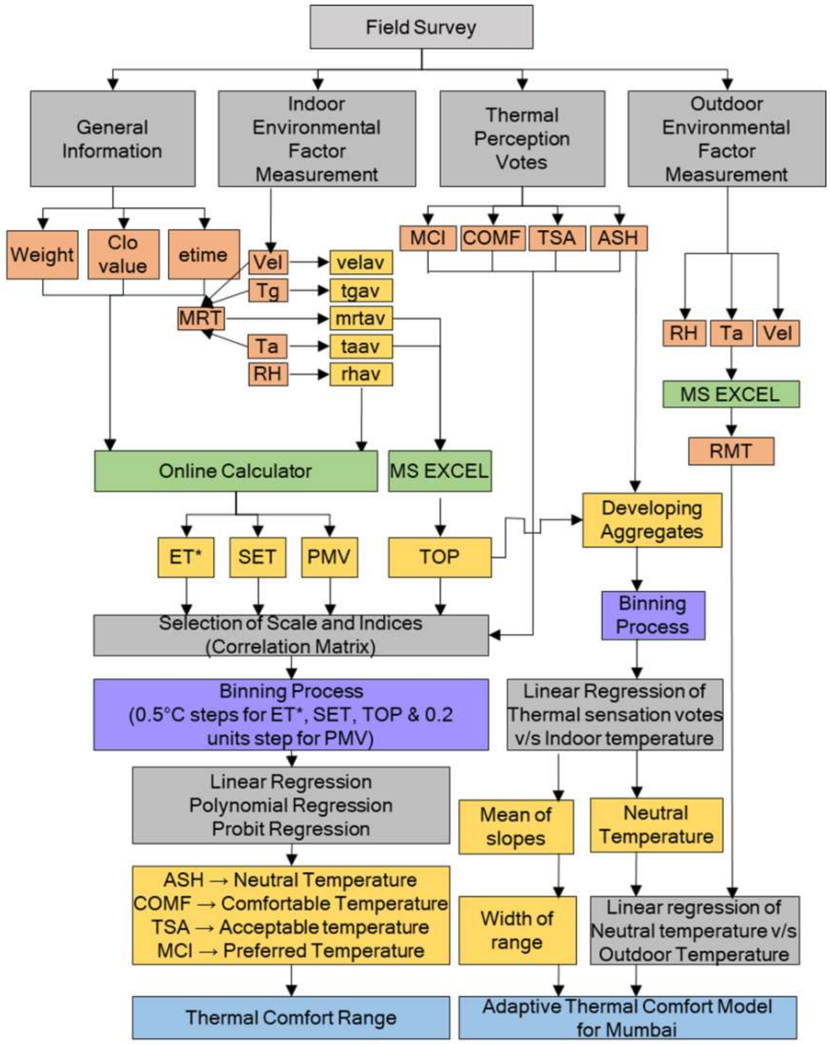


Figure 1: Research Framework Flow diagram showing the process of meta-analysis

LIMITATIONS

The field surveys were conducted in daytime only hence the study could not focus on the thermal comfort needs and adaptation during night time (after 9:00 pm). And they were conducted only in the living room of the respondent's houses due to privacy and permission issues. Present study is applicable to mid-rise Naturally ventilated residential buildings only. The results of this study cannot be generalised for newer high-rise residential development in Mumbai.

ANALYSIS AND RESULTS

Field survey for adaptive thermal comfort was conducted in transverse as well as longitudinal approach. The transverse survey was conducted along the single day with three-time scenario (Morning, Afternoon and Evening). The longitudinal survey of the same respondents was also taken across the seasons in consideration (Summer, winter, and monsoon). The samples were collected from a well-acclimatised population having almost equal proportion of male and female respondents; and covering a wide range of age group of respondents. In this project 14 Buildings, 79 Households, 233 Respondents, and 1643 Samples were studied from Vashi; and 16 Buildings, 60 Households, 135 Respondents, and 964 Samples were studied from Vileparle. A total of 30 Buildings, 139 Households, 368 Respondents, and 2607 Samples were surveyed from both locations in full year. Most buildings studied were 2 or 3 storied tall R.C.C. framed structures with 230mm thick cement plastered external brick wall and flat concrete terrace roofs with water proofing. Most houses surveyed were having area of 25 to 75 sq. meters and had 1 or 2 attached bedrooms. All the occupants surveyed were within the age of 18 to 70 years and majority of them were acclimatised to the present house and city for more than a decade.

Thermal comfort index & thermal perception scale

Thermal indices are used in thermal comfort studies to represent the multiple factors of indoor warmth in a single number which can be used for statistical analysis. PMV, New effective temperature (ET*), SET and Operative temperature (Top) are few of the widely used indices as seen in the existing literature. ET* and SET cover most factors that can be measured / observed in field study such as metabolic rate, air velocity, mean radiant temperature, dry bulb temperature and relative humidity. Thermal perception comprises four variables rather than just one. as advised by Auliciems and Brager (Auliciems A., 1981; Brager G. et al, 1993). Brager et al suggested indirect measurements of dissatisfaction, including "thermal preference ", "thermal comfort" and "thermal sensation ", which produce widely different assessments of the acceptability of a given environment in the field, and recommend that a direct item on "thermal acceptability" should be included. Therefore, in this study, four variables such as thermal acceptability (4-point likert scale), thermal preference (3-point Mclintyre scale), thermal comfort (4-point likert scale), and thermal sensation (ASHRAE 7-point scale) were obtained through questions at the same time and numerically coded for analysis.

Table 2: Summary of correlation coefficients (Full year data) (Source: Author)

Variable	**T_{op}**	**ET***	**SET**	**PMV**
Thermal Sensation (ASH)	0.526**	0.484**	0.451**	0.513**
Thermal Comfort (COMF)	0.455**	0.409**	0.386**	0.444**
Thermal Acceptance (TSA)	0.409**	0.407**	0.377**	0.408**
Thermal Preference (MCI)	0.362**	0.329**	0.303**	0.348**

**. Correlation is significant at the 0.001 level (2-tailed)

The correlation analysis for the matrix of thermal perception votes and identified thermal indices was performed to identify the thermal index that may result in statistically significant thermal neutralities in the present study. In this correlation matrix analysis, (Top) and (ET*) correlated better with thermal scales as compared to other thermal indices. Correlation analysis of all the permutations of scales, indices and seasons were found to be highly significant ($p<0.001$). (SET) and (PMV) overestimate the sensitivity of the respondents in real living environment (Xiong Y., 2011). Operative temperature (Top) is most widely used index because of its ease of application and inclusion in the standards. However, (Top) does not consider the effect of humidity and air movement which is a key player in affecting thermal comfort in warm and humid climate. (ET*) considers these aspects ignored by (Top). (ET*) quantifies the incremental thermal impact of elevated humidity (DeDear R., Brager G. & Cooper D., 1997), hence it is considered as an appropriate index to in this study as it is focusing on thermal comfort in warm and humid climate. Thermal sensation scale (ASH) was selected as it correlates better with all indices.

Developing aggregates for meta-analysis:

Many different methods were attempted in this study to perform analysis and later meta-analysis to ultimately derive the ATC model as shown in table 3. The data collected in the field study needed to be divided into smaller aggregates for which the neutral temperatures and outdoor temperatures can be derived, and these values could be further used to develop the required ATC model. Here the aggregates of the data were developed in several methods to find the indoor thermal comfort condition. Later this indoor thermal comfort conditions were correlated with the prevailing outdoor thermal condition to develop the ATC model. The method resulting in statistically robust relationships in this analysis was selected as the final method for developing the final model. The aggregates of the entire database were developed using following six approaches.

Approach 1 & 2 in above table are well known methods as they were used in IMAC & RP-884 study respectively. Other approaches are developed so as to achieve more than 30 samples per aggregate and to observe the database in different possible ways. It was observed that many aggregates had less than 30 samples in approach 1 & 3. These aggregated data sets were analysed to calculate neutral temperatures for each aggregate. The approaches resulting in negative slopes were rejected as it is physically not possible, the approaches with poor statistical significance were also rejected, the approaches where large number of aggregates / samples get rejected during regression analysis were also rejected, the approach number 6 was also rejected as this method ignores the impact of discomfort votes on the same thermal conditions. Later this indoor thermal comfort conditions were correlated with the prevailing outdoor thermal condition to develop the ATC model. The method resulting in statistically robust relationships in this analysis was selected as the final method for developing the final model.

Table 3: List of approaches used for analysis.
Source: Author

Sr. No.	Name	Sr. No.	Name
1	Per Building	4	Per Month
2	Per Building + Season	5	Per Location + Month
3	Per respondent	6	Full data Neutral Vote Sample (-1,0,+1)

Approach 1, 3, and 4 did not result in statistically significant regression, many aggregates were rejected in approach 2 and 3, approach 6 is not considered appropriate as it ignores the discomfort votes and the regression slope in this approach was found unrealistically steep. The approach 2 (per building + season) is relevant in this study as the results can be comparable with existing Indian standards developed using similar approach. But in this approach many aggregates were rejected due to less samples or not achieving statistically significant results. Since location + month approach resulted in best regression model, and its regression equation is similar to that found from building + season approach, the location + month approach result was considered as the final ATC model.

Stage 1: Identifying thermal neutrality

The database subdivision approach ('Location + Month') was used in developing aggregates along with Weighted linear regression method to derive thermal neutrality. Calculated index (ET*) values were derived for each sample using measured data. The database was divided as per their source location category. This per location database was further divided into the category of months in which the sample was collected. This was done to consider the effect of varying weather conditions throughout the year on adaptive thermal comfort. The per Location + Month categories of data having less than 24 samples were rejected for further analysis, as a smaller number of sample points do not result in a significant linear regression.

The data of each selected aggregates were further divided in to smaller bins corresponding to nearest 0.5°C (ET*) temperature value (e.g. $26.26 \approx 26.5$, $26.24 \approx 26.0$). The number coded (cold = -3, neutral = 0, hot = +3) thermal sensation vote (ASH) within each bin were averaged to derive mean sensation vote (mean ASH) for each 0.5°C bin of (ET*) temperature. This averaging was done to reduce the impact of outliers in the linear regression analysis. Number of votes in each bin of 0.5°C (ET*) were counted for calculating weights for weighted linear regression. These weights are calculated so that each data point in the Weighted linear regression is given importance based on the number of samples it represents within corresponding bin.

Weighted linear regression analysis was performed separately for each selected 'Location + Month' category by using their corresponding 0.5°C bins of new effective temperature (BinET*) as the independent variable, mean thermal sensation votes of each bin (mean ASH) as the dependent variable and calculated weights as weightages of each data point. The scatterplot and regression analysis tables were generated separately for the weighted linear regression of each 'Location + Month' category. Slope and Y intercept of the regression equation and their corresponding significance values, R value and R-squared values, F statistics and its significance values are derived for each Selected 'Location + Month' category from the regression tables. The aggregates not achieving significant regression were rejected and remaining aggregates were used for further analysis. This selection was based on the F statistics and their significance values. Finally, 15 out of 21 aggregates were selected in entire process. These 15 aggregates represent 2158 out of the total 2607 samples.

Neutral temperature is calculated for each selected 'Location + Month' categories by solving their respective regression equation by substituting value of Y (mean ASH) as 0 (neutral sensation). The resulting value of (BinET*) is called as Neutral ET* (Tn (ET*)) temperature for that selected 'Location + Month' aggregate.

Stage 2: Relation of outdoor climate with Thermal neutrality

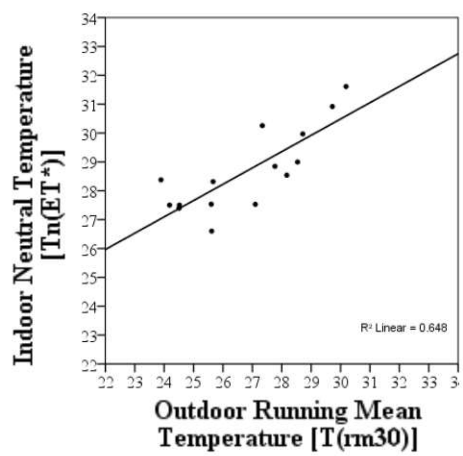
Weighted Linear regression models of calculated indoor thermal neutrality and mean outdoor warmth were computed for all selected "Location + Month" aggregates. The neutral temperature was studied as the new effective temperature while outdoor warmth was in terms of 30 day running mean outdoor air temperature (T(rm30)) from available IWEC weather data files. Weighted linear regression was performed with outdoor 30 day running mean temperature (T(rm30)) as independent variable and indoor neutral temperature of each corresponding aggregate as the dependent variable. Each selected 'Location + Month' aggregate data point was weighted as per number of samples in each aggregate. The resulting regression equation is as follows:

$$Tn_{(ET^*)} = 0.57 \times T_{(rm30)} + 13.255 \quad (1)$$

($R2 = 0.691$, $p < 0.001$,
No. of Participating samples = 2158/2607,
No. of participating aggregates = 15/21),

Where, $Tn_{(ET^*)}$ = neutral temperature using Indoor New Effective Temperature

$T_{(rm30)}$ = 30 day running mean temperature from the historic weather data (IWEC)



Graph 1: Weighted Linear Regression of indoor Neutral New Effective Temperature and Running mean outdoor temperature (Source: Author)

The slope of the resulting regression model is 0.57, which indicates that the outdoor thermal condition strongly influences the thermal adaptation of the occupants of the residential buildings in Mumbai. For every 1°C rise in the outdoor running mean temperature, the indoor neutral temperature rises by 0.57°C. The high coefficient of determination in the model developed with Tn (ET*) and T(rm30) show that there exists a moderate to high correlation between these two variables. Also, the high overall significance in f test of the regression analysis suggests that this model may be confidently considered as the final outcome of this research.

Thermal acceptability limits

Thermal acceptability bands were computed to draw upper and lower bounds of the acceptability band. The slope (m) in linear regression equations (ASH = m × ET* + c), represents the occupant's thermal sensitivity. The slopes identified for 'Location + Month' aggregates having statistically significant results in last step were used for further analysis. A weighted average (using number of votes) of these slopes was calculated which are called as the average sensitivities (0.324). The average sensitivity or slope was used to calculate (ET*) acceptable range as follows:

$$\Delta ASH = (\text{weighted average slope}) \times \Delta ET^* \quad (2)$$

In Fanger's PMV-PPD model, ΔASH of 0.85 sensation vote correspond with 80% and 0.5 with 90% acceptability limits. The resultant ΔET* values ±2.62°C and ±1.54°C indicate respective 80% and 90% the acceptability. This range is equally distributed on either sides of the neutral temperature line. The derived ATC model is represented in Graph 2, where the width of 80% and 90% acceptable ranges are demarcated as dashed lines. This ATC model when used to calculate desired indoor neutral temperature for the entire year gives a band of temperatures (Graph 3); within which the designed buildings must create the indoor conditions in naturally ventilated mode to reduce cooling energy consumption.

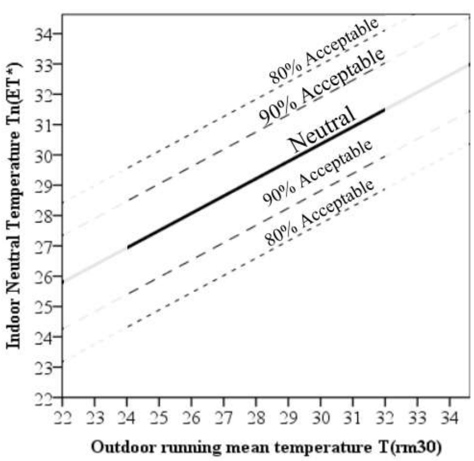


Figure 2: Adaptive thermal comfort model for Mumbai showing 80% and 90% acceptability ranges (Source: Author)

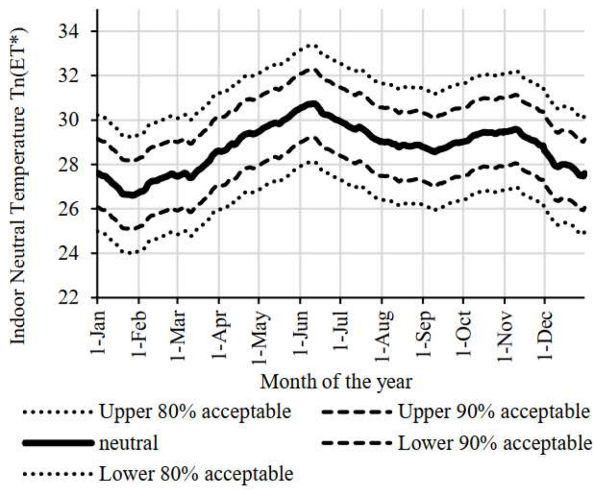


Figure 3: Variation in desired indoor neutral temperatures throughout year. (Source: Author)

CONCLUSION

A class II field study was performed for identifying adaptive thermal comfort range in naturally ventilated apartment buildings in warm and humid climate. Adaptive thermal comfort model, showing relation of indoor neutral temperature with outdoor running mean temperature was derived as $Tn_{(ET^*)} = 0.57 \times T_{(rm30)} + 13.255$, Where the width of 90% acceptability range is ±1.54°C, and width of 80% acceptability range is ±2.62°C. Use of the ATC model derived specifically for the residential buildings in warm and humid climate of Mumbai may be more appropriate as compared to the existing National Building Code (BIS, 2016). Design fraternity may develop localised solutions by using this model. Also, the change in industry standards for air conditioning equipment / appliances related to this localised model may have a great impact in terms of reduction in energy consumption, thereby reduction in Carbon Emission, thus creating an impact on climate change.

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A NEW ARCHITECTURAL DESIGN STUDIO FOR MEANING-MAKING USING REPERTORY GRID TECHNIQUE (RGT)

Ahmed Agiel[1,*], Jon Lang[2], Peter Caputi[3], Matthias Rosenberger[4]

[1] Assistant Professor, Architectural Engineering Department, United Arab Emirates University, Al Ain, UAE, a.agiel@uaeu.ac.ae
[2] Emeritus Professor, School of Built Environment, University of New South Wales, Sydney, Australia, jon.lang@unsw.edu.au
[3] Professor, School of Psychology, University of Wollongong, Wollongong, Australia, pcaputi@uow.edu.au
[4] CEO of the RoTec Rosenberger Intelligence, Leipzig, Germany, mro@rotecqg.com

ABSTRACT

Architectural design educators highlight the uncertainty in the content of design knowledge delivered, creativity in the design process, teaching styles and no documented theory, definite methods or tools for design delivery. Acknowledging Piaget's theory (1971) and Kelly's theory (1955), the authors suggest that individuals construct knowledge and create meanings based on their inherent images/experiences. Integrating the theories of 'constructivism' and 'personality', the authors postulate the applicability of Personal Construct Psychology (PCP) (Kelly, 1955). Hence, the primary purpose of this study is to develop and assess the applicability of a learning-teaching strategic design process model based on PCP to facilitate and 'make sense of' the meanings of design principles in processing creative designs. For this purpose, a new design studio was developed to evaluate the design creativity achieved in the performance of a group of students from the United Arab Emirates University UAEU who joined an advanced elective course in the undergraduate architectural engineering program (ARCH530 Selected Topics in Architecture). PCP based design studio pedagogical framework was established and a comparative analysis of the students design outputs was conducted using Repertory Grid Technique (RGT) to validate the potential of PCP in imprinting a deeper understanding of the architectural image. A sample of participants from the local society and peer students from the same program were involved in construing the meaning of the work developed by students. The results showed the design outputs based on PCP enhanced and facilitated creativity enabling the students to construe concepts from their conceptions, establish relations between the concepts, inherent knowledge and generated inferences based on their reasoning. The findings of this study identify a new conceptual theory for the transformation of conventional design studios into an open constructivist environment for systematically engaging the local society, valuing the local traditions and designing for the health and wellbeing of the future generations.

INTRODUCTION

Recent studies conducted by the MIT suggests student-centered learning paradigms and pedagogies to solve the societal, environmental and technological challenges of the 21st Century (Graham, 2018). The 'Current Leaders' and 'Emerging Leaders' in engineering education comment that: "I don't see any brilliant new techniques down the pipe. We already have the ideas. We are rich in theory. What we will need to get better at is pulling them together" (Graham, 2018). The institutions addresses the ability of the engineering programs to 'pull together' and integrate best practice experiences. Consequently, the current research study attempts to arrive at conceptual learning and teaching theories that enable effective process of creative thinking in architectural design education. Authors stipulate that the design studios should provide the students with an opportunity to construct meanings and make sense of the basic principles of design from their experiences.

Architectural education includes both theory and practice that deals with the process of designing and building structures (Ciravoglu, 2014). Although the discipline falls between science and fine arts, architectural design courses constitute the most critical part of the design education. These include problem-solving tasks requiring critical thinking and decision-making processes (Ciravoglu, 2014). Unlike other disciplines, the design courses are involved at developing “design knowledge, scientific architectural information and strengthening the creative expression” (Demirkan & Afacan, 2011). Thus, the problem solving activities include the integration/transformation of the all the competencies acquired during the architectural education into a site specific design (Badie, 2017). However, in this context, Uluoğlu (2000) and Lawson (2005) argue that designing is not a process requiring skills alone, rather demands reasoning that are cognizant, imaginative, intuitive, creative, selective and intellectual. Clearly, architectural education should embody the design knowledge and the associated tools for practically applying this knowledge to personalize design specific solutions. Architectural design educators, highlight two main problems faced while teaching in the design studio built on the traditional instructor-student relation (Uluoğlu, 2000). Firstly, there is an uncertainty in the content of design knowledge to be delivered at different levels of architectural education. Secondly, there are no definite methods and tools identified for teaching design. Hence, the complexity of the design process necessitates the need for an advanced architectural design pedagogy.

As highlighted by architectural professionals, the learning environments offered by contemporary architectural design education do not provide appropriate experiences to adapt to the latest opportunities. As observed in recent studies, critical understanding of the design process has been generally ignored as a central quest in traditional design studios (Philippou, 2001). In this context, Koolhaas (1991) extorts that teaching in architectural design studio ought to empower the student interpretations by enabling design transformations through different angles using the introduced design tools. According to Demirbas and Demirkan (2003), education in architecture should be structured to facilitate and advance student learning. Hence, enhancing the design pedagogy is critical in order to facilitate and enhance the design theories, professional skills and cognitive abilities in design education. Consequently, authors propose the transformation of conventional studio to an open constructivist environment through theory of ‘constructivism’. Based on the construction process, learning in constructivism is guided by two distinct points of view. One point of view deals with the construction process as a means of augmenting or rearranging the cognition at the mental level. The other point of view considers the construction process as molding or development of the concepts or theories at a figurative level. Here, the theories and modes of reasoning form the cognitive structures. Hence, the two construction processes are interdependent and intimately related. Thus, the construction process undertaken by the students is influenced by both the psychology of cognitive development and epistemology (Bächtold, 2013). Consequently, one among the major challenges for introducing an effective teaching and learning strategy requires an understanding of both the student’s cognitive structures to acquire the theory and methods of enabling the theory to be acquired. The study intends to conduct empirical study in terms of learning and pedagogy in processing creativity within the architectural design education as a means to explore the unknown. Recently, Repertory Grid Technique (RGT) has been applied in research on education and educational psychology as a means to elicit personal constructs or to enable construing meanings related to their personal experiences. As highlighted in, “A review of applications of the repertory grid technology in research on education and educational psychology” (Lin , Wei & Hung, 2017), only 55 studies were conducted using RGT or the theory PCT for over 50 years. Further, only 39 empirical studies were highlighted as dealing with educational context. Consequently, the research study intends to facilitate and ‘make sense of’ the principles of design and the meaning related to processing creative design concepts through empirical studies within architectural design studio at UAEU using Repertory Grid Technique (RGT). This research study is innovative as no empirical studies based on Psychology of Personal Constructs using Repertory Grid Technique have been conducted in processing creativity within the architectural design education. Moreover, RGT has been evolving as a platform and diverse new tools was devised during the course of the study for data collection and analysis.

Thus, the study attempts to answer the following research question: "How can the 'sense of meaning' in architecture be communicated within the creative process of design education based on Personal Construct Psychology (PCP)?"

METHODOLOGY

RGT serves as a method to elicit and explore the personal constructs of participants. This method enables both the quantitative and qualitative methods of data collection and analysis. First, the analytical systematic strategies enable the researchers to examine the participant's cognitive structures by exploring the internal structures of the grid data (Rahman et al., 2022; Agiel & Kutty, 2019). Second, within the educational context, RGT serves to explore the learning problems, and assist in construing design principles based on expert interviews. Finally, in pedagogical process, comparative analysis using RGT enables the participants to review and reflect on their knowledge structure before and after delivery of knowledge. Further, the characteristics of the individual constructs is also obtained.

The Proposed Pedagogical Model

'Personal Construct' refers to the ability of individuals to create their own interpretation of the surrounding environment. PCT enables better understanding of people's perception of their built environment. This theory has been built on reality such that the individuals construe their own meaning about what they see visually as they understand it rather than basing their meaning on the choices assigned to them by those doing the research. Although, various models exist in enabling the design knowledge to be acquired and creativity to be explored; authors argue that PCT facilitates student's cognitive structures in acquiring the design knowledge as well as the society. Thus, the research methodology primarily relies on examining the potential of PCT and its analytical components such as Repertory Grid Technique (online software platform of Rep:grid) within the architectural design studio. Hence, the study uses PCT as a non-invasive approach allowing the instructor to become the facilitator of the student's construct system rather than imposing the instructor's construct on the designer Figure 1.

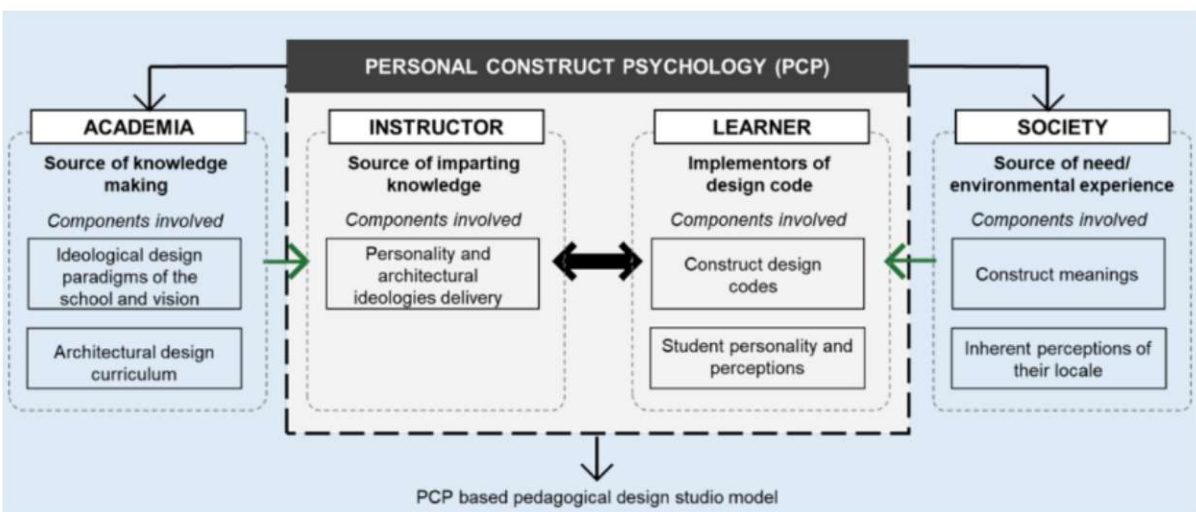


Figure 1: Proposed PCP based strategy explaining interaction of design contributors

RESEARCH DESIGN

Case study Al Ain city

The United Arab Emirates UAE has experienced a rapid growth in all aspects of life. One of the sectors that grew dramatically is architecture and construction. This rapid growth imposes a serious risk of cities losing their architectural identity. Al Ain city for instance faces challenges in visual appearance of buildings as no clear strategy is adapted. As a result, Plan Al Ain 2030 has set four main objectives one of which is protecting and enhancing the cultural heritage of Al Ain. The urban structure framework of the plan is to be built around the culture and traditions of Al Ain city, and as H.H. Sheikh Zayed bin Sultan Al Nahyan wisely stated, "Those who forget their past compromise their future." The indigenous inhabitant of UAE in this city are inherently attached to their heritage (Agiel et al., 2021). However, their perception of what is built in the city is not well recognised, due to the different approaches adapted by architects who contributed to its image of architecture that we see today.

To create culturally sustainable cities with a systematic strategy for visual appearance. Cultural sustainability must be integrated within the architectural design process in the analysis, synthesis, and evaluation stages. The PCP Model here is to process design taking in consideration these matters of people and the place.

Participants

27 students enrolled in the course ARCH530 Selected Topics in Architecture which was the platform of the application of this experiment over the whole regular semester Spring2021 in the architectural Engineering Department at United Arab Emirates University UAEU. Aged from (17-23 years) 24 were Emirati, 13 were indigence from Al Ain. The students were at their last academic year in the program.

Procedure

The course designed to accommodate a design studio based previous discussion see Table 2. It consists of three learning components. These are: 1) Brand Image, 2) Inherent Image, 3) Ideal image.

Table 1: Course syllabus

Week	**Topics**
Week 1-2	Topic 1: Introduction to culture sustainability ***Brand Design Strategy***
Week 3	Topic 2: Construing the ***Brand Image*** of the locality – site visits, sketching, data collections
Week 4-5	Topic 3: Introduction of principles - Andrea Palladio – Case studies Brand-Based Design
Week 6-7	Topic 4: Construing the ***Inherent Image*** of the place based on Personal Construct Theory PCT and its analytical component Repertory Grid Technique RGT.
Week 8	Mid-Term Exam RGT – Integrate the local inhabitants' construct system into building design
Week 9	Topic 5: Developing branding scenarios
Week 10-11	Topic 6: Construing the ***Ideal Image*** – Design development and evaluation
Week 12-13	Topic 7: Visualizations – Using 3D computer programs to render the concepts
Week 14-15	Topic 8: Modeling – Lab work
Week 16	Final Exam Presentation Development - Studio Portfolio - Oral Presentation Final Project

RESULTS AND DISCUSSION

The listed design studio learning tasks were inherently planned on the elicitation strategy of PCP by bringing the contradicting elements and involve the ideal person or object as internal benchmark.

The Brand Image

The course was introduced to students by a lecture about the brand design strategy, which is a strategy that instructs designers to design a product based on the users' visual perception. In other words, the 'visual perception' is the process to associate designers with the users from the place. Thus, when the brand image is not changed, a self-sustainable image is achieved. This does not oppose the evolution of the brand image.

In this design process, the users are the local inhabitants of the city who have the right to preserve the culturally sustainable brand image of the city. It was concluded that by designing through the brand design strategy, a positive psychological connection will be created between the local inhabitants and the building they live in.

To design through the brand design strategy, the brand image must be understood and analysed. This was done through a general study of images of several traditional buildings in Al Ain. Then, every group selected one traditional building to use as their brand image. The traditional buildings were visited by students to understand the scale and proportion, take detailed photos of elements, and to see the textures of different materials.

Introduction of Design Principles
This section of the course aimed to familiarize students with the brand design strategy by first studying Andrea Palladio's work which followed the Roman brand design. Next, the design principles of different design approaches were studied and compared along with case studies describing each. Finally, case studied on villas in Alain following different approaches were conducted.

Analysis of Andrea Palladio's Work
The aim of this section was to understand how Andrea Palladio succeeded in designing beautiful villas in Italy based on the Roman style of architecture. Andrea Palladio's Work is a clear and well-defined example of the brand design strategy in architecture. The villas were examined based on how they followed the Roman brand image, and how certain elements were minimized or maximized.

Design Principles of Brand Design Strategy
After studying Andrea Palladio's Work, students were asked to define the key principles followed in brand design strategy and explain these principles through the applications of Andrea Palladio. Students were given a time extension to improve this task further. The principles discussed were tradition and culture, proportion and scale, balance and symmetry, repetition and rhythm, and emphasis.

Design Principles of International Style of Architecture
To get a better understanding, students were also asked to describe the design principles in the international style of architecture. These principles included, minimalism, balance, truth to material, form follows function, and volume of space. Students got a clear idea of the differences in the two design approaches, especially that the international style of architecture has no local reference and is considered a foreign image.

Design Principles of Deconstruction Style of Architecture
In this section students researched the design principles followed in deconstructivism. This was a very helpful stage since deconstructivism follows principles that are completely opposed to the brand design strategy. The principles included manipulation of structure's surface, complex geometry, fragmentation, non rectilinear shapes, and asymmetry.

Case Study Analysis on Brand Design, International Style, and Deconstruction Style
The case studies on the different design strategies were to ensure that students clearly differentiated these approaches.

Case Study Analysis on Villas in Alain
In this section, students were asked to analyse case studies of villas in Al Ain. The analysis showed how the villa did and did not follow the brand design strategy. For example, did the villa follow the traditional ornamentation, proportion, rhythm, and colour scheme or did the building follow foreign design principles.

THE INHERENT IMAGE

Personal Construct Theory Lectures

Two lectures were presented to students about the personal construct psychology. This knowledge was esablished by George Kelly in 1955. He wanted to find the uniqueness of people by focusing on their personal meanings to people, objects, events, and ideas. Personal construct psychology is not about placing individuals' response along a universal dimension or scale. Instead it is based on eliciting bipolar constructs which are a unique personal scale for each individual. This scale and the elements (objects) included in the study is managed by the repertory grid technique.

One might ask what the difference is between conducting a survey and a repertory grid technique. Surveys are restricted in the sense that the researcher thinks about relevant questions and makes many assumptions about the participants. However, through the repertory grid technique, the participant establishes the constructs for his/herself.

The first lecture explained the need for the personal construct theory and repertory grid technique in different applications to get accurate results from participants. It allows a student/researcher to understand why the participants preferred certain options over others. The second lecture focused on an example in the application of the repertory grid technique. The example presented was about searching for the ideal chocolate bar. This same technique was applied to finding the ideal villa in the city of Al Ain.

Integrate the Local Inhabitants' Construct System into Product Design Using RGT

The repertory grid technique can be used to understand local inhabitants' construct system. The method is as follows: a participant is shown a group of villa images. Then, the participant is shown a random selection of two of these images. The participant is asked if the images are similar or different and why are they similar or different. This is how a construct is created. The participant then scales all the images according to the created construct and indicates where do would they prefer their ideal image to be. The Figure 2 below illustrates the process.

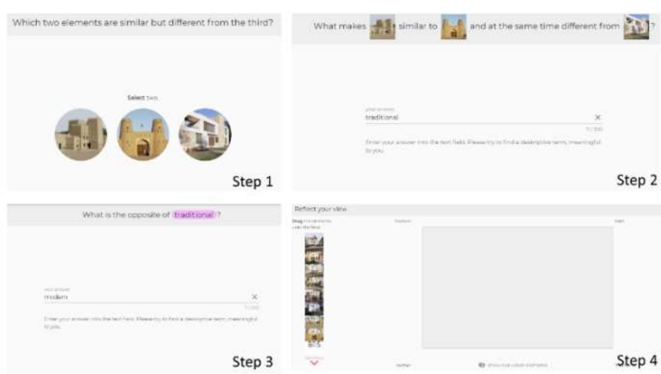


Figure 2: Steps of Creating Constructs

Using RGT to Understand Students' Perception to the City's Brand Image

As part of the midterm examination, students were asked to perform the repertory grid test to find the ideal image. Students were presented with nine images. Two traditional buildings, two following the local image, two following a foreign image, and two following deconstruction style of architecture. The final image "BDS" was placed for students to scale it as their ideal image. The Figure 3 below shows the images presented.

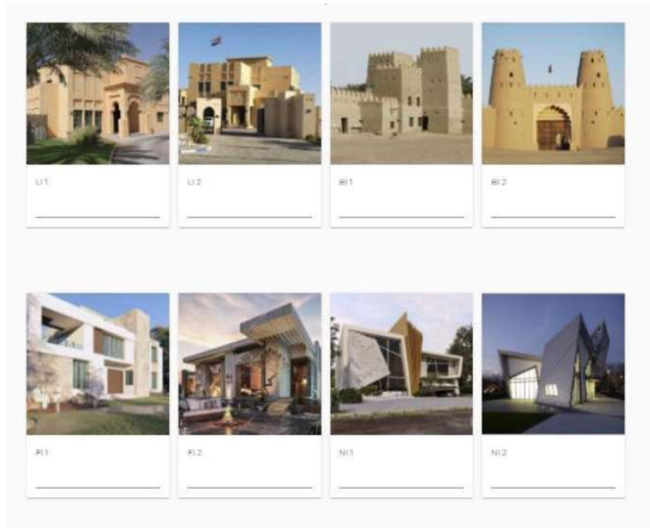


Figure 3: Repertory Grid Elements

The Ideal Image

Analysis of Repertory Grid

The results of the repertory grid conducted were analysed to develop an ideal design for a villa in Al Ain. A general visualization of the results is shown in Figure 4. The buildings following the same design strategy were ranked equally. The X-axis represents meaning to the participants, and the Y-axis represents the principles. Thus, the local images and traditional images were the most meaningful to students, and the local images and foreign images followed the required principles.

Figure 4: Results of Repertory Grid

The test taken by students resulted in 143 constructs that were important in creating the ideal image. Some of the constructs were more important than others. To analyse these constructs and rank their importance students grouped them into clusters. Every construct was given a rank of importance from 33 to 100 according to the results from the repgrid website. Figure 5 shows the clusters of one group.

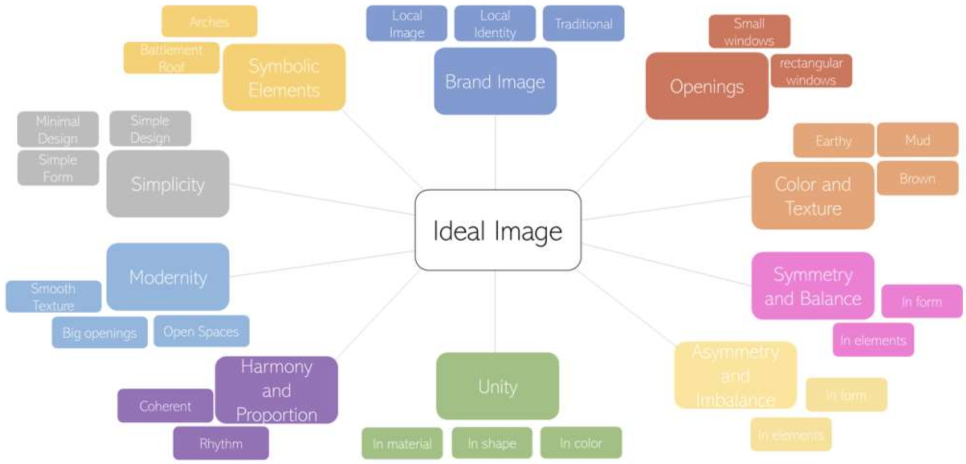


Figure 5: Sample Clusters

The clusters were then ranked according to their importance. This was done by adding the importance ranking of all the constructs under the cluster. Figure 6 shows that the most important clusters are brand image, color and texture, and symmetry and balance. It also shows that asymmetry and imbalance had a very low importance compared to symmetry and balance thus it could be disregarded.

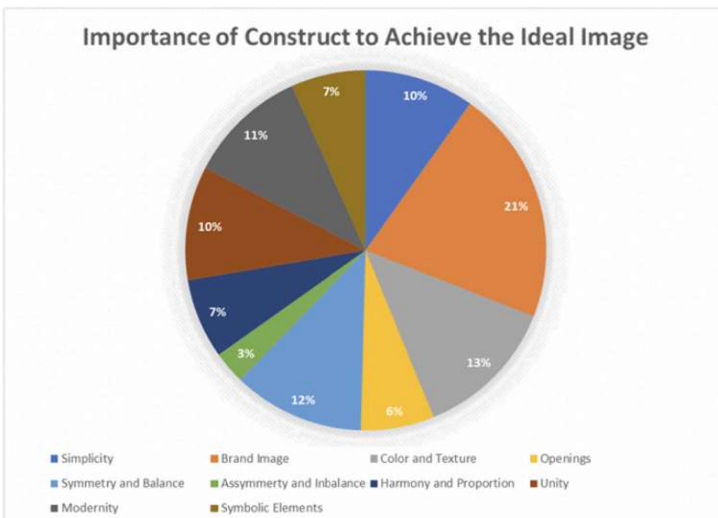


Figure 6: Clusters' Importance

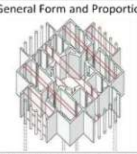
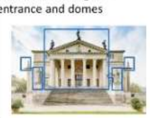
Each cluster was then analysed separately to get a better understanding of what is required to be achieved. Figure 7 shows a sample cluster analysis for the simplicity cluster.

Figure 7: Sample Cluster Analysis

Construing the Ideal Image

The ideal image was construed based on Villa La Rontonda and the analysis of the repertory grid. Students were asked to analyse Villa La Rotonda based on the conclusions in previous studies. A sample analysis is shown in Table 2.

Table 2: Analysis of Villa La Rotonda in Relation to Clusters

Element	Clusters it Obeys	Clusters it Disobeys	Decision
General Form and Proportions 	• Symmetry and Balance • Harmony and Proportion		Keep the same
Roman Elements: Columns, statues and triangular entrance and domes 		• Simplicity • Modernity • Symbolic Elements of Alain	Replace with Minimalized Alain Symbolic Elements while keeping the same proportions
Openings 	• Openings (which are small)	• Modernity	Keep most openings the same, but make a few bigger to achieve modernity
Materials 	• Unity	• Color and Texture	Change color and texture of materials to one that matches Alain Brand Image
Arches 	• Symbolic Elements of Alain		Keep the same
Window Pediments 		• Simplicity • Modernity • Symbolic Elements of Alain	Remove to achieve a more modern look

Design Development and Visualization

According to the decisions taken in previous section, students were asked to individually develop their designs. The design focused on the rebranded image of La Rotonda to match Al Ain brand image using the repertory grid analysis. Figure 9 shows a sample of a student's design development work.

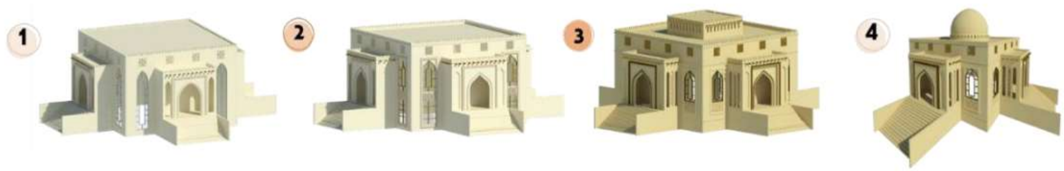


Figure 9: Sample Design Development

Model Making

Students who had good design developments and ideas had the chance to visit the architectural engineering lab, where they created basic models to get a better understanding of the form and elements. After creating the basic models, some students decided on making some changes to their design, such as window position and size in relation to internal spaces.

CONCLUSION

The design studio worked effectively between the society opinions on architecture and the students' individual opinions. This approach of teaching/learning helped facilitating the students' thoughts using the RGT with no major impact from the instructor. The design studio, I think, has developed self-awareness and cultural emergence for the students about taking the right decisions on architectural style that is appropriate for their locale. They understood that modernizing the local brand image of architecture is possible, and designing a unique style-based culture is possible as shown in the concept developed by students. However, the academic thoughts that are bushing students towards modernity as a concept to create boxy glass and steel forms should be limited or eliminated.

The inclusion of the local inhabitants' evaluation using the Rep-grid was valuable as it helped students understand how their society is looking at these concepts. They were confident that there is no bias in the evaluation generated by RGT. The students were satisfied that every element developed in their project was there for a reason and it has the opportunity to evolve overtime responding to the local identity and modernity.

As instructor I enjoyed observing the students' performance and development with the course progress during the semester. I was surprised when I saw the students' developed ideas. I was not expecting that much of concepts can be developed by students from the same brand image of Al Ain. The major concern was how would students develop their own individual brands using the same brand image, however, I received a variety of concepts during the design process in this architectural design studio each represented the student's individuality. However, some design skills need to be started earlier, such as control the scale and proportion and freehand sketching techniques as the program should make more emphasis on form-making which is the major contribution expected from an architect or architect engineer.

The Rep-grid developments today promises new techniques to emerge to help the learning experience to be much interesting. For example, the involvement of the artificial intelligence features with the RGT elicitation process. This will make possible to ground RGT on other digital platforms currently used in the built environment to process and manage design such as Building Information Modeling BIM.Based on previous studies and this design studio study, the case of Al Ain as a city and its inhabitant is unique. The UAEU has the potential to host the future UAE School of Art, Design and Architecture as it is established in the city of Al Ain and most students target this institution for university education are locals. In fact, a major interest in architectural education need to be directed to form and meaning-making human-based knowledge as major and technical-based knowledge as minor or critically balance in between.

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POE & BUILDING DESIGN: DESIGN INTERVENTION ON OCCUPANT SATISFACTION AND WELL-BEING

Pratima Kiran Mandadi[1], Manjari Khanna Kapoor[2], Ramesh Raghavendran[3], Aanchal Sharma[4]

[1] Associate Professor/ Ph.D Scholar , G.D.Goenka University, Sohna Road, New Delhi, India, 190070602001.pratima@gdgu.org
[2]HOD& Professor, SoAP, , G.D.Goenka University, Sohna Road, New Delhi, India, manjari.kapoor@gdgu.org
[3] Professor, Visiting Faculty JNAFAU, Hyderabad, TG ,India, ramesh@archinovadesign.co.in
[4] Associate Professor, School Of Architecture and Design, DIT University, India, s.aanchal@gmail.com

ABSTRACT

The main intention of the research is to comprehensively evaluate the occupant's satisfaction in the workplace surroundings based on pre and post-occupancy and determine its association with wellness and performance. Post occupancy evaluation in the building design plays a vital role as it is a system to identify the potential problems and provide a pathway to resolve the challenges by efficiently utilising innovative approaches. The paper chooses an analytical approach to determine the demographic parameters in the sample collected from random sampling methods that rely on a quantitative methodology. The study sample addresses 122 participants who took part in the questionnaire-based empirical study to determine their experiences working in the IT office (office A). The paper uses the BUS(Building Use Studies) Occupant survey method to conduct the post-occupancy evaluation. The POE (Post-Occupancy Evaluation) reveals that the design features of the office are well-distinguished as it offers a modern, cooperative, timeless design with advanced gleam technology. They effectively enhance the employee's productivity through their comfortability, likeability, appropriate light on the desk, ambience, IAQ (Indoor Air Quality), and IEQ (Indoor Environment Quality), among others. The analysis also observes that occupant's well-being correlates with the inevitable design features and encourages optimal health outcomes covering air quality, distraction-free environments, and so on.

The results showed that all indoor environment variables as well as the overall indoor environment satisfaction are significantly correlated with the occupants' work performance. The findings of this study can provide guidance for architects and designers to concentrate on enhancing the design features to improve the indoor environment to attain high productivity and well-being of the occupant's.

Keywords: Post occupancy evaluation, Occupants well-being and employee productivity, POE and building designing, IEQ.

INTRODUCTION

Post occupancy evaluation is identified as a procedure of thriving discipline that explores the performance of the building after its construction and is occupied for some duration. Although it emphasised the insight of occupancy and their necessities in the workplace, it did not collect any technical specifications information as illustrated in the study Lei, Q et al., (2022). The parameters that play a significant role in identifying occupant essentiality in the workplace embrace security, well-being, convenience and comfort, functionality and efficiency, and aesthetic quality of the building as exhibited in the study Choi, J.H. and Lee, K., (2018). Identifying the surrounding influence building results in the formation and adaptability of advance and cutting is technology innovative designing architectural design operational strategies, the utility of new material in construction building as said by Kooymans, R. and Haylock, P., (2006). These components of building construction can only be evaluated after the occupation utilises the structure as their workplace. The transforming and emerging technology and increasing the functioning of automation in working culture make it challenging for the building to use them in a more effective, efficient, and accessible manner as observed in Hua, Y., (2013).

Post-occupancy evaluation (POE) is a platform for the systematic study of buildings once occupied, so that lessons may be learned that will improve their current conditions and guide the design of future buildings. Various aspects of the occupied buildings' functioning and performance can be assessed in a POE, both chemo-physical (indoor environment quality (IEQ), indoor air quality (IAQ) and thermal performance) as well as more subjective and interactional (space use, user satisfaction, etc.) in Alex. (2009).Occupants' satisfaction with the performance of their buildings reflects the quality of design, construction, operation and management of the facilities serving the buildings mentioned in studies by Hou, H. C., (2020).

The parameters embraced in IEQ are classified as thermal comfort, indoor air quality and ventilation (IAQ), visual convenience, and acoustic comfort. The employee's well-being, amenity, and productivity are significantly impacted in the indoor workspace as mentioned in the manuscript Esfandiari, M. et al., (2017). Simultaneously other parameters are the spatial structure design, interaction of workplace employees with nature, and location availability of public-private assistance associations.

India still does not have any thermal comfort standards, and the National building code of India also does not mention occupant adaptation for the workplace. The comfort temperature with personalised touch is considered to be effective in improving overall comfort which lies between 25.5 degree centigrade to 30 degree centigrade. The humidity criteria considered to be ideal for indoor air is between 30 to 50% RH as data extracted from WELL V2[16]. The Parameters affecting indoor air quality are set and recognized by the World health organisation concerning the Indian scenario.

Table 1: The Parameters for indoor air quality.
Source: Indraganti, M et al., (2015); Mujan, I et al., (2019)

Parameters	WHO	India
Temperature of air	22-27°C	0-45°C
Relative Humidity	25-45%	10-90%RH
Air flow	0.25 m/s	0.1-50.0 m/s

The paper by Mujan I et al. (2019) emphasises exploring the correlation between the IEQ and occupants' comfort, which has a powerful influence on transforming employee behaviour. It focuses on building design, thermal, hearing, furniture, glare comfortability, and working environment. The paper by Esfandiari, M et al. (2017) is intended to identify the correlation among IEQ parameters and its influencing impact on occupant satisfaction, wellness, and productivity in the workplace. Several post-occupancy evaluation studies go through conventional and green building exploration though they do not provide an effective outcome to indicate occupant satisfaction and its relation with IEQ components.
Asojo et al. (2021) study analyses designing intervention in a workplace and its correlation with occupant satisfaction by determining pre and post-occupancy surveys. The outcome demonstrates that the renovation in the design outlook of the organisation significantly enhances the occupant satisfaction, work productivity, and wellness is also improved in POE. Another study by Choi, J.H. and Lee, K. (2018) focuses on case

[16]https://f.hubspotusercontent40.net/hubfs/7039796/Evidence%20Box/evidence%20box-%20thermal%20comfort%20final.pdf

study (Office A) to determine the POE through four variant studies. The paper intended to analyse the seasonal difference and its linking with POE. The outcome shows that similar patterns concern various seasons of environmental satisfaction in the workplace.

Rational of case study:

India has emerged as a global outsourcing destination for IT and IT enabled services (ITeS) and is well known for providing world class technology solutions and business services. Indian IT & ITeS industry is increasingly contributing to country's GDP, employment and exports. The key factors contributing to the huge growth and success of this sector access to skilled manpower, cost competitiveness, strong quality orientation, availability of high quality infrastructure, enabling policies of the government and mature industry eco-system.[1]

However, the pattern of growth and cluster formation is not uniform across in India. Bengaluru, Hyderabad, Chennai, Pune are the cities which have undergone an immense growth in the IT sector.[2] Telangana, which was formed in June 2014, is the 29th state of India, with Hyderabad as the state capital. Leading IT companies like Facebook, Google, IBM and Microsoft already have presence in Hyderabad. Hyderabad is one of the advanced cities of India and is one of the major IT centre due to the presence of technology hub - Hyderabad Information Technology and Engineering Consultancy City abbreviated as HITEC City, a tech oriented cyber city. In the past years, HITEC City has seen significant economic growth and has approximately 1500 IT companies, including companies such as Apple, Microsoft, Google, Yahoo, Infosys, Tata Consultancy Services etc. Many of these companies have made Hyderabad the base for some of their most critical global operations. For example, the only R&D center of Microsoft outside USA is in Hyderabad. Google has its largest campus outside US in Hyderabad and TCS has its largest development center, globally in Hyderabad.

From software development to IT enabled services to Internet startups, to e-business companies to small and medium IT companies to logistics companies- all types of companies have established their base in this city. These IT companies employ close to 4 lakhs professionals, besides supporting an indirect employment to over 6.5 lakhs people. Also, according to the World Bank Group, Hyderabad is the second best Indian City to do business[3]

With high potential study to determine the growth, it is very important to record the development of infrastructure through and around HITEC City, Hyderabad, which is an example of successful IT parks to accelerate the relationships between indoor environmental quality (IEQ) and work performance of occupants satisfaction along with well-being with a set duration to investigate the POE.
The limitation include a interpretation of several researches which have been performed with an objective of establishing the hypothesis that there is a relationship between the satisfaction of the user and the physical conditions of the indoor built environment. Ample literature is available on POE using occupants satisfaction but this study also have varying interpretations on addressing the complexity associated with users satisfaction indicators what constitutes POE, seeking physical parameters in workplace and in different purposes and ways to suit varying project contexts.

Case Study- Office A

The Office A location flourished in the area around 2,00,000 square feet, which is located in the tech industry hub of HiTech city. The organisation is the innovation partner, vital technology incubation centre located at Hyderabad. It is the only such centre in India with a strengthened full group of thousands of strong employee workforce. The organisation has the experience of more than 25 years. The selection of the office is based on the criteria, being located in the potential zone of tech industry hub of Hitech city. The pre analysis of the office is conducted to explore their aspects and it was identified that it is suitable for further analysis. Thus POE analysis is evaluated over the occupants of the office A to determine the design impact on occupants satisfaction and well-being of them, the time duration of the investigation of POE is six month.

The main intention of the research is to comprehensively evaluate the occupant's satisfaction in the workplace surroundings based on pre and post-occupancy and determine its association with wellness and performance. Seeking and enhancing more understanding, researchers have already published four distinct papers in the interior designing section like kiran Mandadi, P. and Zutshi, N.S.(2021); Kiran Mandadi, P., et al., (2022) These papers can act as a pre evaluation and thus present study is focusing on post evaluation. Subsequently, two corresponding objectives are 1) the paper emphasises on determining the design features of the workplace that rely on IEQ satisfaction and its impact on occupants' productivity along with 2) determining the influence of these design characteristics on occupants' well-being and satisfaction. The Paper also explores office A to justify the context by collecting data from the employee from Office A and identifying the post-occupancy evaluation of the workplace.

METHODOLOGY

The paper chooses a qualitative methodology that relies on an empirical survey approach. The survey was conducted online through distributing google form and samples were collected from random sampling methods. The sample size was about 122 participants, who took part based on the criteria as mentioned in the questionnaire they needed to fill while taking part in the survey. The survey is intended to determine the employees experiences who were working in office A for more than six months. The measuring scale for analysing the result, the study uses the Likert Scale ranging from 1 to 5, where these numbers show the perception as 1 (Strongly Agreed) and 5 (Strongly Disagreed).

The paper uses the BUS (Building Use Studies) Occupant survey method to conduct the post-occupancy evaluation. It assists in evaluating specific parameters to analyse the IEQ satisfaction that comprises overall auricular quality, aesthetic, sunlight activity, artificial glare conditioning, and furnishing influence on the employee. Moreover, along with IEQ, the finding also seeks to identify the designing intervention such as workplace productivity that relies on appropriate interaction space, workspace composition, comfortable and convenient accessibility of an elegant room, and the practical utility of furniture and table.

Hypothesis

H0: Designing intervention did not correlate with IEQ satisfaction, occupants productivity and well being.
H1: Designing intervention correlates with IEQ satisfaction, occupants productivity and well being.

DATA ANALYSIS

The data analysis section explores the data collected from samples in the tabular form to conduct the post occupancy evaluation of the participants who willingly share their experience. Table 2 contains demographic details, working experience of the professional, and the type of workplace obtained from the sample whose size is 122.

Table 2: The table demonstrated the Sample analysis.

Parameters	Groups	Data in percentage
Age band	23-30 30-45 45 above	31.2% 51.6% 17.2%
Gender	Male Female Third Gender	51.2% 43% 5.8%
Professional Experience	1-5 6-10 11-15 16-20 21-25	27.9% 40.0% 16.3% 11.6% 4.2%
Type of workspace	Assigned Workplaces Co-working Office Layout Cubicle Office Flexi Design Home-Office Low Partition Open Workspaces Open-Plan Workspaces	15.8% 6.5% 26.5% 2.3% 3.3% 15.8% 6.5% 23.3%

FINDING

The BUS occupant survey method that opt as a methodology to gather data from questionnaires is processed manually through excel spreadsheet and classified into two sections- section one explores demographic information like age, gender, experience etc, followed by section two where the finding is focusing on evaluating the distinct questionnaire regarding interior designing, furniture comfort, HVAC (Heating, Ventilation, and Air Conditioning), IEQ among others. So, the first section is mentioned in the data analysis part and the other section is discussed in the finding part as follows.

The indoor environmental quality ensures effective natural connectivity in the workplace and has an immense impact on the well-being of the employee and the company. It is a qualitative measurement of the building environment correlated to the personal health and health of the surroundings. It is evaluated on the prominent factors like natural and vibrant light, fresh air, the air quality inside the building, and other nature-connected elemental situations. To explore more on practical grounds, the study conducted POE to analyse the experience of the employees who have been working for the last six months or more.

Under this certainly questionable ask regarding furniture and Interior physical attributes from the employee who is working in the office A, the data reveals that how furniture and the office space effectively corporate in coordination enhance comfort and satisfactory level, interior ambience, lighting and the temperature of the workspace, the ventilation of the office whether it effectively encourage an employee to work for long hours.

The satisfaction of the furniture and the lighting plays the most crucial role which is directly correlated with the working hours' efficiency and productivity of the working of the employee as well as it acts as a vital component and linked with the well-being of the employee because the sitting posture has an impact on their back and improper sitting lead to back pain, as well as the lighting, plays a most essential as it relates with vision power. Comfort is directly connected with the light, colour, furniture setting, and the material of the furniture, which enhance or reduce the potential and the productivity of the employee working in the workplace.

Parameters in the workplace

To measure the POE in the workplace and try to perceive the impact on the occupants' work productivity and well-being while working in the interior layout provided by the organisation. To calculate the study, selected specific parameters like *Ambient Environment* (Well ventilation, thermal comfortability, glare from lighting fixtures, access to daylight from the desk, sufficient artificial lighting to support work., likeability toward Interior ambience of office/workspace and whether employees have a hard time concentrating due to poor acoustics or not) *Ergonomics related* (Office furniture is comfortable, the desk is height-adjustable, the seat is height-adjustable, desk provide comfortable height for footrest, and reaching out for storage is satisfied). The figure 1 demonstrates the data extracted from the survey.

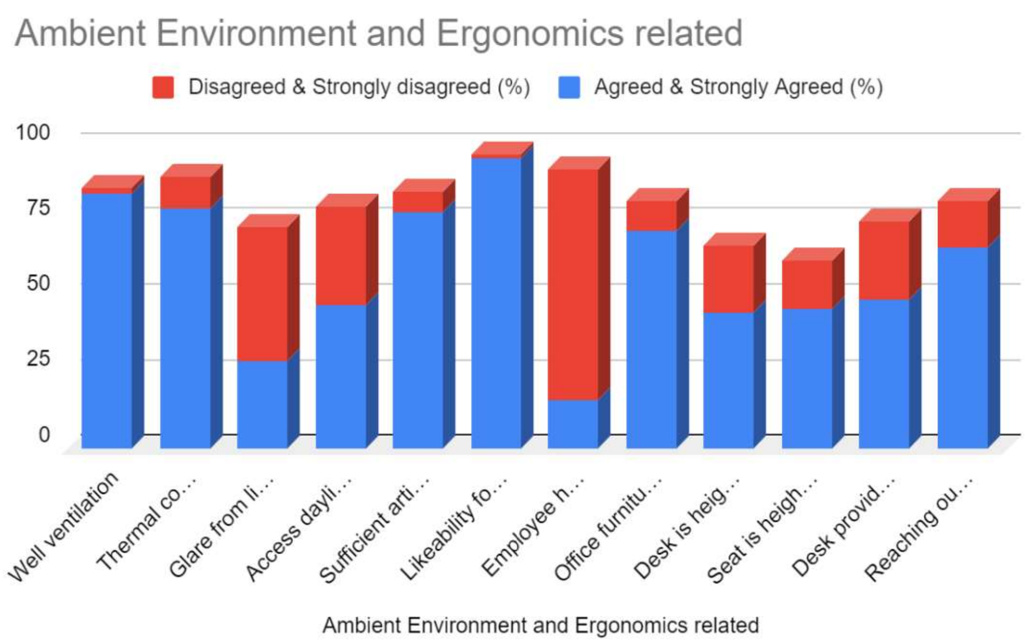


Figure 1: The Ambient Environment and Ergonomics related data.

Individual Work Environment has two components one focuses on exploring the health-related concern of the occupants, and the other focuses on work productivity. The parameters that focus on productivity and efficiency of the employees are like (Office/workspace helps to work efficiently, the spatial environment of the building supports employee ability to get work done, and employees feel that current working organisation be distraction-free feel safe and productive in the current workspace, office design motivates me to spend more time in the office). The figure 2 demonstrates the data extracted from the survey of the office A.

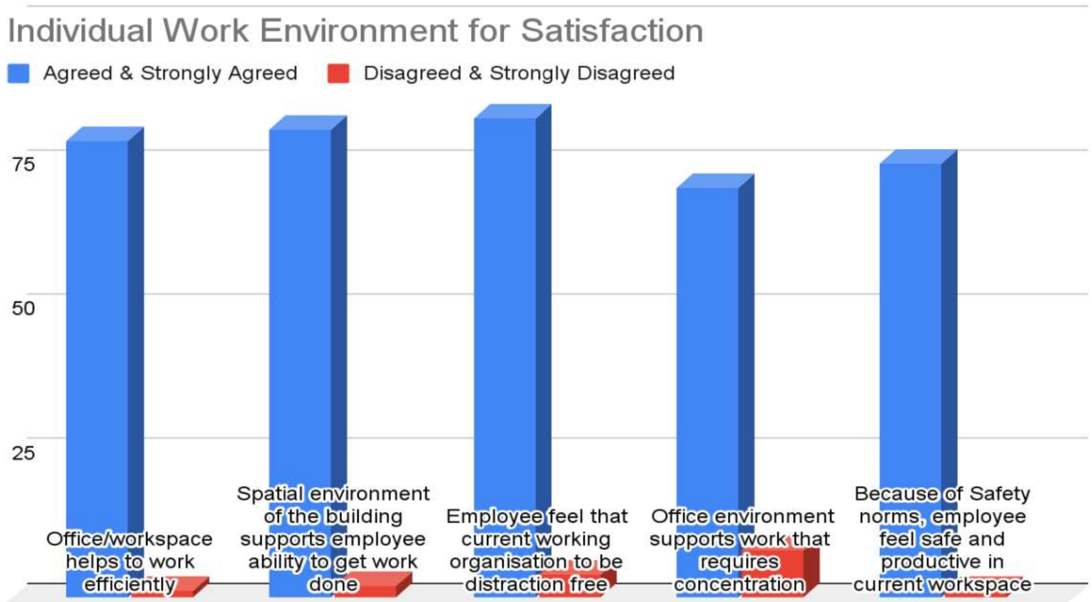


Figure 2: Individual Work environment parameters.

With the wellness concern- direct parameters that focus on designing features like (comfortable lower back-rest support, back and lower back pain after prolonged sitting, feel sick after spending many hours in the office). The data of occupants' experiences is extracted, and the outcome of the statistical analysis is illustrated in Table 3 and its pictorial representation is illustrated in figure 3.

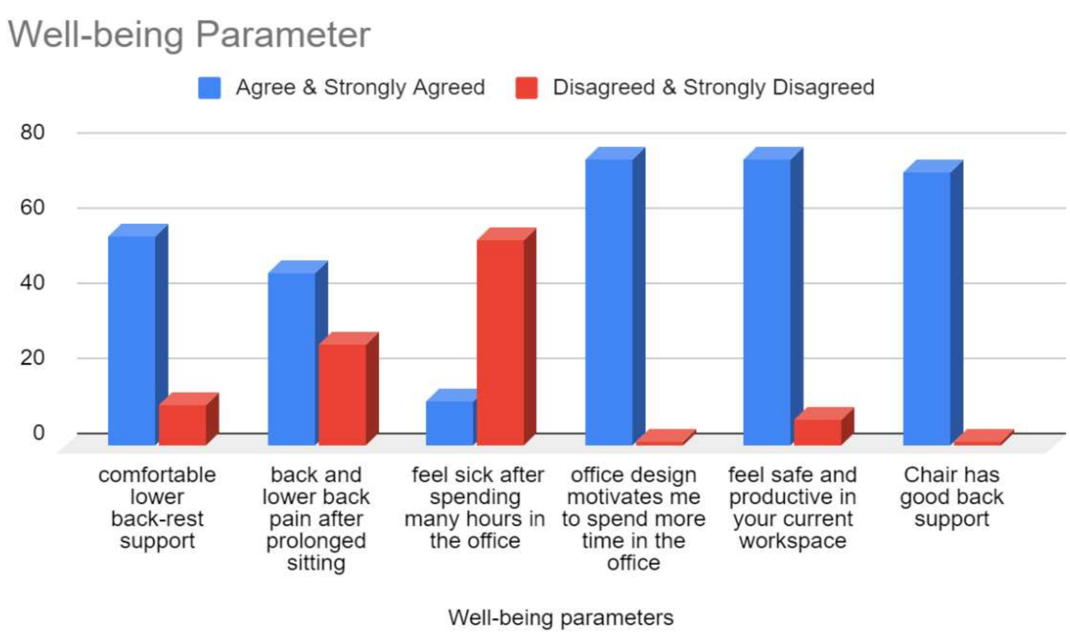


Figure 3: Well-being parameters of workplace

Communications infrastructure and *Collaborative work environments* has components like (accessibility of management by common occupants, office encourage teamwork, socialise with colleagues in informal areas, informal meeting spaces are distributed around the office, office environment sufficiently supports occupants to get tasks done, office environment allows employee to communicate effectively with colleagues, informal spaces are available to use for collaboration sessions, environment supports collaborative work, satisfied with the spatial environment of this building, and the adequate storage space). These parameters specifically reveal the workplace surroundings and infrastructure that assist to build a cooperative and collaborative environment along with the spatial space for interaction, meeting and physical activity engagement. These parameters are demonstrated in the below figure 4.

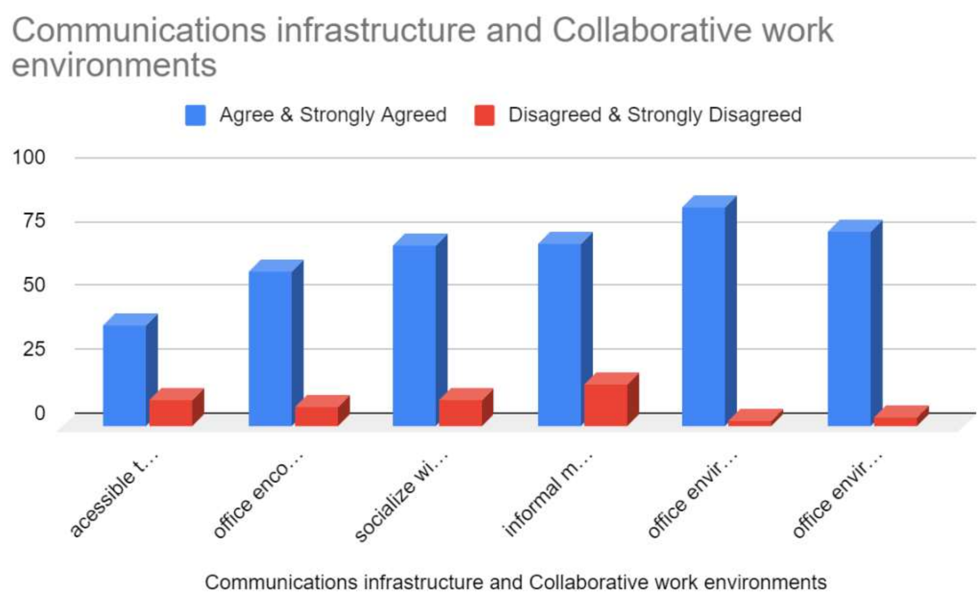


Figure 4: Communication, infrastructure and collaborative work environment.

ANOVA and t-test Statistical Analysis

The parameters which explained above are used to statistically analyse them by using ANOVA statistical test and t-test.

The average mean of the hypothesis is 972.45.

The value of $p<0.5$ ($\propto = p = 0.05$)

Confidence interval = 95%

Table 3: The statistical study based on ANOVA & t-test method

Components	SS	df	F	Mean Square	t-test	p-value	Hypothesis
Between treatments	34083.37	1	F= 89.4143	972.4513	-4.7	<.0001	Null Hypothesis H0 (rejected)
Within treatments	21346.34	56					

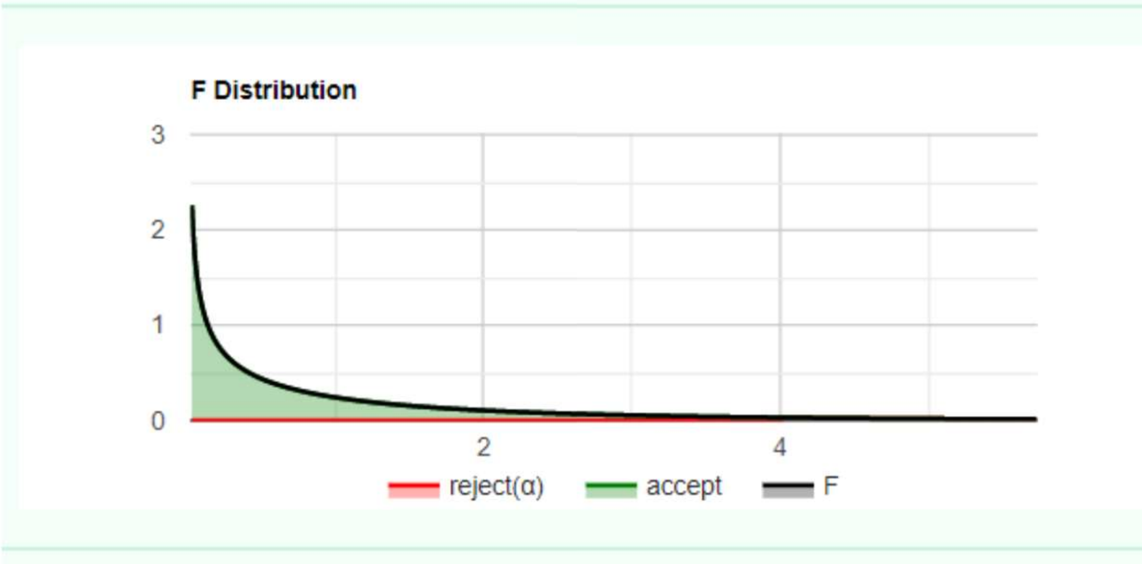


Figure 5: Demonstrate the F-distribution of the statistical test.

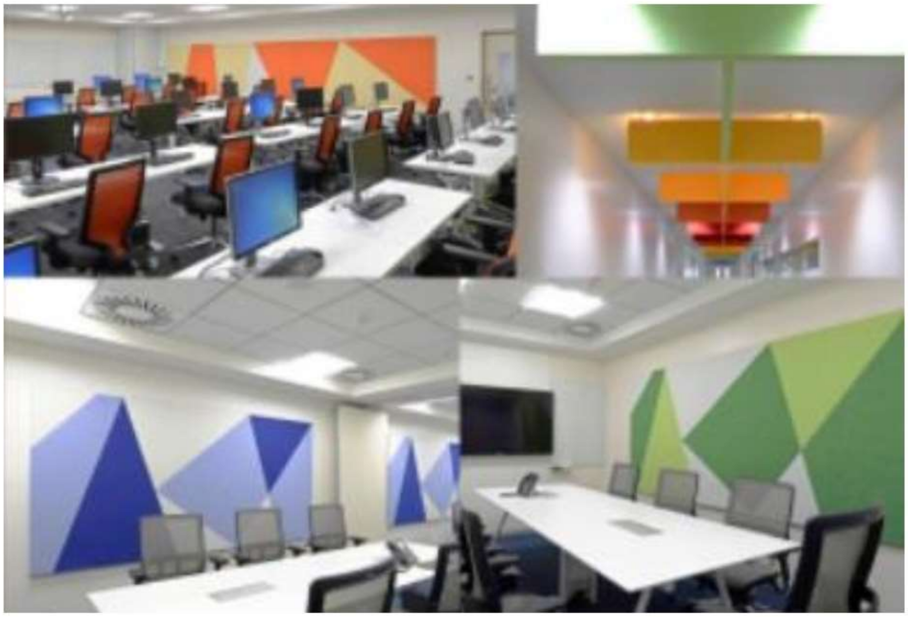
The data reveals that the value of $p < \alpha$, where significance level $(\alpha)= 0.05$. The smaller the value of p, the stronger it supports H1 (alternate Hypothesis). Therefore H0 (Null Hypothesis= α) is rejected, and H1 (Alternative Hypothesis) is accepted.

Moreover, the study also reflects some most vital parameters of IEQ based on scientific guidelines like the thermal and acoustic comfort in the workplace. The outcome reveals that 36.4% of the participants were nodded for 22 - 25 degrees Celsius being optimum AC temperature, followed by 26. 4% of the occupants believed in 20-22°C, and around 20.7% agreed to 21-23°C for thermal comfort. Another central question was the noise level in the workplace. The data reveal that 36.4% of the participants work upgrade for 35 - 40 decibel, while 24.8% suppose 40 to 45 decibel, around 22.3% of the occupants assume that the noise level in their workplace is lying between 45-55dB and approximately 16.5% of the participant favour with 30 - 45dB. This shows that the office A satisfies the guideline set by WELL V2 of background noise level ranging with 35-45dB[17].

The acoustic features configured by the workplace and the lighting comfortability in Office A are illustrated in Figures 6 & 7, respectively.

[17] https://v2.wellcertified.com/en/v2.2/sound/feature/2

Acoustic Solution provided by Office A



The Acoustic solution of different floors like ninth floor, tenth floor, eleventh floor and ground floor respectively.

Figure 6: Acoustic solution of floors.

Lighting in the office (Office A)

These LED lights with UGR-19 have various features like cost effective, high energy efficiency, pleasant light and low installation.

Figure 7: The lighting feature of the workplace.

Nevertheless, the comfort chart provided by the BEE proclaims that the temperature up to 25 degree centigrade is quite comfortable for the human body along with desired humidity and air movement value.

At the same time it is estimated that the workplace usually sets the lower temperature around 18-21°C[18]. This shows that thermal comfort of the building was convenient with respect to the health of the occupants. Although, the acoustic level lies between 30 to 65 dB being an ideal sound level for the office. For the open plan workplace the recognised level of sound is 40-45dB[19]. The study data showed that both the vital component of IEQ in the workplace is under the norm or a guideline set by the expert.

RESULTS

An organisational occupants' satisfaction should be embedded with critical factors like a friendly environment, flexibility and autonomy at the workplace, cooperation and team building, harnessing innovation technology, interaction and engagement of employees in an amicable manner, motivating employees to put in their best efforts, and intensifying the capabilities. And all these factors directly depend on the building design and the features it braces for comfort and eases the working practices of the occupants. The POE and building design exhibit from several pictorial representations depicted in the finding section reveals that the comfort level of the employee chairs, tables, and furniture located in open space enhances productivity, increases concentration, and flourishes the work capability among the employees in a company. The spacious, comfortable furniture, lighting, acoustics and IAQ of the working area encourage occupants to work for long hours without sacrificing the well-being of the employees. Moreover, informal spaces are available to be appropriately used for collaborative sessions, and the office environment supports their workers to work in a coordinated, cooperative manner. The team cooperation and collaboration environment supported by the building layout enhance the teamwork spirit, which eventually reduces the stress and improves the friendly atmosphere, making the work more comfortable and accomplished on time. The POE of Office A reveals that the design features of the office are well-distinguished as it offers a modern, cooperative, timeless design with advanced gleam technology. It has a diffuse light emission, adjustable diffusers, and perfect illumination set stylish accents in modular system ceilings. And almost complete freedom from maintenance. Other vital characteristics are high energy efficiency, simple installation, pleasant light and low investment costs, which support and prove the statistical analysis.

CONCLUSION

Indoor environment quality demonstrates the interior features of the workplace. The IEQ directly impacts occupants' working convenience and practices, and the indoor environment profoundly influences the occupant's health and working arena. The organisation's commitment is to furnish a healthy environment and opportunely facilities for its occupants to feel satisfied and embrace the functioning to attain prosperity. A healthy workplace is stimulated to protect and encourage all the occupants' well-being, safety, and health through the collaboration of employees and managers. The POE analysis of Office A reveals that the workplace effectively provides grounds for cooperation and safety mechanisms for its occupants as it already proclaimed by pre-occupancy investigation through several other research accomplished previously such as kiran Mandadi, P. and Zutshi, N.S.(2021); Kiran Mandadi, P., et al., (2022) and now proved by POE in this research. The most vital ingredient identified in the analysis is that the occupant's well-being correlates with the inevitable design features and encourages optimal health outcomes covering air quality, distraction-free environments, and availability of appropriate light. The physical parameters of the interior design have an immense role in employee working capability. They effectively can enhance the employee's productivity through their comfortability, likeability, appropriate light on the desk, ambience, IAQ, and IEQ, among others. Other parameters specifically reveal the workplace surroundings and infrastructure that assist to build a cooperative and collaborative environment along with the spatial space for interaction, meeting and physical activity engagement.

[18] https://beeindia.gov.in/sites/default/files/press_releases/FAQ.pdf

[19] https://www.cetec.com.au/services/office-noise.html

Eventually, the pre and post occupancy analysis of the workplace is vital and significantly demonstrates the building configuration and interior infrastructure. Moreover, the statistical analysis perceives that work design is directly correlated with the occupant's well-being and productivity. Additionally, the IEQ created an influential position in enriching the productivity and satisfaction of the occupants.

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ADDITIONAL INFORMATION

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AN EXPLORATORY STUDY ON ASSESSMENT OF STAKEHOLDERS' PERCEPTION AND ATTITUDE TOWARDS NET ZERO RADIATION SMART HOME USING NEUROARCHITECTURE

Reshna Raveendran[1] Ala' Albdour[1], Mazen Alresh[1], Noora Abdullah[1], Noura Alblooshi[1], Shaikha Alkhateri[1], Kheira Anissa Tabet Aoul[1]

[1,] Architectural Engineering Department, College of Engineering, United Arab Emirates University, UAE

ABSTRACT

Electromagnetic radiation in smart buildings is viewed to cause health damage to dwellers, thus, calling designers to develop buildings and, eventually, radiation-free cities or smart cities that cause zero radiation. Several building factors play a role in dissipating electromagnetic radiation in a smart building, like building materials shielding capability to block radiation, wired internet connectivity, and radiation blocking trees. The proposed novel model incorporated several of these strategies to produce zero radiation and was confirmed with electromagnetic simulation software Computer Simulation Technology (CST). This exploratory investigation aims to understand stakeholders' perception of the concept of zero radiation smart building relying on neuroarchitecture approach. A short video was developed presenting the radiation risks and some mitigation strategies, which was presented to stakeholders seeking their attitude and perception as evaluated with an Emotiv headset. The paper presents the results and analysis of the transient mood states on six performance metrics: stress, engagement, excitement, interest, focus, and relaxation. It was found that there was a statistically significant difference in the participants' response to the video, with excitement being significantly increased in alignment with the mitigation strategies part of the video, while the remaining metrics were not affected.

Keywords: ElectroMagnetic Radiation (EMR), Smart Buildings, Zero Radiation Strategies, Computer Simulation Technology (CST), Neuroarchitecture, Perception.

INTRODUCTION

Currently smart buildings operating via artificial intelligence (AI) are considered the most modern form of buildings as they are easier to manage, more flexible, adaptive, and more responsive while offering real-time control to users. While smart buildings are proclaimed to have many benefits, researchers and environmental point out that they also have many negative aspects that are equally important but not taken into account as much as the positive ones (Raveendran & Tabet Aoul, 2021 a). A number of negative impacts have been reported, including concerns about cybersecurity (Ghayat *et al*, 2015) and radiation exposure. The World Health Organisation (WHO) and scientific evidence indicate that the radiation may cause unintended health problems such as tumours and cancer driving the quest for the design to create a zero-radiation smart building to help overcome many health and environmental problems. One of the first to address how to create a building that is not only smart but also "safe" in addition to offering wired connection is the innovative idea of "zero radiation smart building" architecture. Research motivation is to demonstrate how radiation generated in a smart building may be reduced to zero, several interior and outdoor design elements including building zoning, material selection, and landscape design were tested and proved to significantly reduce radiation propagation (Raveendran & Tabet Aoul, 2021, b Raveendran & Tabet Aoul, 2022). However, potential acceptance of such strategies will heavily rely on their acceptance and perception by key stakeholders, such as architects.

Hence, this research takes a step further by exposing the participants to the novel concept to understand their attitude and perception before physically developing such an adaptive space. The concept revolves around the development of smart homes or buildings that produce zero radiation and the testing of participants attitude through virtual neuroarchitecture experiments.

The reciprocal interaction between physical spaces and human well-being has been established (Chiamulera *et al.*, 2017). Neuroarchitecture, a concept that evolved from the convergent assimilation of humans and physical spaces, has treated the interaction with space as dynamic rather than static (Chiamulera *et al.*, 2017). Virtual neuroarchitecture refers to the testing of occupants' mental state for a building without being physically present, and this adaptive form of neuroarchitecture evaluation makes it easier to develop interior spaces per end users' needs and requirements (Higuera-Trujillo, Llinares and Macagno, 2021). Therefore, these virtual spaces produce a feedback loop for architects and planners for a better understanding of the end users' needs and their perception of physical spaces. The brain data measurement needed for neuroarchitecture studies is obtained using Emotiv headset. The headset can measure active EEG of users and convert it into emotional performance metrics. Generally, research works based on neuroarchitecture and virtual architecture were limited to measuring brain data either by, physically taking the participants to the actual physical space like a library or hospital, or by virtually showing them in a monitor (Kayan, 2011) (Higuera-Trujillo, Llinares and Macagno, 2021), thus, this being the research gap that the study is aiming to cover exploring a new concept that is tested for stakeholder attitude and perception before it being included as startegies in health and wellness and sustainability rating systems.

METHODOLOGY

This is an explorative study aiming to investigate the effect of presenting video about the radiation in smart homes, its risks, and mitigations on the stakeholders' perception. Using videos, music or still images as a valid stimuli to evoke emotions or affect cognition has garnered recognition among many scholars (Jadhav et al., 2017, Dhindsa and Becker, 2017, Katsigiannis and Ramzan, 2015, Blaiech et al., 2013, Tromp et al., 2018). However, there are issues with the method. One of them is usually in selection of the suitable tool to observe and record the impacts. Lee et al. (2022) noticed that most of the studies that measured the neurophysiological responses of participants to the built environment had used either the electroencephalography (EEG), electrocardiogram (ECG), functional magnetic resonance imaging (fMRI), electrodermal activity (EDA) or saliva cortisol. However, the EEG was the most used tool to measure the emotions between them (Lee et al., 2022). de Paiva and Jedon (2019) explain that many tools require the participants to be inside the machine such as the fMRI, which might affect the results of the study. Moreover, the EEG now is easier to measure because of the availability of portable wireless devices such as the Emotiv Epoc+ headset (figure 1). This tool has been validated by many studies such as (Hulliyah et al., 2017, Katsigiannis and Ramzan, 2015, Blaiech et al., 2013, Jadhav et al., 2017). As a result, Emotiv Epoc+ was used to conduct a neuroarchitecture study that is proven to record the different emotional states of mind. It functions by using 14 channels to record EEG raw brain data and convert it to measurable outputs.

The participants (n = 11) were shown the video regarding smart buildings and radiation to directly measure their brain's response. The video induced to create immersive audio/visual stimuli for the participants. Emotiv headset recorded the six-performance metrics relayed to Emotiv BCI software.

Figure 1: Emotiv EPOC + headset (*EMOTIV EPOC+ 14-Channel Wireless EEG Headset - EMOTIV*)

The performance metrics were manually transcribed at three specific time intervals of the video:

First, when the smart city and smart homes were introduced (T1), second, when the risks of electromagnetic radiation (EMR) in buildings were presented (T2) and third, during the explanation of the strategies to mitigate EMR in smart homes (T3). The video length was 172 seconds, and the experiment was conducted in a quiet room in the architectural engineering department of the University of the United Arab Emirates (UAEU). A 1.90 m x 1.20 m screen was connected to a laptop to play the video. The participants were sitting 2 meters away from the screen and the room lights were all dimmed. The temperature of the room was set at 22 °C. Prior to the test, each participant was briefed with a short introduction about the study. The participants were also asked to focus on the video content and to remain relaxed. The average viewing time for each participant was around seven (7) minutes, four (4) minutes for setting the Emotiv device and insure the connectivity and three (3) minutes for watching the video itself. One of the records was rejected because of maintaining low connectivity, therefore, the analysis of the data was conducted for a lesser number of participants (n = 10). Six (6) participants were faculty members at UAEU, two (2) Master's Degree students and two (2) bachelor's degree students. All participants were from the architectural engineering department, because they are all considered stakeholders in the smart home development. All experiments were screen-video recorded, using OBS studio. This setup enabled the research team to record the screen of the laptop which showed the records from the EEG, in addition to the large screen which was playing the video for the participants. This also helped the team to align the recordings from the Emotiv device with the video in order to transcribe the three interval recordings.

RESULTS AND ANALYSIS

A one-way repeated measures ANOVA analysis using SPSS were conducted to the EEG data recorded from the participants to compare the performance metrics of the participants in three stages: the smart cities introduction stage (T1), the radiation risks stage (T2), and the mitigation and solutions stage (T3). The repeated measures ANOVA analysis reveal statistical significance between two or more dependent records in case the records passed the sphericity test. The recorded data of four performance metrics for the participants passed the sphericity test, namely: engagement, excitement, focus and relaxations. The remaining two metrics failed? the test. Therefore, a Greenhouse-Geisser correction was used to the remaining two metrics, namely: interest and stress. The descriptive analysis and the sphericity test for the six metrics is shown in Table 1, Table 2 respectively. For engagement, Maulchy's test indicated a compliance of the sphericity assumption, $\chi(2)$ = 1.515, p = 0.469. For excitement, Maulchy's test also indicated a compliance of the sphericity assumption, $\chi(2)$ = 4.980, p = 0.083. For focus, Maulchy's test also indicated a compliance of the sphericity assumption, $\chi(2)$ = 0.398, p = 0.82. For relaxation, Maulchy's test also indicated a compliance of the sphericity assumption, $\chi(2)$ = 3.441, p = 0.179. While for interest, Maulchy's test indicated a violation of the sphericity assumption, $\chi(2)$ = 9.538, p = 0.008. Also for stress, Maulchy's test indicated a violation of the sphericity assumption, $\chi(2)$ = 6.112, p = 0.047.

Table 1: Descriptive statistics

	Mean	Std. Deviation	N
Engagement Introduction	76.3000	10.31773	10
Engagement Radiation	72.8000	9.99778	10
Engagement Solutions	71.6000	5.68038	10
Excitement Introduction	19.3000	9.82118	10
Excitement Radiation	28.1000	8.39907	10
Excitement Solutions	29.2000	11.27239	10
Focus Introduction	37.8000	9.76160	10
Focus Radiation	39.9000	7.72370	10
Focus Solutions	36.9000	11.63758	10
Interest Introduction	45.6000	7.64780	10
Interest Radiation	52.2000	13.34832	10
Interest Solutions	47.4000	7.15231	10
Relaxation Introduction	29.9000	6.99921	10
Relaxation Radiation	31.5000	9.65229	10
Relaxation Solutions	35.5000	11.28667	10
Stress Introduction	42.2000	13.65284	10
Stress Radiation	49.3000	18.73826	10
Stress Solutions	40.9000	14.99963	10

Table 2: Mauchly's test of sphericity

Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
						Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	**Engagement**	.827	1.515	2	.469	.853	1.000	.500
	Excitement	.537	4.980	2	.083	.683	.764	.500
	Focus	.951	.398	2	.820	.954	1.000	.500
	Interest	.304	9.538	2	.008	.589	.626	.500
	Relaxation	.650	3.441	2	.179	.741	.853	.500
	Stress	.466	6.112	2	.047	.652	.717	.500

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Since Mauchly's test indicated a violation for interest and stress, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.589$, $\varepsilon = 0.652$) for interest and stress respectively, Table 3 shows the corrections. The results show that there was no significant effect of video stages on the participants' interest $F(1.179,10.610) = 1.364$, $p = 0.277$, $\eta^2 = 0.132$. Nor the participants' stress $F(1.304,11.733) = 1.409$, $p = 0.270$, $\eta^2 = 0.135$.

While for the other performance metrics, Mauchly's test indicated non violation. However, the pairwise comparisons show significant effect of video stage T3 on participants' excitement compared with T1 $p =$

0.046. While all other comparisons show no significant effect of video stages on participants' performance metrics, see Table 4.

Table 3: Univariate tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Time	Interest	Sphericity Assumed	232.800	2	116.400	1.364	.281	.132
		Greenhouse-Geisser	232.800	1.179	197.467	1.364	.277	.132
		Huynh-Feldt	232.800	1.252	185.993	1.364	.278	.132
		Lower-bound	232.800	1.000	232.800	1.364	.273	.132
	Stress	Sphericity Assumed	408.867	2	204.433	1.409	.270	.135
		Greenhouse-Geisser	408.867	1.304	313.638	1.409	.270	.135
		Huynh-Feldt	408.867	1.434	285.132	1.409	.271	.135
		Lower-bound	408.867	1.000	408.867	1.409	.266	.135
Error(Time)	Interest	Sphericity Assumed	1535.867	18	85.326			
		Greenhouse-Geisser	1535.867	10.610	144.752			
		Huynh-Feldt	1535.867	11.265	136.341			
		Lower-bound	1535.867	9.000	170.652			
	Stress	Sphericity Assumed	2611.800	18	145.100			
		Greenhouse-Geisser	2611.800	11.733	222.610			
		Huynh-Feldt	2611.800	12.906	202.378			
		Lower-bound	2611.800	9.000	290.200			

The changes in values of the six-performance metrics between the three stages; introduction, risks and mitigations, is shown in Figure 2. And it displays fluctuating values between the negative changing and positive changing, but only one is significant and it is positive changing.

Table 4: Pairwise comparisons

Measure	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Engagement	1	2	3.500	2.482	.576	-3.781	10.781
		3	4.700	2.708	.350	-3.244	12.644

	2	3	1.200	3.454	1.000	-8.931	11.331
Excitement	1	2	-8.800	3.441	.092	-18.893	1.293
		3	-9.900*	3.318	.046	-19.633	-.167
	2	3	-1.100	1.656	1.000	-5.958	3.758
Focus	1	2	-2.100	2.807	1.000	-10.332	6.132
		3	.900	3.220	1.000	-8.544	10.344
	2	3	3.000	2.704	.888	-4.931	10.931
Relaxation	1	2	-1.600	1.759	1.000	-6.759	3.559
		3	-5.600	3.085	.309	-14.649	3.449
	2	3	-4.000	3.166	.714	-13.286	5.286

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

The repeated measures ANOVA analysis over the six-performance metrics showed that the presented video was able to significantly affect the excitement of stakeholders in a positive way by increasing the mean excitement 9.8% (T1 = 19.3% – T2 = 29.2%). The results also showed that the video did not have any significant negative effect on the other performance metrics of the stakeholders. This finding may be an encouragement to develop better videos for future studies to better assess he perception and attitude of different stakeholders towards zero radiation in smart homes.

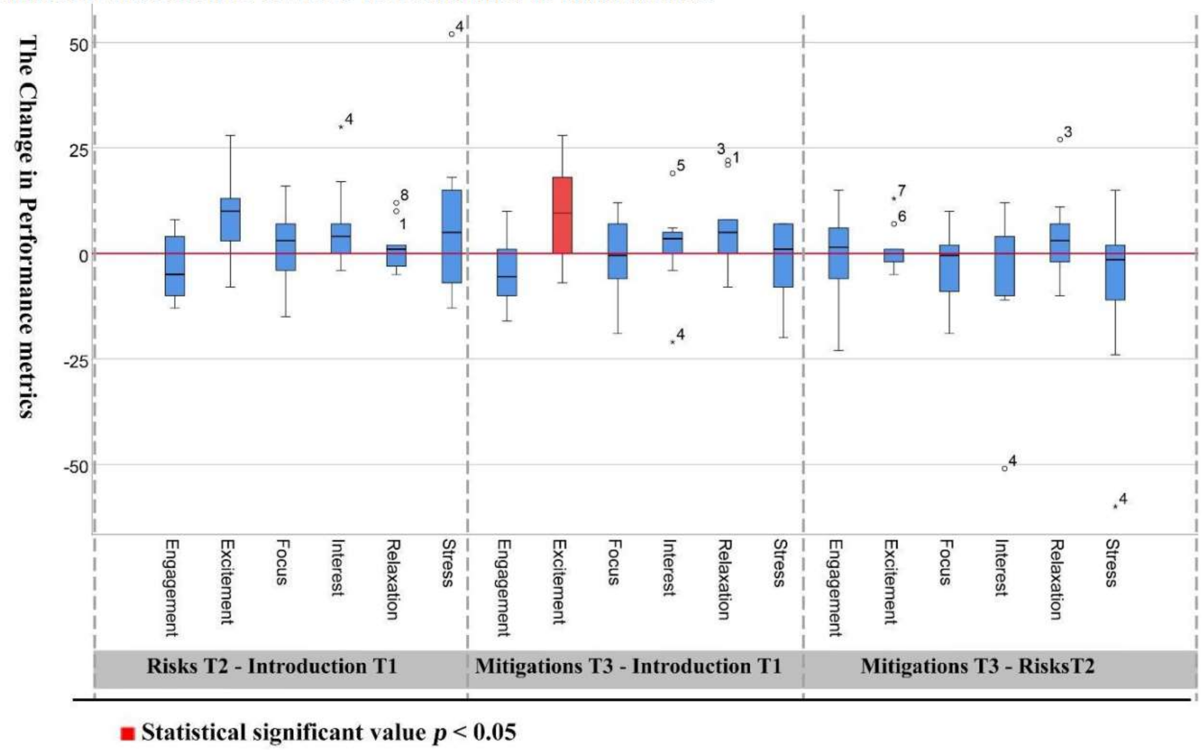

Figure 2. The Change in the Performance metrics across the three stages

CONCLUSION

The study focused on estimating stakeholders' actual brain responses in understanding the attitudes towards zero radiation smart buildings. Most of the metrics showed fluctuating results except for stress and interest which peaked when the EMR risks were shown to the participants, and excitement when the EMR risks and mitigations were presented. However, the repeated measures one-way ANOVA test for all performance metrics among all participants, reported a statistically significant variation only in the excitement for two timings (T3, T1) for EMR and strategies video/audio stimuli. The exploratory study found that, on average, stakeholders were not averse to the idea of smart buildings and were in fact interested in the presented novel idea.

One of the limitations of the study was related to the limited diversification in the stakeholders, as all participants in this study were either faculty members or students in the Architectural Engineering program. Future studies should involve other stakeholders such as housemakers, developers, authorities and other involved parties. The last limitation of this study is the statistical analysis conducted for the data which compared only between three timings during the viewing of the video; future studies should also explore changing the metrics, along with improving the video content to better understand the stakeholders' perception of the video.

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AN EVALUATION OF SCHEMATIC PHYSICAL MODEL AS A TEACHING TECHNIQUE IN THE IDEA GENERATION STAGE IN THE ARCHITECTURAL DESIGN STUDIO

Ahmed Agiel[1], Ala' Albdour[2], Rahma Adan[3], Lindita Bande[4]

[1] Assistant Professor, Architectural Engineering Department, United Arab Emirates University, Al Ain, UAE, a.agiel@uaeu.ac.ae
[2] PhD student, Architectural Engineering Department, United Arab Emirates University, Al Ain, UAE, 201770158@uaeu.ac.ae
[3] Instructor, Architectural Engineering Department, United Arab Emirates University, Al Ain, UAE, r-hassan@uaeu.ac.ae
[4] Assistant Professor, Architectural Engineering Department, United Arab Emirates University, Al Ain, UAE, L.Bande@uaeu.ac.ae

ABSTRACT

The physical model is one of the popular techniques in teaching architectural design studios in most architectural schools worldwide. However, the usage of the physical model might vary from one school to another; some schools use it for visualization while others use it as a design tool or even a thinking tool. Physical models could be categorized into three types based on the purpose of using them; sketch model, schematic model and presentation model. Usually, the sketch models are used for idea generation, while schematic models are used in the idea development stage, but the presentation models are used to present the final design concept. This paper used a schematic model approach employing hotwire cutter machines and blue foam as raw material in the idea generation stage. The study was conducted on first-year students in the architectural engineering program in the UAEU. We adopted descriptive and analytical approaches for this study, in which a reference (case study) project was given to the participated students to propose concepts. The students were requested to generate the design idea by manipulating the schematic foam models of the case study. The outcomes of the students were evaluated using structured interviews with the students to understand their reflections about the experience. The initial results revealed that schematic foam models play a significant role in helping first-year architectural engineering students control scale and proportion issues, in addition to helping the students make unique and good designs from the idea generation stage. The participant students were excited about learning using physical models.

INTRODUCTION

Physical models in architectural design studios are usually used in the final representation phase of the design as a design communication method. Ibrahim and Utaberta (2012) consider the physical models as a student's communication techniques in addition to drawings, computer models and other techniques. Oh et al. (2013) also highlight the physical model as one of the visual representation methods used by students and instructors, in addition to the sketches and 3D computer graphics. Saghaf et al. (2014) highlighted the students' impression of the physical models in design studios and how they are much more human engaging than virtual design studios. Gutai and Palaiologou (2021) argue that physical models have the same impact as constructing a project in terms of challenges and the need for additional design considerations, but with much fewer expenses. Moreover, Oh et al. (2013) argued that without an artifact – which could be a physical model, sketch or diagram- teachers can't understand the students' ideas, therefore they can't evaluate them or give them any feedback. Some researchers tried investigating the potential of using the physical models in the early design stages, such as Abdelhameed (2011) who found that physical models develop the students' visual design thinking differently than sketching in terms of available opportunities and responding to the constraints. Also, Afify et al. (2021) conducted an experiment to evaluate the use of physical models as a design approach from the idea generation stage until the presentation stage. They evaluated this approach by comparing it with another two approaches; using only 2D sketches and mixing 2D sketches with physical models (hybrid approach). They found that the hybrid approach was the best, and then comes the physical models approach and lastly the 2D sketches approach. However, studies in the literature on physical models use in architectural design studios are very rare, even though physical models are a critical tool in architectural design education, as discussed earlier.

Physical models can be divided into three types as Afify et al. (2021) suggested, namely: *sketch models*, which are rough models that are used for generating the design idea in the early stages of the design. They are used to investigate the relationships between masses in terms of scale, proportions, overlapping, and so on. *Schematic models*, which are much neater models but with few details, show the major articulation on the form. *Presentation models*, which are fully detailed models used usually to present the final design for the instructors or the jury. In this paper, we are investigating the use of schematic models in the early design stages instead of the sketch models for students who are lacking for scale and proportion sense.

Hull and Willett (2017) used another approach to divide physical models, they classified physical models into five types, namely: *Sketch models*, which are inexpensive models usually made to explore design options. *Concept models*, are models that used to focus and concentrate on the core idea of the project. *Working models*, which are the models that are used to develop the final design. *Context models*, those are models used for studying the relationship between the project and the surrounding landscape and context. *Presentation models*, which are used to display the final design. However, Hull and Willett (2017) classification was based on the model types used by architects in practice. While Afify et al. (2021) classification was for architecture students.

Physical models can be made with unlimited materials, they are limited only by the imagination of the student. From our observation and experience, we noticed that there are very common materials which are used typically by most of the students. Those materials include, but are not limited to, cardboard, foam block, sheets of papers, plastic, insulation foam, foam boards, balsa, cartoon, gypsum, floral foam, transparent or coloured plastic sheets, acrylic, steel bars, and wood sticks. Each material is chosen based on the ease of use, the model type, the effect of the material, the price of the material, and the availability of the material.

Polystyrene foam materials are usually used in product design to make physical models using flexible cutter, hot wire cutting, band sawing, or sanding (Broek et al., 2002). It is a cheap and available material. Closed-cell extruded polystyrene foam is a type of polystyrene foam, which is an insulation material used for building construction. However, it is also common in the product design model making field, it is easy for shaping and creating very complex shapes (Sketch Modeling with Foams, n.d.).

The research question for this study: does using a schematic model from foam material and heated wire cutting machine as a method in the early design stages would be helpful for architectural engineering students?

METHODOLOGY

This study aims to monitor and record the benefits of using schematic physical models in the early design stages for first-year architectural engineering students. Therefore, structured interviews were conducted with the students to track the benefits of physical models. The tracking process was concerned on recording six factors that reflect the advantages and disadvantages of using the schematic physical models. The six factors are 1) the students' impression. 2) Uniqueness of the design. 3) Helping in realizing the scales. 4) Helping in generating ideas. 5) Easiness of using this method. We have also tracked an additional sixth factor to record the motivation behind the idea generation of the students from their own perspective. The sixth factor was tracked to insure that the new design is coming from the students' imagination rather than a randomly modified copy of the case study, and to insure that the students avoided the design fixation of the case study. All the six factors were recorded using open ended questions. The students were asked to describe those factors in a recorded interview by responding to six questions. The transcript of the interview was analyzed and divided into six concepts, each concept about one of the six factors.

A group of 14 students (all are female) in the first year of the architecture engineering program in United Arab Emirates University were asked to choose a case study to analyse and understand that should be similar to their project. Each one of the students selected a case study based on their project's requirements in terms of the occupation, design, area and designer. The students were asked to create schematic physical models for the case study masses with the blue or white foam using the lab foam cutting machine, to preserve the scales and proportions of the case study. The students were asked to manipulate the masses and articulate them while trying to preserve approximately the same volume of the used foam; to preserve the areas and spaces from the starting case study. Many reviews and feedback were provided by the instructors on the physical models to finalize the design throughout the course. Students were asked to consider the zoning for functions in their designs while manipulating the masses. For the final submissions after reaching satisfaction with the masses and zoning, students made schematic plans and 3D Revit models with full elevation details for the design. The interviews with the students were conducted at the end of the fall semester 2022.

The interview's six questions are (1) How you explain your experience doing this model? (2) How this form is different or similar to the case study? (3) Give us the dimension for a random part from the physical model and its corresponding dimension from the case study? (4) How the model helped you to understand the environmental issues and how the model helped generate an idea? (5) To what extent the cutting machine was easy to use and helpful? (6) What was the reason to change ideas and elements from the case study in what they adapted in their physical model?

RESULTS AND DISCUSSION

A deductive content approach was used to analyze the data because the authors determined six concepts for the interview that need to be tracked (see Table 1). The first concept, which is the student's impression, was answered by 9 students with positive impressions, one student with a neutral response and 4 without response. The responses for the positive impressions were such as (fun, easy, good experience, interesting, enjoyable). While the neutral response was:

"Fine, a little bit difficult for one of the concepts because it has a curve, but as general the experience was good."

The second concept, which is the uniqueness of the design, was tracked using the 2nd question. All the students provided us with responses. Part of the students did not response to this question directly. They tried to describe their design either as different from the case study or similar to the case study. Five students who reported the similarity was referring to partial inspiration; inspired by the elements, inspired by the composition, inspired by the circulation concept, or inspired by the main concept, one of the students who reported similarity said:

"They similar, got inspired by the case study, specially the volume, circulation and shading devices."

However, even the students who reported a difference, they were partially inspired by the case study in the same manner as the students who reported a similarity, one of the students said:

"They are different, got inspired by some elements such as curved corners and shading devices."

Meanwhile, six student who neither reported similarity nor difference, they reported inspiration, they highlighted how they got inspired from the case study directly. Therefore, from the responses of the students, we cannot say whether the students provided unique designs or not as an elaboration between the student and the interviewer is missed in this question. However, we can judge that from looking at Table 2 to see the difference between the case study design and their own design. The third concept, which is helping about realizing the scale, was tracked by asking the 3rd question in the interview. 12 students provided us with responses. All of them provided correct answers to the dimensions, which reflect how the schematic model helped them in realizing the scales and demonstrating them. One of the students said:

"The foam helped me to understand the proportion specially with the given thickness of the foam"

The fourth concept, which is helping in generating ideas, was tracked by revising the responses to the 4th question. 13 students provided responses to this question. Seven of them acknowledged the schematic physical model as a helpful tool for making decisions related to the opening and shading devices. Four students mentioned that the model helped them in make better functional design. Three students explained that the physical model is helpful for deciding the orientation of the model and courtyard. Three students said that the physical model helped them in understanding the proportions. Part of the students reported two points, while most of them reported one point. One of the students said:

"The model helped me to select the right orientation and specify the right opening locations"

One of the students' responses indicated that the physical model helped her reject the original concept of the case and make a new concept for her design, she said:

"The case study was more in organic form with resulted in wasted areas. That is why I changed and used regular line to keep the spaces more functional."

Therefore, we can say that the schematic physical model is helpful for taking design decisions related to the elevation design, the plans design and the main concept of the design.

The fifth concept, which is the easiness of using this method in the early design stages, was inspected by asking the fifth question to the students. 10 students provided us with responses to this question. Eight of them reported that the method was easy and simple, especially the machine for cutting the foam was very helpful. Meanwhile, two students reported that cutting the curve edges was challenging but manageable, one of them said:

"In the beginning the machine was difficult to use, but with practice it was easy"

Even though it might be challenging when the design has curves, it is still much better than using only hands. One of the students said:

"The machine was easier than making model in traditional way using cutters"

Therefore, the schematic physical model using the foam and the cutting machine might be more helpful than using the sketch model in the early design stages.

The sixth concept, which is about the motivation behind the design concept, was tracked using question number six. 9 students provided us with responses to this question. Six students provided responses that reveal that the main motivation for the idea generation is changing the case study design to fit with their project requirements and needs, such as fitting the desert climate, courtyard area, functionality of the plan, or the orientation of the building. One of the students said:

"Changes were adding shading devices, and reduced waste areas, inspired but many changes from the case study"

While the remaining three students reported that they learned from the case study what they should avoid in their design, and that was the motivation for their ideas, one of the students said:

"The first model showed me the wasted areas and wrong of proportion of the composition helped me to organize spaces and make them more functional"

The students' responses to this question show to what extent the students think their design is related to the case study design. Even though their responses implies that the students design are similar to the case study design, in fact the final design is very different from the original case study design, as shown in Table 2, which shows photos for schematic physical model of the case study for some students and their own design's schematic physical model. This highlights one of the advantages of this method that the idea generation is easy and produces unique designs from the original case study.

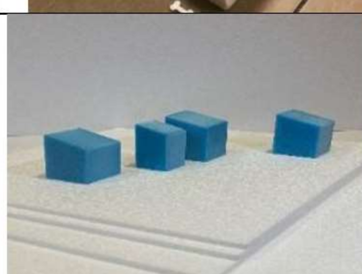
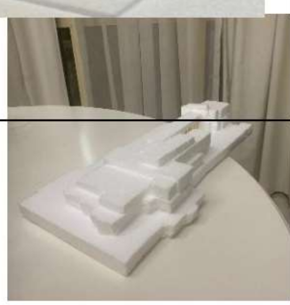
Table 1: Students' responses to the interview questions.

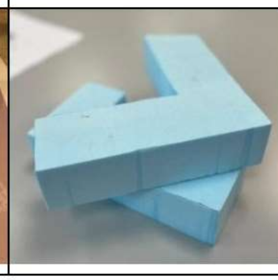
Question number	Student response	student
1	"Easy process, using different tools that I didn't know that they existed" "Fine, a little bit difficult for one of the concepts because it has a curve, but as general the experience was good" "Good experience to understand the volume and level of the composition and visualize the final products" "interesting and fun and developed my ideas" "Exciting experience, felt doing my design with my hands, feeling of being an engineer" "enjoyable experience" "good experience to visualize the design in 3D dimensions" "Exciting experience, difficult in beginning to manage the contour site." "fun experience"	St.1 St.2 St.3 St.4 St.5 St.6 St.7 St.8 St.10
2	"They similar, got inspired by the case study, specially the volume, circulation and shading devices" "They are different, got inspired by some elements such as curved corners, shading devices" "They similar in space organization but they are different in levels and heights of the composition" "They are similar in composition linear and organic composition" "Inspired by the linear composition" "Inspired by the form but the changed the sharped angles of the case and internal organization with long corridor to have more compact design and sustainable" "The design is different, I tried to simplify more and more compact spaces that is more functional and easier to control" "Inspired and learned from contour lines and site management" "The design is different, inspired by the organic design that I used in some places and other used the regular shape" "Similar to have a courtyard, but different in the proportion of it" "Inspired by the form organization, to create privacy" "Inspired by the organic form but organize spaces to control waste areas" "Eliminated the curved corners, to control wasted areas" "The composition of the case study was complex, I inspired my creating courtyard and learned right proportion. Similarities, connection between outdoor and indoor"	St.1 St.2 St.3 St.4 St.5 St.6 St.7 St.8 St.9 St.10 St.11 St.12 St.13 St.14

3	the model is to scale and student answered the question correctly "The foam helped me to understand the proportion specially the with the given thickness of the foam"	All students St.5
4	"The model helped to visualize openings and required shading devices according to orientation." "Visualize the required sides for shading devices specially on the South and West, and proportion of the courtyard" "Visualize shading devices location and proportion of the courtyard which helps in ventilation" "Visualize opening sizes and shading devices and location according to orientation …helpful" "Understand the wasted areas in the design and unfunctional, and openings for ventilation" "The model helped with orienting the wings of the design, and creating spaces that are shaded" "The model helped to understand the proportion of the courtyard, and controlling wasted areas" "The relationship between the design and site, first created the site (contour lines) then placed the house/ design in the site according to right orientation and levels " "The model helped me to select the right orientation and specify the right opening locations" "The model helped me with understanding orientation and proportion of the courtyard" "The proportion of the courtyard" "Control internal spaces and reduce wasted areas" "Helped to understand the location of the shading devices"	St.1 St.2 St.3 St.4 St.5 St.6 St.7 St.8 St.9 St.11 St.12 St.13 St.14
5	"In the beginning the machine was difficult to use but with practice it was easy" "The curved corners was challenging using this machine" "Easy to use" "Easy and simple to use" "The machine helped me with edges and extrusions" "Easy and simple to use" "With machine, making the model was easier than using just hands" "Easy to use and helpful" "Helpful with organic form" "The machine was easier than making model in traditional way using cutters."	St.1 St.2 St.3 St.4 St.5 St.6 St.7 St.8 St.9 St.10
6	"The changes were in materials, and circulation within the building" "The change was in the volume in the building, the courtyard was bigger to accommodate client's requirements" "Changes where in the composition of the volume, by adding courtyard that fits desert climate." "Changes were adding shading devices, and reduced waste areas, inspired but many changes from the case study" "The first model showed me the wasted areas and wrong of proportion of the composition helped me to organize spaces and make them more functional" "Changes were avoiding sharp edges of the case study design which were not functional" "Simplify the case study composition and reduce the linear space and make it more compact"	St.1 St.2 St.3 St.4 St.5 St.6 St.7 St.8 St.9

	"Changed orientation of the angled roof to suite our climate and place solar panels" "The case study was more in organic form with resulted in wasted areas. That is why I changed and used regular line to keep the spaces more functional."	

Table 2: Schematic physical models for the case study and the student's own design.

Student	Schematic models for Case studies	Schematic models for the students' own designs	How model helped the students	Authors comments
13			Reduce waste areas	The student removed the curves and made a new geometrical design
14			Locating shading devices	The student inserted the curves to design concepts
8			Orientation of the building and relation between the building and the site	The student combined the masses of the original design and made a brand new design from the same masses
3			Locating and visualizing shading devices, in addition to locating the courtyard for ventilation	The student introduced angulare masses to the design and made a brand new design
7			Proportion of the cortyard and control waste areas	The similarity in the concepts of the design can be noticed because of preserving the curves

9			Orientation of the building and location of the openings	The concepts are completely different and the student design is more balanced than the case study design
6			Orientation of the building and location of the openings	The design concepts are different.

Even though the design approach that the student adopt in the early design stage might affect the possibilities of studying the environmental performance of the design, the schematic physical model can be easily studied environmentally by the manual method or using lab devices such as heliodon and artificial sky device to study the solar shading performance, and 3D scanner to complete the environmental assessment on the computer. Dalumo and Lim (2021) compared the computer simulation software with the heliodon and artificial sky in studying the solar shading. They found that computer simulators are more accurate than heliodon and artificial sky, but they acknowledged both methods.

CONCLUSION

The aim of this paper was to understand the impact of a schematic model on first-year architectural engineering students' program in the UAEU. The schematic models in this study were built with blue foam and hot wire cutter in the model making laboratory. The students referred to their case studies to generate their ideas and build their models. The outcomes of the students were evaluated using structured interviews with the students to understand their reflections about the experience. The initial results revealed that schematic foam models play a significant role in helping first-year architectural engineering students control scale and proportion issues which helped them to avoid waste spaces and control shading devices. In addition, foam models helped the students in making unique and good designs from the idea generation stage.

Based on the results and findings, further investigation can be done in the impact of the sketch model, where the students can understand better early stages of concept, mass, openings, and environmental potential. Also, an additional presentation model impact on the student understanding on the evolution of the design ideas shall be investigated. While further investigation can be done in the impact of sketch models for second and third year students, where the students can evaluate and redesign their concepts based on the environmental performance which can be assessed in the lab as mentioned earlier. Even though the students are in the first year on this course, the learning through physical models and the efforts done during the process can have a better impact in understanding the relevance of design stages. Advanced machines such as CNC Routers can help to computerize the cutting process especially after the design of the building is completed.

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A TRAVEL-BASED DRAWING APPROACH FOR RECORDING CULTURAL VALUES OF URBAN GREEN SPACES

J Godwin Emmanuel[1], G Ophylia Vinodhini[2]

[1] Professor, C A R E School of Architecture, Tiruchirappalli, godwin.emmanuel@care.ac.in
[2]Associate Professor, C A R E School of Architecture, Tiruchirappalli, ophylia.vinodhini@care.ac.in

ABSTRACT

For centuries, human settlements evolve and reflect their cultural values in the natural settings. Recording knowledge of such cultural values on ground plays a vital role in the architectural design processes. Architectural drawings illustrate the physical qualities of buildings as part of the design process. But, beyond the buildings, whether architectural drawings help one to record their observations and experiences comprehensively is seldom studied. This article intends to examine the potential applications of a travel-based drawing approach in recording the cultural values of urban green spaces.

With the Travelling Transect-based Drawing approach, this article discusses the observations and experiences of participants on a two-day academic trip to Bengaluru city. During the trip, the researcher, as a participant-observer, with a team of fourteen students and a faculty, visits two green spaces in the city. The working method includes a constant engagement with what one can observe and experience through modes of thinking, drawing, and writing during travel.

The study results include analytical drawings, field notes, interview transcriptions and photographs. The analytical drawings inform significant tangible features, public activities, and meaningful relationships as cultural values of the urban green spaces. Knowledge of these cultural values can further evoke appropriate context-based responses to the current challenges in Architectural Design, Heritage Conservation and Landscape Planning.

The Travelling transect-based drawing approach examines the non-formal applications of architectural drawings. These drawings are further applicable to gain a comprehensive understanding of the larger context beyond space and time. Also, in the context of heritage conservation, such analytical skill sets would further help list unprotected natural and cultural heritage in historic urban landscapes.

Keywords: Analytical Drawings; Travelling Transect; Cultural Values; Conservation Planning; Historic Urban Landscapes.

INTRODUCTION

Architectural design calls for an appropriate response to foster a deep relationship with nature and culture. Such relationships are often represented through drawings a primary means of Architectural design. Drawings are not merely aesthetical representations but they can also help one to think through. Drawings are an asset to any Architectural design process in evolving multiple design solutions from their immediate or faraway contexts. Drawing along travel helps one to engage more with the subjective experiences and objective observations in the landscape.

This article suggests the "Travelling Transect-based Drawing approach" for students of Architecture. The Travelling Transect helps one to analytically think through by drawing the relationships between people and places in their environment. Analytical drawings are helpful here as a rapid tool to record the knowledge gained from onsite observations and travel experiences. Such knowledge applies to several architectural design processes and is an inspiration to many students of Architecture.

LITERATURE REVIEW

Values in Landscape

Sarapik (2002) explores several pictorial representation ways, suggesting that the landscape can be a suitable example to illustrate interrelations between representation, depiction, and description and further its connections with reality. A landscape can, therefore, represent both pictorial expressions as well as verbal descriptions. Taylor (2007)'s study has explored a few concepts that are associated with landscape and memory. Türkyılmaz (2016) has discussed cultural landscapes' values as the most vulnerable and endangered locations on earth because of the rapid social and economic growth. The study suggests three inter-related value sets of the landscape. a) Formal features b) Functional features c) Intangible features. Reynard and Giusti (2018) have discussed the following six dimensions that characterize the natural, cultural, individual, and social poles of landscape: a) Sensorial b) Aesthetic c) Identification d) Political e) Economic f) Ecologic.

Stephenson J (2008) proposed the Cultural Values model to describe the dynamic interaction among 'Forms', 'Relationships' and 'Practices' as components in the landscape. The term -'Forms' signify all tangible elements that include built forms of the landscape. The term - 'Relationships' refer to several meanings interpreted by human beings. The term – 'Practices' signify events associated with the landscape. In the end, two types of cultural values: 1) Surface values that are merely from a visual response to the cultural values of the present and 2) Embedded values from cultural values of the past.

Methods for interpretation

Bergeron et al., (2014)'s study on several anthropological approaches to look at landscapes that contain many endogenous forms to bring insight into people's relationships to places. Diedrich et al., (2014) suggest the Trans areal travelling method for understanding transformations on a site. This method evolved from Alexander von Humboldt's scientific model and contributes to several design approaches by way representing places with their ephemeral, dynamic and narrative qualities. Such an approach can help architects, to observe, analyse and represent the ephemeral qualities of sites in the landscape, Braae et al.(2013). Mads Farsø & Henriksson (2016) defines the travelling transect approach, as a bodily research method that focuses on the appropriation and representation of values and experiences across time in a site.

Thinking through Analytical Drawings

Studies define the differences between Creative thinking and Analytical thinking. Creative thinking is a cognitive process of the right brain that gives rise to conceptualisation of ideas and solutions that are unique and meaningful. On the other hand, analytical thinking is more of a left brain's logical and systematic process on different parts or details of things to resolve a case. The process of drawing facilitates a cyclic path between the right brain and the left brain. Drawing becomes a tool to communicate, share stories and solve problems. Drawings are the primary means to express values and experiences in the landscape. Some of the common drawing typologies include charts, graphs, infographic diagrams, Venn diagrams, brain sketch, and mind maps.

Farrelly and Crowson (2014) suggest three types of drawings for representing the landscape. They are 1) Observational drawings, 2) Analytical drawings, and 3) Conceptual drawings. Observational drawings are concerned with visual aesthetics whereas an analytical drawing is significant to understanding any architectural built form, Di Mascio (2015). Conceptual drawings are visualised from a new thinking process to illustrate significant features and their inter-relationships in design, Julia K Johnson, and Stephen K Reynolds (2005).

Analytical drawings in comparison with the other two types of drawings are more than a mere graphical representation. They call for good technical skills yet have an interpretative process with them to evolve several concepts and theories, Di Mascio (2015). Analytical drawings do not emphasise scales and they can be drawn to show only fewer characteristics of a site. Using orthographic principles, these drawings are often represented as Plans, Sections and Elevations. Isometric or axonometric drawings are also useful in illustrating a few details in construction. One can use several line types, textures, thicknesses, and colours as representational techniques, Di Mascio (2015).

STUDY METHODOLOGY

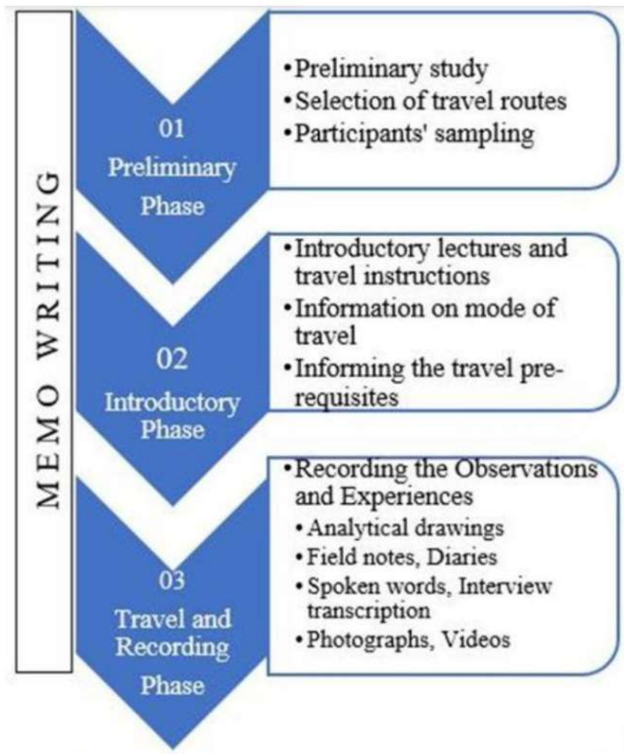


Figure 1 The study methodology for the proposed Travelling Transect-based Drawing approach
Source: Author

The study methodology evolved from the Grounded Theory research methods in Architecture and Design, by Bollo and Collins (2017) and Lianto (2019). This approach is the combination of Mads Farsø & Henriksson (2016)'s Travelling Transect approach and Di Mascio (2015)'s definition of Analytical Drawings. This study examines the application of analytical drawings along the travel. 'The Travelling Transect-based Drawing approach' is used in this study to record the cultural values of the green spaces in an urban area. **Figure 1** shows the study methodology for the proposed Travelling Transect-based Drawing approach. This approach focuses on recording observations and experiences on-site in the form of analytical drawings and textual narratives.

The author travels along with the team on a two-day academic trip to Bengaluru City in south India in the year 2018, as part of the academic course plan. The participants include the author along with a teaching faculty and fourteen undergraduate students of architecture. The intent was to understand the design and planning aspects of significant landscape elements in urban settings. In this regard, the team chose to study two green spaces in the city. They are 1) Lal Bagh Botanical Garden and 2) Good Earth Malhar, an eco-village. **Figure 2** shows the locations of the two green spaces in Bengaluru city.

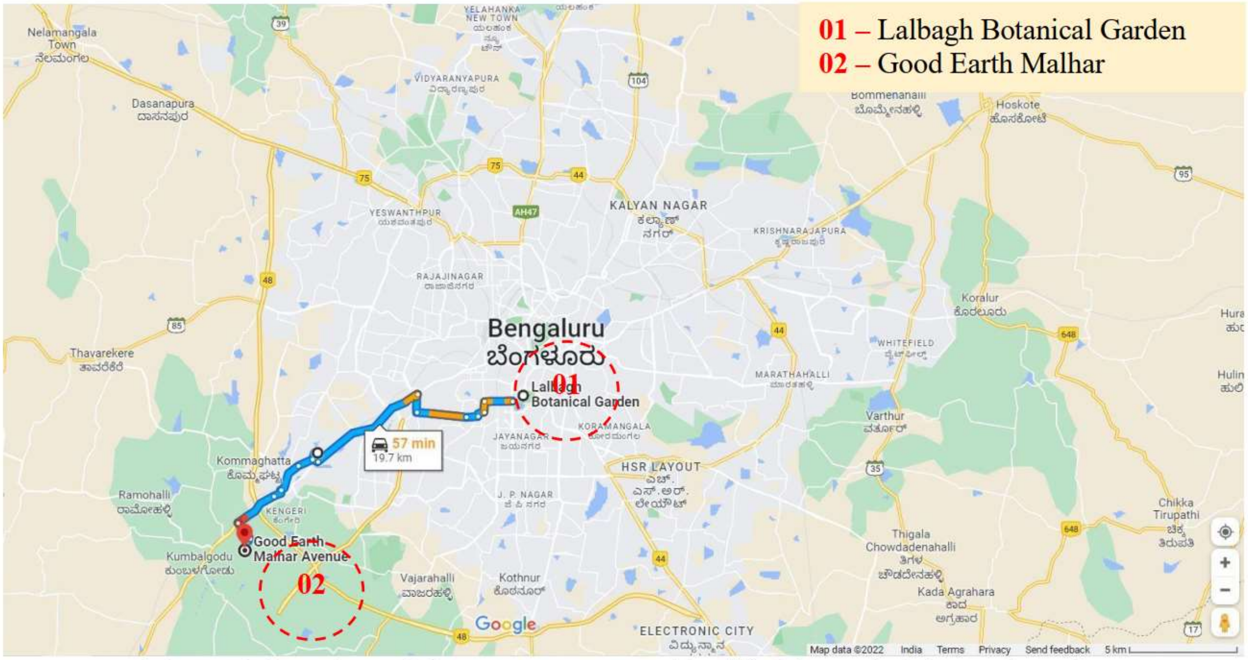


Figure 2. Locations of the two green spaces identified for study in Bengaluru city
Source: Google map

During the two-day trip, the author and team studied the two green spaces each on the respective days. The work process includes a constant engagement of thinking, drawing, and writing about forms, relationships, and practices that one observes and experiences as cultural values in the study area.

FINDINGS

The results of the study are in the form of analytical drawings, field notes, interview transcriptions and photographs done by the author. In particular, the types of analytical drawings are as Plans, Sections, Elevations, Isometric views, and a combination of the aforesaid. **Figure 3 and 4** show the two analytical-section drawings done during the train trip towards Bengaluru city. **Figure 5 and 6** show the field notes and interview transcriptions from an architect cum historian about the history of Bengaluru city and the Lal Bagh garden.

Figure 7 and 8 show the analytical-plan and section drawings of the entry avenue near double road circle at Lal Bagh garden. **Figure 9** shows the part section of the old aquarium building along with the analytical-elevation of two large trees in the Lal Bagh garden. **Figure 10** shows a few short notes from an architect's presentation of the landscape architecture development projects in the city. **Figure 11** shows the combination of analytical drawings on the way to the green space-02 at Mysore road. **Figures 12, 13 and 14** shows the combination of analytical drawings of several landscape features at the Good Earth Malhar.

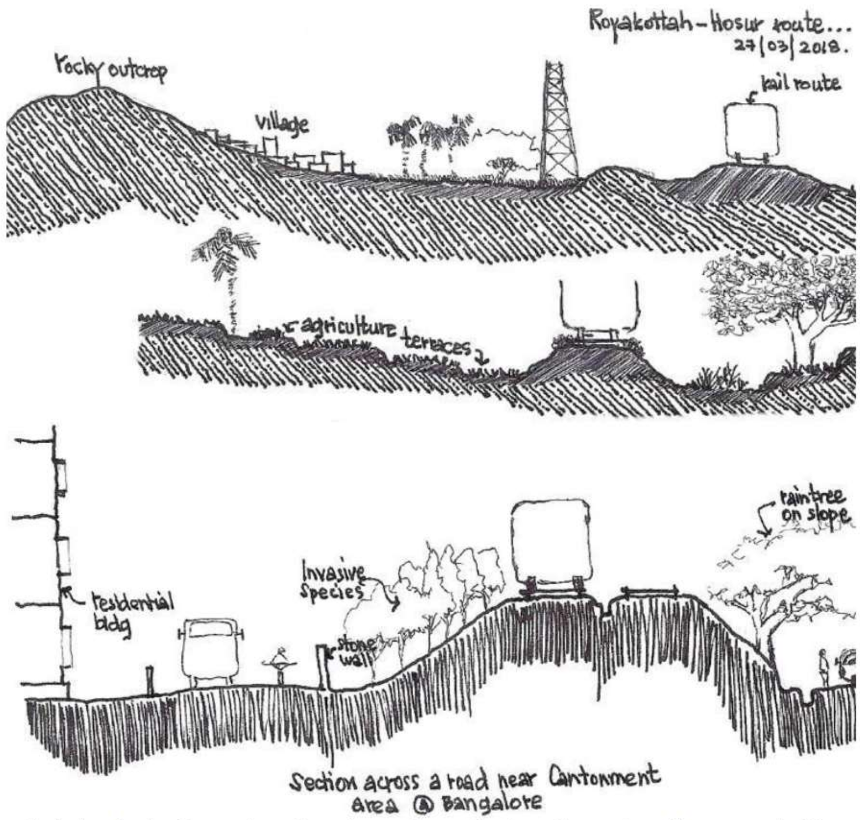


Figure 3 and 4 Analytical-section drawings done during the train trip towards Bengaluru city.

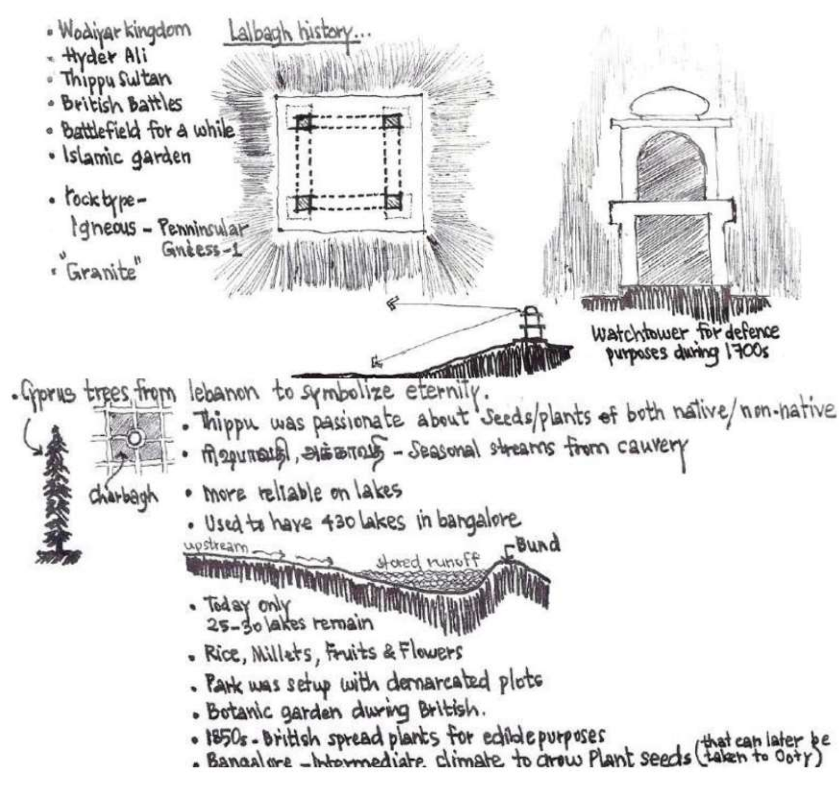


Figure 5 and 6 The interview notes from an architect cum historian about the history of Bengaluru city and the Lal Bagh garden.

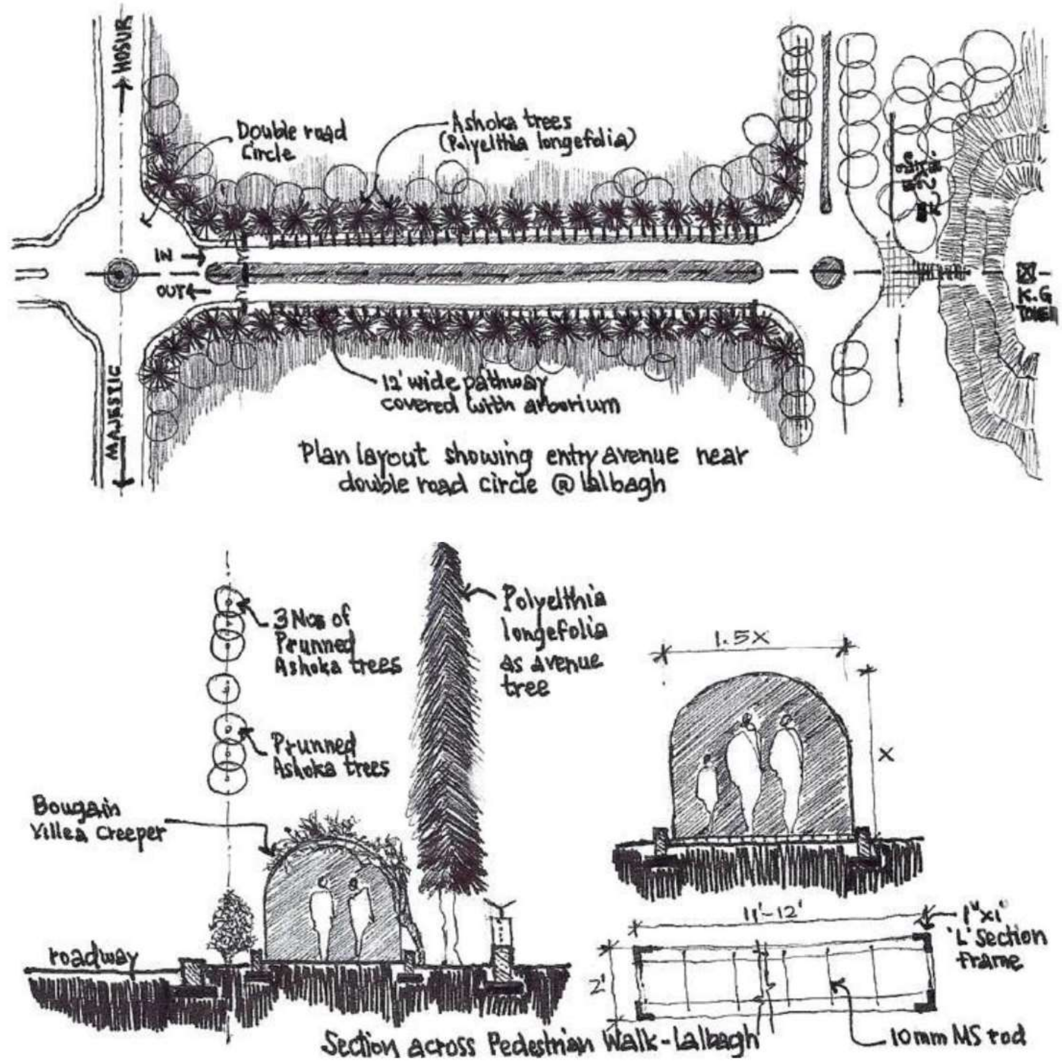


Figure 7 and 8 Analytical-plan and section drawings of the entry avenue near Double road circle at Lal Bagh garden.

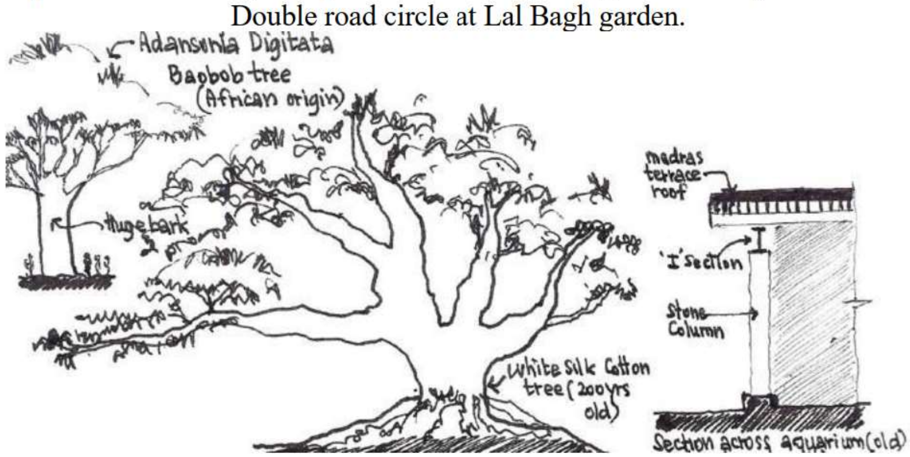


Figure 9 The part section of the old aquarium building along with the analytical-elevation of two large trees in the Lal Bagh garden.

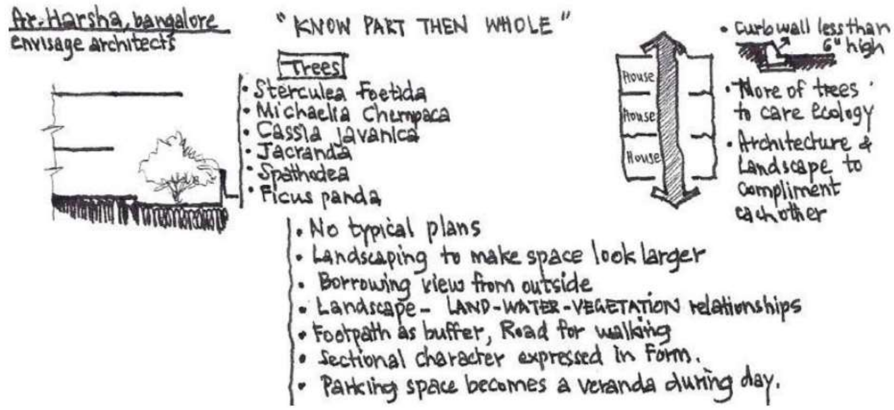


Figure 10 A few short notes from an architect's presentation of the Landscape architecture development projects in the city.

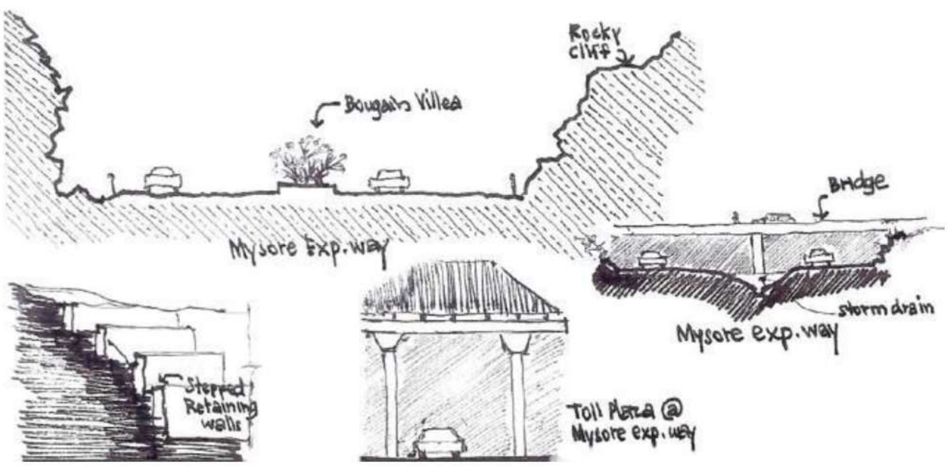
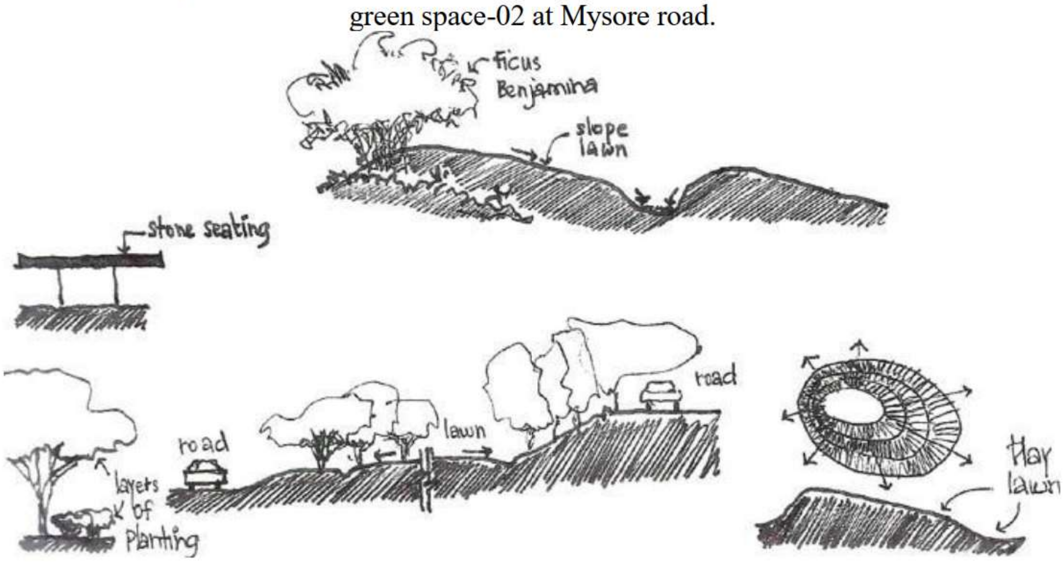
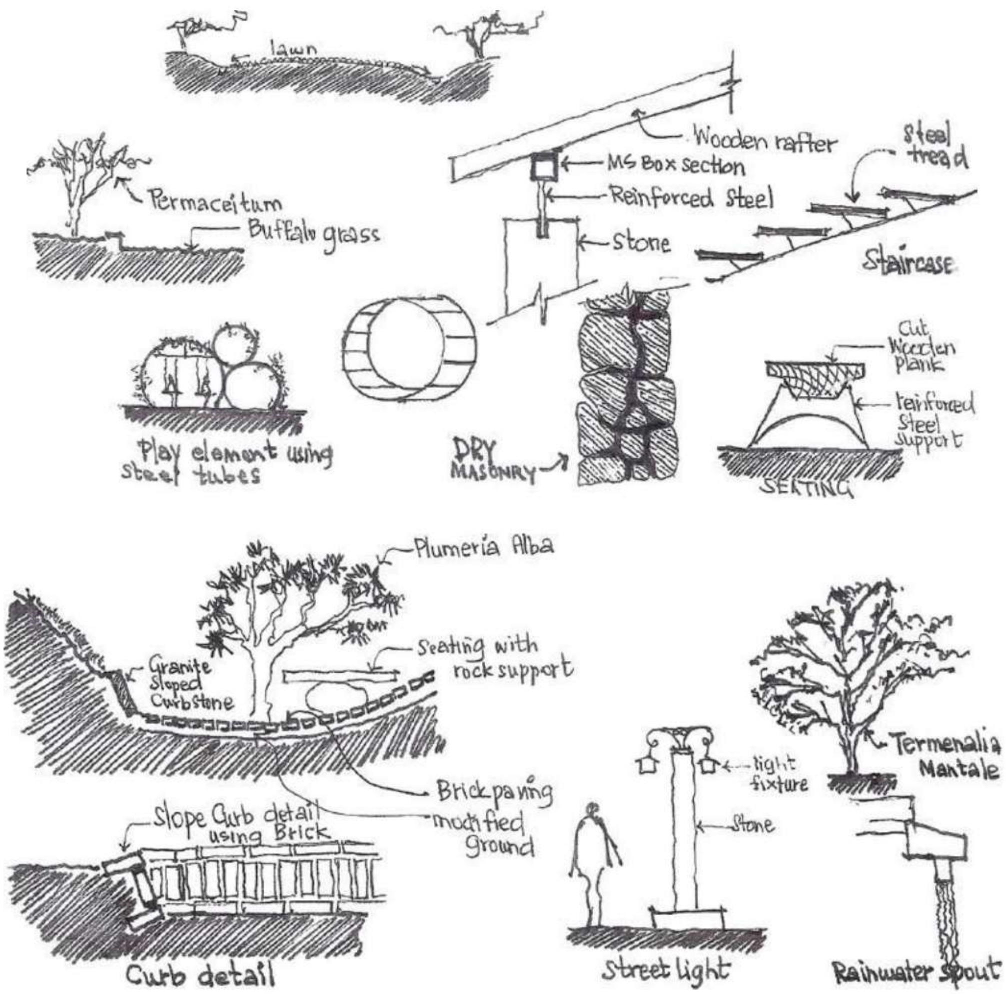


Figure 11 The combination of analytical drawings on the way to green space-02 at Mysore road.





Figures 12, 13 and 14 The analytical-composite drawings of several landscape features at the Good Earth Malhar.

Further, it is possible to decipher several Forms, Relationships and Practices as cultural values recorded through these analytical drawings illustrated above. **Table 01** shows a sample list of Forms, Relationships and Practices deciphered from the analytical drawings of the figures 7 and 14 to represent cultural values recorded in the green space-01 and 02.

Table 01 List of Forms, Relationships and Practices deciphered from the analytical drawings of the figures 7 and 14 to represent cultural values recorded in the green space-01 and 02.

Green spaces	**Recording of Cultural Values as**		
	Forms	**Relationships**	**Practices**
01- Lal Bagh Garden (From Fig. 7)	Roads, Double road circle, Traffic island, Entry structure, Ticket counter, 12'wide pathway, Arborium, Benches, Ashoka trees, Veerakkal (an inscription), Rocky outcrop, Steps on the	Physical relationships, Historical relationships, Sacred relationships, Spatial relationships, Functional relationships, Visual relationships, Memorable relationships,	Vehicle movements, Ticketing, Parking, Pedestrian walking, Photography, Sitting and relaxing, Listening to history, Rock climbing, City viewing,

	rock, Kempe Gowda tower,		
02 – Good Earth Malhar (From Fig.14)	Plumeria Alba, Seating on a rock base, Brick paving, modified ground slope, Sloped curb wall with Granite, Lawn, Sloped curb wall using Brick, Street lights, Light fixture, Stone support for the street light, Rainwater spout, Terminalia Mantale tree	Physical relationships, Spatial relationships, Functional relationships, Visual relationships, Memorable relationships, Sensorial relationships	Playing, Sitting and relaxing, Water channelling, Walking, Gardening,

CONCLUSION

Each of the analytical drawings aforesaid enables one to list the significant tangible features, activities, and meaningful relationships thereby recording the cultural values of the study area. Despite its subjectivity in thinking, the knowledge obtained from these cultural values is relevant in providing solutions to several architectural design contexts. It is therefore possible for architecture students to take up clues from these components of cultural values and further improve upon or develop newer iterations as part of their design processes. Such a thought process can bring a comprehensive understanding of any given site context for one to respond through appropriate design interventions.

The travelling transect-based drawing approach helps one to observe, analyse and comprehend places in their entirety. The participants would be able to record their thought processes, expressions, and emotions at every point of their travelling. Further, one's thoughts on height-width proportions are also significant learning to architectural design. Irrespective of the classical proportion, one gets to understand the volumetric qualities of spaces better, a knowledge that is often much lacking in the current digital era.

Besides facilitating the architectural design process, the travelling transect-based drawing approach, can prepare theme-based transect routes to connect places of cultural heritage. Such routes would help one to identify unprotected places of cultural heritage along the way and thereby a comprehensive understanding of the system is possible. Further it is also useful in the heritage listing process, an ongoing initiative of the (Indian National Trust for Art and Cultural Heritage (INTACH) across several Indian cities and towns. Comprehensive understanding of cultural values can facilitate conservation to go beyond the present monumental approach for Indian urban contexts.

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THE RE-CREATION OF TROPICAL RESIDENTIAL THERMAL COMFORT

Karl Wagner

Prof. Dr., Technische Hochschule Rosenheim, Germany, karl.wagner@th-rosenheim.de

ABSTRACT

In the limelight of recent building research since 2013, studies comparing different systems to achieve "Tropical Residential Thermal Comfort (TRTC)" have become rare. Arguments disputing the meaning of comfort between tropical open concept passive architecture and the airtight universalistic Passivhaus framework are not seen to be exchanged. The same counts for approaches that still confirm and favour the (Passivhaus-related) generic psychrometric chart in conditioned areas vs. those (more open concept related) that support "adaptive" flexible tropical thermal comfort. For each, thermal comfort studies from theory into obtaining role model standards are separately translated for their users. We will name them as system/ standard A or B.

Since 2021, a new dimension (standard C) comes stronger into the play by global (and "glocal") warming which would mean: The higher the acceptable indoor temperature, the less the occupants need to be accounted for active cooling measures respective of their carbon footprint. The USL (upper space limit)-approach comprises the question how building scientists and practitioners can produce CO2-mitigating thermal comfort strategies for their occupants, hereby refreshing and potentially facilitating a prolific series of necessary studies. Hence, this article performs a journey, from the current conventional standards of tropical thermal comfort towards the question of how to achieve an environmental-friendly and more family- and group-orientated comfort. Hence, the USL-concept is based on the applied standard A (PMV-Predicted Mean Values studies) measuring average scores and acceptable standard deviations of 85% occupants' satisfaction, plus the adaptive standard B simultaneously. Therefore, it probes users how to increase the anyway hot tropical temperatures as high as thermally feasible, while taking relative humidity and the power of velocity for humans into consideration. Hereby, starting out at the microscale of individuals, it concludes by showcasing how occupants as individuals or groups can contribute on a microscale helping to reduce global warming.

Keywords: Thermal Comfort, Passive House, Natural Ventilation, Climate Change, Sustainability

TRTC (Tropical Residential Thermal Comfort)

Talking about thermal comfort is like asking two building scientists who refuse talking to each other for decades to communicate again. The "higher" reason is assisting to reduce climate change. We will call the first type of researches "thermal comfort type A (by natural ventilation)" and the second one Type B using (by air condition). After a few pioneering studies, in the mid 2010s decade it seemed each side has settled the topic for themselves[20]. By thinking out of each box, it will help that combining natural ventilation and aircons in a hybrid mode might become a thread for the future of homes in the decade to plan steps against climate change. The reason is that the climatic tailored *Tropical-Residential* Thermal Comfort elaborates on the role everyone in the households can play in the 2020s-decade to jointly "bottom up" combatting global warming: Setting temperatures which reduce the carbon footprint, is politically sane. It is acceptable by already created and established tropical thermal comfort standards for naturally ventilated and air conditioned homes as well. Indeed, both would have a role to play. Whether "A" and/or "B", in the tropics

[20] De Dear, R.J., et al. (2013), Progress in thermal comfort research over the last twenty years. In: Indoor Air 2013; 23: pp. 442–461.

and during summer, we will most likely have to rethink our standards in terms of straight forward "***Upper* Space Limits" (USLs)** of temperatures *instead of the common spectrum of thermal "ranges"* set by both approaches: Ranges provide just shallow excuses accepting *lower* temperatures space limits (LSLs) that may create a bit more comfort, but by each degree C they are more expensive and increase the carbon footprint[21]. Not to be mistaken, in a scientific paper, we will not talk about forcing anyone to increase temperatures in their homes to the highest setpoint. Still, we would like to create awareness how revised family or individual thermal comfort standards may contribute to less climate change[22].

So, after 10 years of more or less sole application, we refresh the generic tropicalised thermal comfort discussion for its tropical application again with the newly created acronym of the four letters Tropical Residential Thermal Comfort. Hereby, we need to throw our light onto the TC's 3 main pillars, which are part of most thermal comfort apps: A. most commonly, *ambient felt air temperature*, B. *relative humidity* (incorporated into the temperature as "*heat index*" which we believe does not play a significant role along with the *wet bulb temperature*"[23]. BOTH indices are not reliable to predict the felt temperature for humans. The renowned wet bulb temperature is rather a technical term to calculate the probability of moisture[24]. Instead, we will be using the applied side of sciences with detailed weather APPs, where occupants can see on their tablet or smart phone with one pressed button how the "real" felt temperature is in their area everywhere on this globe. We will shortcut the introduction by connecting temperature and humidity for a saturated, CLO 0.5 person (typical for homes). If needed due to high humidity, we will zoom in and utilise ventilation as antidote of high RH to bring the temperature down to an acceptable level again. As the bottom line, after clarifying, from the temperature/humidity plus velocity data we will derive three clear-cut energy-saving strategies plus suggest ways how to save energy and costs.

BENCHMARKS OF THE "CORRECT" SYSTEMIC COMBINATION OF TEMPERATURE(S), HUMIDITY AND VELOCITY FOR AIR-CONDITIONED AND NATURAL AIR HOUSES TO REACH UPPER SPACE LIMITS

The Interplay of Ambient Air Temperature, Relative Humidity and Air Velocity

In an easy recallable layman's term for simplicity reasons, here we are first addressing the *felt air temperature*. Apart from justifiable other technical definitions, the feeling of humans appears as the only one important "translation" of what surrounds us thermally. The interconnectivity of *air temperature via thermometer and the covert humidity is like the following*:

By our apps we find proven record that people who are sitting in a calm place independent of the humidity will feel any temperature roughly between 7°C – 26°C as such, just as the reading on a calibrated thermometer will show (WYSIWIG).

What the "heat index" combining both does not show, but what is a typical temperature in tropical countries: If the read temperature exceeds 26°C, ONLY THEN the felt temperature due to the humidity might be higher. When 26 is no longer 26 and 28 no longer 28, is a progression fact. Whether read and felt temperature are the same, then depends on the air's relative humidity as a catalyst to feel higher temperature in the tropics (at > 26 °C). But if the same temperature on a simple thermometer's reading might be felt higher in case of high humidity, involves tremendous consequences for thermal comfort even with tiny deviations. If sweating of a normally casually CLO0.5 dressed not overeaten individual starts with a reading

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[21] In this publication, we will still continue to talk about USLs and not "setpoints" to illuminate that we avoid to spend only necessary carbon by choosing the highest setpoint.

[22] "There is reason to believe that the progress in thermal comfort research over the next 20 years will be driven by climate change and the urgency of decarbonising the built environment" (de Dear, R.J., et al.,2013: 456).

[23] Cf. heat index by the National weather service, as it calculates deviating temperatures just in five-grade steps. https://www.weather.gov/images/safety/WBGT-02.jpg (accessed 15/7/2022). E.g. we could use the less precise US-calculator at https://www.wpc.ncep.noaa.gov/html/heatindex.shtml (accessed 15/7/2022).

[24] https://www.kwangu.com/work/psychrometric.htm (accessed 15/7/2022).

of 28°C at a medium Central European typical humidity of 50%, it is going to start and bother in the tropics already with 26.1°C measured on the same thermometer. The humidity is – as typically found in the tropics- might be 70% and higher[25] - along with the felt temperature. The common tropical **ASHRAE SS 554**-standard (which is based on the commissioned "adaptive" model by De Dear&Brager,1998) set a banding of 4°C with its maximum of 26°C USL, but also recognises a maximum RH of 70% USL which practically exceeds the 60% standards of the cold hemisphere.

However, if we are under the reach of tropical -natural or artificial- wind (velocity), we can still enjoy a lower temperature than the humidity-temperature. Below, we will factor in the cheap and almost zero carbon air speed (=meter/second =m/s), all the more if PV panels with small storage are used. We will recalculate by practical examples what temperature we actually feel: *felt temperature including humidity 26°C upwards MINUS equivalent velocity if needed.*

The Thermal Borderline Experience

Typically, the borderline experience happens frequently when we travel between Singapore and Kuala Lumpur during the night time. Whereas the night time weather log in Singapore due to the heat urban effect typically can show 28 °C at an RH of 83%, in the North West just 15 km away of the island the typical situation 'night by night' is different: On the way through the Malayan peninsula the temperature will show a thermally agreeable temperature of 26 °C – regardless of the RH which might even be higher than in urban and suburban areas like Singapore or Kuala Lumpur. This creates not just bluntly 2 °C less, but a completely different feeling, even though the RH might be similar. On 3/12/16 Singapore measured 83% at 28 °C which felt quite hot like 33 °C. Ayer Panas (1h south of Kuala Lumpur) measured 26 °C plus a very high 94% RH which equates in about just 29 °C FELT temperature just slightly higher than the sweating point and easy to balance by velocity. If the RH is only slightly lower, the temperature is only 26°C, 26=26 and not even 29°C. In the following table, 26°C which is the thermal borderline between comfortable and uncomfortable, will be still 26°C with lower RH, but if it exceeds 60 % and above, it will stepwise become a sweating factor. The coastal Baranquilla in Colombia with similar latitude features like Malaysia serves as an external validation from a different continent with the same logics behind:

Table 1: Borderline Temperatures of 26°C between typical Sweating and Non-Sweating (Apple Weather App)

Ambient Temperature	RH	Felt Temperature	Balance	Location
26°C	89%	29°C	+3°C	Kuala Lumpur, Malaysia 8am
26°C	89%	27°C	+2°C	Kuala Lumpur, Malaysia 11pm from different provider weather.com or different velocity factored in
26°C	94%	29°C	+3°C	Penang, Malaysia 8am
26°C	94%	29°C	+3°C	Kuala Lumpur, Malaysia midnight, early morning Baranquilla, Colombia
26°C	100%	30°C	+4°C	Baranquilla, Colombia
27°C	45%	27°C	0°C	Pnom Penh, Cambodia

USL (Upper Space Limit) as the "best" Temperature Set Point to reduce the Climate Catastrophe from a Standard Home Perspective

If we utilise the Temperature above 26°C-Humidity-Velocity approach, we are able to monitor the temperature to save energy. We could keep all kinds of tropical occupants still thermally comfortable around their preferred thermal comfort temperature before sweating at any time. Then the pivotal question would still be *"what is the best energy saving* felt USL-temperature suggested the occupants can choose from".*

[25] I have pointed this out in a lecture presented to 30 leading engineers of AStar research unit / Singapore 2016 to the astonishment of the whole group.

Setting USL-Standards
For the CO_2-alerts and the myth hunters both of type A and type B, is the USL 25°C ambient temperature like suggested for any Passivhaus[26]? Is it ASHRAE's proposed 26.2°C? Or can the general environmental friendly USL range up to >28°C digesting air speeds up to 1.1m without feeling them as draughts – as proposed by Pasut (2014)[27]? Recently the SDE4 building at NUS (National University of Singapore) and follow-ups with a hybrid of air con and velocity-creating ceiling fans as proposed by our team in 2018 confirms this theory. The difference – the same thermal comfort at the expenses of a hybrid solution would have tremendous conferences for the carbon footprint especially for households where higher temperatures can be accepted.

The clue is generally provided by Aynsley& Skolodai (e.g. 2013), who measured *a minus of 3.8°C with a still reasonable air speed of 1.1m/second on the human skin*. If the air temperature is e.g. 30°C, by velocity the occupants only feel 30-3.8=26.2°C. Astonishingly or perhaps planned by its creators, it meets exactly and compatibly with the tropical ASHRAE-standard without velocity[28]. This is how Lamberts & Cândido (2013) factored in velocity for naturally ventilated buildings located on Brazil's tropical warm and humid North-East representatively for other tropical equator-near regions on the globe in 3 stages:

Table 2: Allowable High End Thermal Comfort Bandings creating also High USLs.

24°C - 27 °C (minimum air velocity for thermal and air movement acceptability is	0.4 m/s)
27°C - 29 °C (minimum air velocity for thermal and air movement acceptability is	0.41 -0.8 m/s)
29°C - 31 °C minimum air velocity for thermal and air movement acceptability is	>0.81 m/s.

After looking at the research in open and closed areas, air conditioned and mechanically ventilated spaces, it is tempting to draw the following conclusion: Completely different kinds of adaptive bandings with different LSLs and USLs demonstrate that setting a standard for temperature including relative humidity plus velocity is dependent on the way the selected sample on average or the researcher feels. The influence of relative humidity and velocity was not measured for some time. Hence, common researches of the 1990s and 2000s based their research often solely on temperatures and 80% standard deviations in the traces of Fanger's PMV and PPD. Critics even disregard the fact that he measured relative humidity indeed, but, different to warm countries, in cold hemisphere's except for summer it was probably easy to disqualify them as draughts.

With tribute to thermal comfort research, most *binding tropical thermal standards* evolved from mean scores. Some became legally notable, trying to bring research results into life. Some regulations that tropical thermal comfort can be part of green building indices are:

[26] Passivhaus followers admit that increasing their automatically software produced 25°C only to 26°C like in the case of the certified Austrian embassy in Jakarta "is okay but 28.6 (as proposed by KW is not acceptable if we want to be fair" (Kress, D. in an email to KW 04/10/2021 and Clare Perry in an email to KW 30/09/2021).
[27] In this study, at 28°C and 50% RH it was found that "the majority of subject (70%) perceive the thermal environment without fans comfortable". This figure rose to 100% when using fans.
[28] Cândido, de Dear, Lamberts (2010) hypothetised 29°C - 31 °C minimum air velocity for thermal and air movement acceptability with > 0.81 m/s.

Table 3: Comparison of Tropical Thermal Comfort Banding Standards

(Tropical) Thermal Comfort Banding Standards	Ambient Temp. (lower space limit (LSL) min.	Ambient Temp (USL without Ventilation) max.	RH USL max.	Building Type
World Health Organization (1990)	18°C (N/A for tropics!)	28°C	-	all types of buildings
ASHRAE SS554 (Singapore, Malaysia)	22.8°C	26° C.	-	Legally binding only for Commercial offices and malls
Green Mark 2016 (Commercial)	-	26.2°C	70% (existing buildings) 65% (new buildings)	Commercial (because the developers at BCA Singapore stated they cannot enforce TC for private households)
OUR RESEARCH	No LSL (only USL is of main relevancy to reduce carbon footprint)	26.2 °C. (coinciding with the ASHRAE and the Green Mark USL It is necessary to factoring in RH and velocity as below with any higher temperature)	70% (following the Green Mark's upper limit for existing buildings)	Residential, with echo to Commercial (less clothing by less wearing ties and jackets in the 2010s and increasing complaints allow higher temperatures

The conclusion we drew is that only the ASHRAE554 and, based on it, the Green Mark standard derived from Singapore cater for a comprising and fully convincing framework of thermal comfort standards.

The Indoor "Airea" as the Third Dimension: Tropical Thermal Comfort incl. Velocity, used as practical Antidote for High indoor RH (based on Aynsley and Szokolay (1998)

Most standards of the past did not consider velocity as the 3rd imperative driver of thermal comfort: "From a ventilation perspective, (like) the 'Australian Nationwide House Energy Ratings Scheme' (NatHERS) underestimates the cooling effect of air movement at high humidity levels" (Shiel et al. 2017). Riding a bicycle with a speed of just 1m/sec, we experience a similar cooling air speed like by a stronger fan in an indoor "**airea**" as "appreciative draft"[29]. Gonzales & Firrdaus (2019) called this kind of building an ***airhouse*** which sounds more appropriate than naturally "ventilated" building[30]. (Often there is no wind despite the open windows, and if there is, the walls radiate their daytime overheating).

So we used airea as a neologism for an 'area' where tropical people live comfortably with a significant mechanical fan's 'air' speed of at least up to 0.7 to 1.1 m / sec directed on their body[31]. This

[29] Toftum, 2004; Zhang et al., 2011; Cândido et al., 2010.

[30] Gonzalez-Longo, C. & Mohd Firrdhaus M. S. (2019).

[31] Occupants adapted tropical climates not only accept, but even prefer higher air speed values (higher than 0.80 m/s) in order to restore their thermal comfort. Results also indicated that the risk of 'draft' resulting from higher air speed values recommended by ASHRAE 55 (2004) and ISO 7730 (2005) is irrelevant for the overwhelming majority of building occupants" (Lamberts, et al. 2013). ASHRAE 62.1 can go up to 27.8°C, but this is only for naturally ventilated buildings . The normal design dry-bulb temperature for comfort air-conditioning shall be within 23ºC – only 25ºC, and resultant relative humidity ≤ 65% in accordance with SS 553 : 2016 - Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings.

cooling effect can be achieved by natural ventilation as well, but wind from outside is rarely reliable like in the most upper floors of high rises with open windows. An airea defeats its purpose and is medically critical, if the arriving wind blows onto us with such a speed that we feel as uncomfortable hotness of 35°C (found at some LRT- and MRT-stations) and above. Or, conversely for the colder hemisphere, when air arrives with a coldness of 11°C like being directly exposed also to air conditioners or natural draughts, if the temperature is more comfortable without any velocity. If the arriving air produced by the ceiling fan on our skin dashes in with the enclosing temperature of e.g. the predicted average Malaysian temperature of 32°C in 2050, the skin translates this temperature depending on the actual air speed. In the table below, we used just a typical tropical nowadays average temperature of 28°C plus an RH of 60%.

Mean temperature/RH Wind speed in the Airea => felt temperature MINUS =AMBIENT TEMPERATURE/RH plus WIND SPEED/sec effects in COOLING of = FELT TEMP (scenario 1, 2, 3, 4)

28°C/ felt at 60% RH	1	0.25 m	- 1.0 °C	= 27.0°C
	2	0.5 m	- 1.9 °C	= 26.1°C
	3	0.75m	- 2.8 °C	= 25.2°C
	4	1.0 m	- 3.8 °C	= 24.2°C

Figure 1 : Example A: Cooling Effect of Different Ventilation Speeds for 28°C at 60% RH (Rainbow colour indicates residential thermal Comfort Level devised by the ASHRAE-Standard SS554)

AMBIENT->felt TEMP. (1) /RH plus WIND SPEED/sec effects in COOLING = FELT TEMP

28°C = 33°C felt at 80% RH	1	0.25 m	- 1.0 °C	= 32.0°C
	2	0.5 m	- 1.9 °C	= 31.1°C
	3	0.75m	- 2.8 °C	= 30.2°C
	4	1.0 m	- 3.8 °C	= 29.2°C

Figure 2: Cooling Effect of Different Ventilation Speeds for 28°C at 80% RH (Rainbow colour indicates residential thermal Comfort Level devised in this Publication based on the ASHRAE Standard SS 554)

In the first case above, with an RH of 60%, it is easy to reach the tropical residential thermal comfort zone by the balancing effect of velocity. If the RH just rises above the USL to 80%, like in the second case below, it is harder for velocity to fight sweating successfully. It means to reach a felt temperature below 28.7°C (as discussed). Subsequently, in the tables below we got an RH of 80% which is quite realistic and can be found through the courses of typical nights. Hence, despite the same temperature, example B. looks completely different than A., if we select the real time data at 3 pm of 28°C, but with an RH of 80%:

https://www.bca.gov.sg/greenmark/others/Green_Mark_NRB_2015_Criteria_Draft_R3.pdf. (accessed 25/3/2022) https://www.ashrae.org/File%20Library/Technical%20Resources/Technical%20FAQs/TC-02.01-FAQ-92.pdf.

CONCLUSION TO COMBAT CLIMATE CHANGE BY OPTIMISING TRTC

Three adaptive "individual" TRTC Ideal Types

The often quoted PMV based on the psychrometric chart stated that 80% of humans get to freezing and sweating at the same temperature range, and it is the target to make it right for them indoors (20% may deviate lower than 17.5°C or higher than 22.5°C). Therefore, in the tradition of Fanger (1970), researchers propose to use the same temperature banding for everyone in air conditioned areas, because people are or can be "conditioned" to one stable temperature banding.

Along this line, different kinds of adapted occupants as laid out in the paragraph above, may still have different USL-thermal comfort acceptances. As a result, the target of the tropical climatic design for indoors is still to go with an adapted Fanger's PMV of perhaps his 80% of the population in the middle on the high end levels in compatibility with outside air ventilation. This article was written to choose three flexible USL-temperatures that make it right / congruent for the majority of people (PMV) AND sustainable for our Planet. Depending on the setpoint, the occupant still can prefer air condition, fan or a hybrid system for day and night usage – with determination for each how many hours are being usually spent at home[32].
More **individualisation** among the following ironically paraphrased ***group clusters*** brings ideal typologies[33] into the USL-playing field, where occupants measure just the precise upper temperature in their home with casual dress and probably find themselves:

Coldies feel they can just stand temperatures up to 24 °C without fan or preferably A/C. It might be hard for this group to increase the temperature toward any proposed higher USL. They might be used to climatic conditions even lower than 24°C. Whether they go shopping or to the movies, they are part of the often paraphrased "air condition society".

Coolies feel they can stand temperatures up to the Green Mark's 26.2º C at any RH usually below extraordinary 90% without fan or A/C (=Green Mark USL-Standard without ventilation). They feel they can stand temperatures up to 28.6 °C with a tropically still moderate fan speed of <1.1 m /s which has the opposite (i.e. positive) effect compared to droughts in cold surroundings.

Hotties find the upper residential temperature borderline up to 28.6 °C regardless of the RH with reasonable ventilation as still comfortable. Only temperatures above 28.6°C as USL, but below 30°C (without an additional fan with the necessary velocity on the skin) will cause discomfort with physical sweating. This is also again exactly in line with the tropical ASHRAE or the Green Mark standard, which to date does not differentiate between cooling by ventilation and non-ventilation, with air conditioning or without[34].
Ideal type also means that there is no issue about the still artificially crafted temperature borderlines, until PMV-studies of a reasonable number of occupants (85%?) satisfied occupants along all three types prove that they are working. Even there is no issue if people find themselves swapping from one of the three type to another, depending on what they do, when they eat or move / sit and what age they are and were, and

[32] Personalised ventilation system (Sekhar, 2018).

[33] The sociologist Max Weber coined the term "ideal types" as features that shape up at purity, but it is unlikely that they appear like this in real life. It is a "conception or a standard of something in its highest perfection. Ideal type is a model… a kind, class or group as distinguished by a particular character" (Webster Dictionary in: https://www.yourarticlelibrary.com/sociology/webers-ideal-types-definition-meaning-purpose-and-use/43758 (accessed 15/07/2022). An ideal type is a common mental construct in the social sciences derived from observable reality although not conforming to it in detail because of deliberate simplification and exaggeration. It is not ideal in the sense that it is excellent, nor is it an average; it is, rather, a constructed ideal used to approximate reality by selecting and accentuating certain elements. https://www.britannica.com/topic/ideal-type (accessed 15707/2022).

[34] Scheatzle el al. (1989) in a pioneering study found that at least 80% of tropical occupants (PMV) could be comfortable at a temperature limit of 28°C and air velocities up to approximately 1 m/s.

how they want to make it right for others… Ideal types just give directions of a certain quality, and are hence not carved in stone like mathematical formulas like "1+1=2". However, similar like for personality profiles, most people can recognise their own behaviour between those ideal types.
Unfortunately, using air conditioners with low set points and therefore inevitable high carbon footprints. They are often to be found not only as part of a more wealthy lifestyle, but as unquestioned complacency zones of people. Once again, once getting used to it, the way out higher from the air condition zone of a "coldie"-behaviour toward a more adaptive "coolie" is harder than the other way round.

Adapted tropical residential Thermal Comfort, the USL-Approach and its Macro-Effect on Global Warming

In this planet's most serious episode of Global Warming, determining thermal comfort from an *adaptive* point of view, is no longer a story of just "preferring and liking a range of temperature". Under climatic conditions with growing disastrous effects, micro-action on the part of occupants needs to be taken toward more natural temperatures. Perhaps it implies more and better ventilation, but certainly it means minimising the usage of air conditioners. Hence, for tropical homes equipped with cheap, but once operated highly expensive carbon triggering aircons, creating TRTC receives a completely different meaning. In this respect, the only temperature in a household counts whether or not to switch on any cooling device, is ***the agreed tipping point between comfort and sweating*** that statisticians call Upper Space Limit (USL). It works only if RH and reliable natural or mechanical velocity are factored in by the weather log via the app. The optimal result may be a "mixed mode"[35] of natural and mechanical including "hybrid ventilation" [36]. Whatever aircon-based cooling we still need to choose, *warmer and still comfortable* is the most carbon saving way for hot and humid climatic conditions. Depending on the 3 ideal = real types derived above, it can be proposed for studies that the USL setpoint of the indoor temperature can vary individually tentatively to ventilated maximum 30°C, maximum 28.6°C, maximum 26.6°C and 24.6°C. Rising RH as a driver of discomfort above 26.1°C will be counterbalanced by air condition – or, as it is proposed here as CO2-saving– by using the velocity of directly on the occupant blowing ventilators like ceiling fans and fresh air supply fans from cooler outside temperatures[37].
Educating occupants and developing smart prominent mass gadgets to control the temperature according to the USL, can have the desired macro-effect on homes' contribution on global warming in the future.

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[36] *Advanced* hybrid ventilation, "which includes intelligent controls, can achieve a balance between indoor air quality, thermal comfort, energy consumption, and electric peak load" (Berkeley Lab at https://svach.lbl.gov/hybrid-ventilation-and-adaptive-comfort/ (accessed 15/07/2022).

[37] "The temperature and humidity conditions for … tests were 28° C and 50% RH. It was found that the majority of subject (70%) perceived a thermally fine environment without fans comfortable. This number rose to 100% for some configuration with fans (Pasut, et al. 2014).

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INDIVIDUAL AND GROUP VARIATIONS IN WAYFINDING AMONG USERS IN AN EDUCATIONAL BUILDING

S Baarat Krishna[1], Hiruthik Dharsan[1], Rajiv Vinod[1], J Abinaya[2], Sibin Mathew Nesin[3]

[1] Student, School of Architecture, CHRIST University, Bengaluru, Karnataka, baarat.krishna@barch.christuniversity.in
[2] Assistant Professor, School of Architecture, CHRIST University, Bengaluru, Karnataka, ar.abijay1011@gmail.com
[3]Assitant Professor, Department of Psychology, CHRIST University, Bengaluru, Karnataka, nesin.mathew@christuniversity.in

ABSTRACT

The effective performance of users in an Educational Building is determined by the available resources and also the environment in which they dwell. Wayfinding is a daily occurrence for every user of an academic institution and this is facilitated through the distinct articulation of different spaces and recognizable circulation systems. The user behavior in a known/unknown building varies as an individual and with a group of individuals. This variation can be observed in an enclosed space and public setting. For an individual, the psychological state could influence navigating within the building whereas, for a group of individuals, the group dynamics could influence each other to navigate. The paper uses mixed methods to understand and assess the individual and group variations in wayfinding. The study was undertaken in a recently constructed School of Architecture at CHRIST University, Bengaluru. The understanding was accomplished with elaborate literature studies and the assessment was through the field observation techniques and surveys carried out with identified users like frequent individuals, new individuals, frequent groups, and new groups.

The study tells that for both individuals and groups, the parameters like architectural elements, sensorial qualities, wayfinding behavior, gender, and psychological state influence them in wayfinding. It was also noted that most of the student users prefer shortcuts rather than the formal entrance and lobby to navigate the classrooms. Accomplishing easy, comfortable, and efficient wayfinding within an educational building requires effective layout planning. These findings aim to contribute to the detailed understanding of effective layout planning in an educational building and its impact on user behavior for architects and decision-makers.

Keywords: Individuals, Groups. Wayfinding, Navigation, User-Behavior.

INTRODUCTION

An individual in a new building develops his/her perception either through human space or spatial order whereas a collection of individuals influence each other in their navigation. The incorporation of greater user experience through sensory qualities, signages (John Cope, 1999), and spatial hierarchies in wayfinding makes effective layout planning for an institutional building. Wayfinding is a purposeful & directed movement in a single or group to achieve a destination from an origin(Chang, 2019). It is important to understand wayfinding & producing buildings that are easy to navigate for all individuals. However, when wayfinding in a building is mishandled, it leads to disorientation & confusion(Theses, Brandon Abrams and Brandon, 2010). The user performance in wayfinding in an educational building is better when wayfinding factors align well with the layout plan (Theses, Brandon Abrams and Brandon, 2010). The master architect Le Corbusier said, "Users must stroll around and traverse the building to truly appreciate the architectural environment". The circulation in any type of building is a crucial factor in organizing its layout. It becomes necessary to study individuals & groups during wayfinding as they all use spatial, cognitive, and behavioral abilities to find their way(Chang, 2019) and also to do post-floor plan analyses for architects. Some Studies suggest that linear circulation is the easiest when compared with curved & grid-based(Natapov, 2019). It is used to understand how certain architectural elements like corridors, staircases, ramps & elevators act as thresholds and play an important role. Even though there were various studies on wayfinding (Chang, 2019; Theses, Brandon Abrams and Brandon, 2010; Jamshidi, Ensafi and Pati, 2020), there is a lack of research focusing on educational buildings on Individual and Group Variations in Wayfinding wherein lot studies focus on "Typology"(Arthur and Passini, 1992; Natapov, 2019). The study seeks to answer the following – a) What are the types of users in an educational building in Wayfinding and Why do the users differ as individuals and groups in wayfinding? b) How do the impacts of individual and group variations affect the users in Navigation? The study focuses on wayfinding variations between individuals & groups, a) To understand the individual & group variations in wayfinding; b) To investigate the impacts of individual & group variations of users in wayfinding. Wayfinding as a daily activity promotes physical activity, emotionally it reduces the complexity of the buildings, and with easy navigation, it increases the Sense of Belongingness with the space. The Methodology is a mixed-method analysis of Questionnaire Surveys, Observational mapping, and interpretations of it.

STUDIES FOR UNDERSTANDING

Lynch coined the word "wayfinding," which he defined as "the constant application and regulation of sensorial stimuli within the setting." (K. Lynch, 1960). In the literature on Wayfinding, several professionals have discussed the factors contributing to making successful Wayfinding in Institutional Buildings. People daily have to navigate multi-level buildings including workplaces, universities, train stations, hospitals, and retail centers(Feng, Duives and Hoogendoorn, 2022). Jamshidi and Pati categorize wayfinding theories into four groups: perception, the development of spatial knowledge, the display of spatial knowledge in memory, and spatial cognition(Saman Jamshidi, 2020). Many wayfinding studies elaborate on the concept of wayfinding, its elements, factors, and significance but other people's contribution to the wayfinding process is under-researched (Dalton et al., 2019). Especially, when an individual follows prior route instruction whereas a group does true collaborative wayfinding(together). Wayfinding varies in different aspects, including individual and group variations, eg: Gender Variations. People develop a cognitive relationship with the environment they dwell in and this relationship dramatically impacts their behavior physically and mentally(Raipat, 2021). According to empirical data, there are variations in how well men and women do spatial tasks, and these variations can be understood by evolution, they argued that females engaged in foraging while males engaged in hunting throughout the period of evolution, and each group gained distinct spatial abilities that were ideally adapted to the tasks they were performing(Jamie I. Campbell, Ilana J. Hepner and Laurie A. Miller, 2014) While some empirical evidence suggests that effective navigation techniques at health facilities and airports provide positive benefits, further research is needed to assess the effects of wayfinding issues on stress in educational settings. (Kanakri et al., 2016).

Individuals can make a plan to get to their goal, execute the plan, and negotiate any changes along the route owing to effective wayfinding design, which enables individuals to locate within a place, determine their destination, and devise ways to take them there(O.K. Suzer, N. Olgunturk and D. Guvenc, 2018). The main reason for effective wayfinding design is that it promotes healing which gives users a sense of power and control over their surroundings, which are crucial components in lowering stress, worry, and fear—emotions that inhibit the body's capacity to recover(Huelat, 2007). An effective wayfinding system should also be sustainable, Costs related to difficulties with wayfinding are frequently hidden. As an example, imagine the indirect cost of lost performance due to frequent users spending time away from their responsibilities to assist lost new users to their destination(Zimring and Templer, 1984). In a survey conducted at an Ontario university, 70% of participants said that accessing and traversing indoors was the most difficult wayfinding task there(K. Oyelola, 2014). The hardest task, specifically, was said to be finding classrooms.

In Wayfinding in Architecture(Theses, Brandon Abrams and Brandon, 2010), the paper aimed to identify architectural elements that create difficulties in wayfinding. Secondly, to propose a solution for the school's campus to have an organized & comprehensive wayfinding system. The scope is to understand attributes, and elements associated with institutional setting in the wayfinding system. The proposal was to include enhanced user experience through the sensorial aspects, signs, and spatial hierarchies to achieve simple wayfinding. According to (Jamshidi, Ensafi and Pati, 2020), the paper aims to review the different domains like individual and group differences, wayfinding behavior, wayfinding cognition, and environmental factors using a systematized search of databases. The paper review contributes to interior wayfinding and serves as a guide for architects and policymakers. In Interactive Wayfinding: Through the use of cues by male and female(Devlin and Bernstein, 1995), the paper tests how effectively men and women use cues of wayfinding in Computer Simulation Campus Tour. The Results indicate that men use spatial-visual cues more than women, and all participants use landmarks easily to navigate rather than signages. (Yuan et al., 2019). Wayfinding Applications like color, lighting, sign maps, and numbering system impacts human behavior in the built environment (Alansari and Professor, 2022). Lawton's Paper investigates if people from similar and multiple cultures differ in wayfinding(Lawton and Kallai, 2002). The Paper's Results show that people from multiple cultures differ whereas people from similar cultures differ slightly less in wayfinding. It led us to investigate if New and Frequent users in a built environment will vary or not.

METHODS

Study Context

The Primary Study was carried out at the School of Architecture (SOA), CHRIST University, Kengeri, Bengaluru, Karnataka. The five-year-old department has a stand-alone massive building on the campus for a bachelor's & master's in architecture. At the moment, the school houses 250+ students & 20+ faculties on G+6 floors with multiple entry & exit points. The reason to choose SOA is to understand the variations in wayfinding among users in an educational setting with different architectural elements, and high-performance circulation systems. The building serves department students, faculties, and non- teachings staff as frequent users, and the exhibition setting & seminar halls also invite visitors/new users occasionally to the building.

Figure 1. Study Building

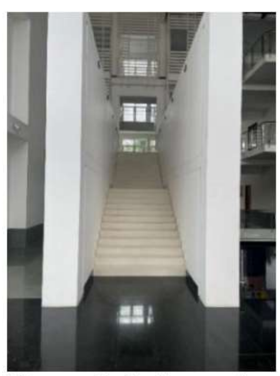


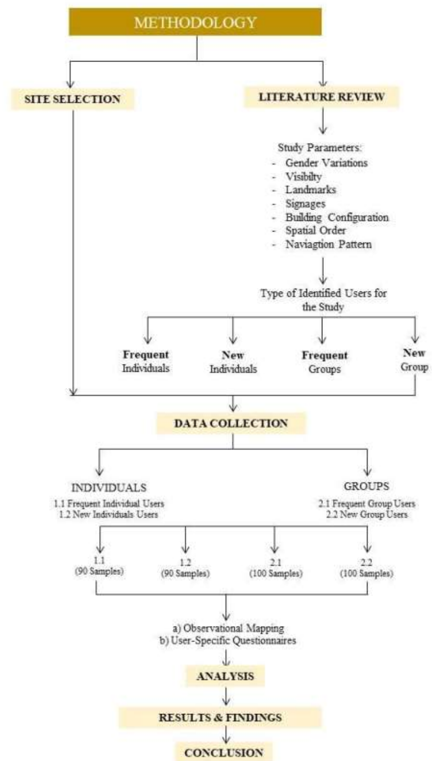
Figure 2. Staircase 1

Figure 3. Staircase 2

Figure 4. Lift in Ground Floor **Figure 5.** Towards Entry 1 **Figure 6.** Towards Entry 2**Source**: Author[1] (Figures 1,2,3,4,5 and 6).

Study Methodology

After the site selection process, the study parameters from literature studies helped to understand and assess the variations in wayfinding. To assess the variations in wayfinding for individuals and groups, the different user groups were identified for the study Frequent Individuals, New Individuals, Frequent Groups, and New Groups. The Data collection was carried out in four different phases for the four different sets. The Targeted Individual sample count was 200, whereas it was 200 group samples. Further, the questionnaire survey was distributed to specific user groups and authors involved in the real-time observational mapping to understand differences in preferred paths, circulation systems, and navigation patterns. The Four Different Questionnaire Surveys were co-related to analyze the differences between individuals and groups in wayfinding. Further, the maps were created to understand variations in the behavioral performance of users like pausing time, disoriented junction, and preferred circulations.

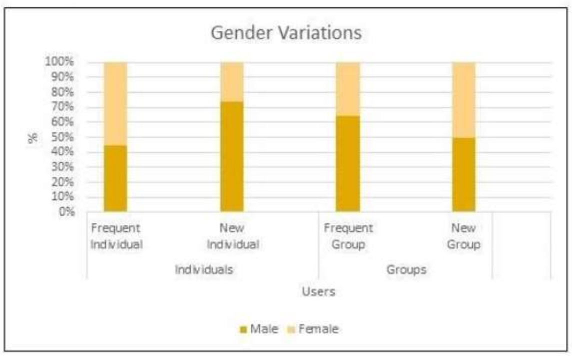


The Participants were divided into four user groups as mentioned in the study methodology. The Data was collected in four different phases with user-specific questionnaires. Participants received a destination location in the study building to use as their wayfinding target without any restrictions on time. Specifically, participants were instructed not to seek help from the existing building users unless they lose their route to reach the destination. Simultaneously, the authors involved in observation to map the participant's path/route to reach the destination. After reaching the destination, the participants were given a questionnaire to answer concerning the wayfinding aspects. The Four Different Questionnaire Surveys were co-related to analyze the differences between individuals and groups in wayfinding aspects. For example, Male and Female Gender data were correlated to understand the gender variations as individuals and groups. The Collected data was sorted, filtered, and analyzed using a statistical tool like Microsoft Excel. The Physical observations were converted to maps as a soft copy using graphical tools like Autodesk-AutoCAD, and Adobe Illustrator.

RESULTS & FINDINGS:

Questionnaire Survey

This study conducts a mixed method of questionnaire surveys and observational mapping for four different identified user groups as study samples. Over the span of a week, participants were instructed to complete 400 questionnaires on Google Forms, including those for frequent individual users, new individual users, frequent group users, and new group users. There were 380 valid surveys in all, and the declared response rate was 95%. Figures 6 to 14 show the profile & preferences of the users in wayfinding. Males accounted for more than half of the respondents (58.1%). Less than three-fourths (71.1%) of the frequent individual users preferred other paths to enter rather than Entry 1 and approximately more than half of new individual users (58.1%) had used the staircase as the primary circulation element. More than half (61.2%) of the New Individual Users preferred group navigation rather than individual navigation. More than half (65%) of the Frequent Users felt comfortable accessing the entrance of the study area. More than three fourth (85.55%) of the frequent user's behavioral performance in wayfinding depends on distance and comfort.



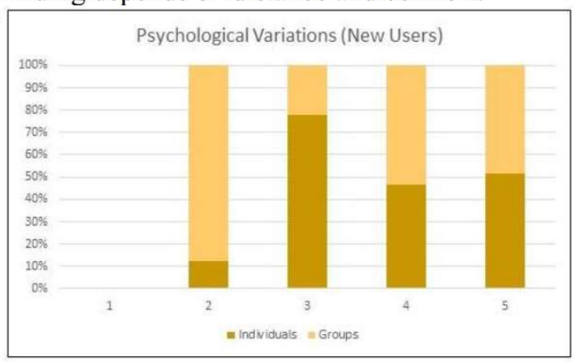
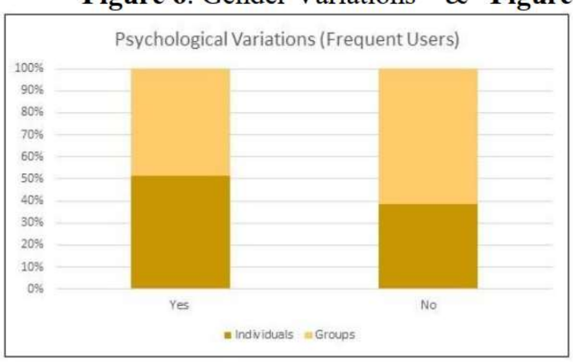


Figure 6. Gender Variations & **Figure 7**. Psychological Variations for New Users



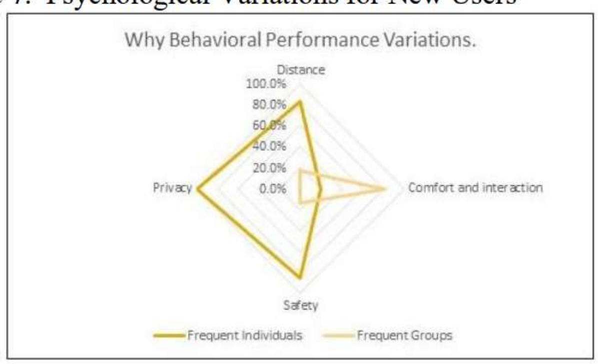
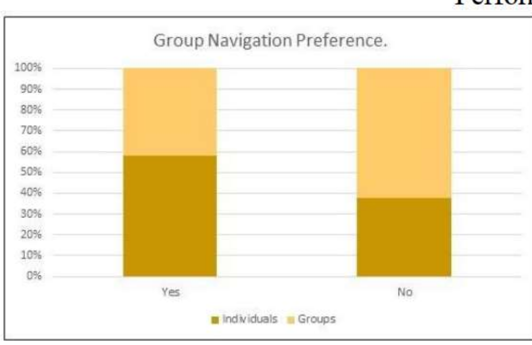


Figure 8. Psychological Variations for Frequent Users & **Figure 9**. Reasons for Variations in Behavioral Performance



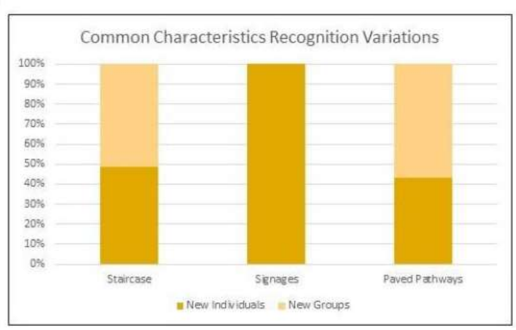
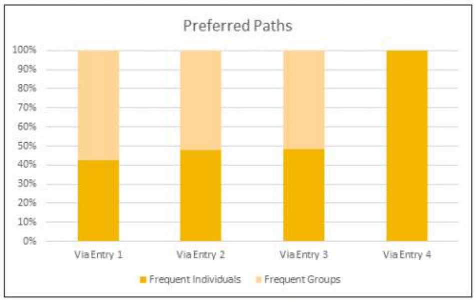


Figure 10. Group Navigation Preference & **Figure 11**. Common Characters Recognition Variations.



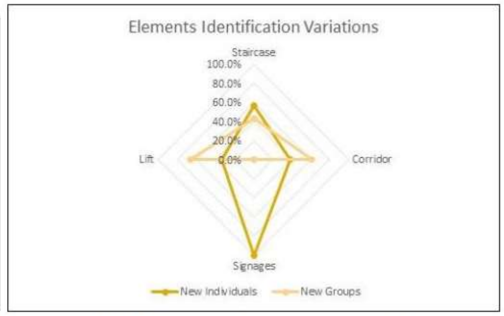


Figure 12. Preferred Path Variations & **Figure 13**. Elements Identification Variations

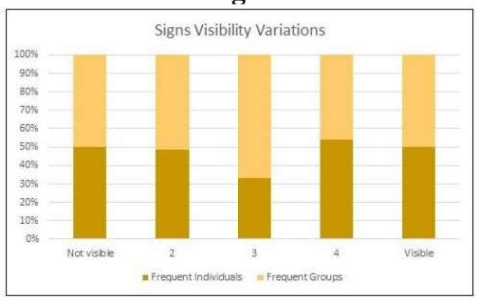


Figure 14. Signs Visibility Variations

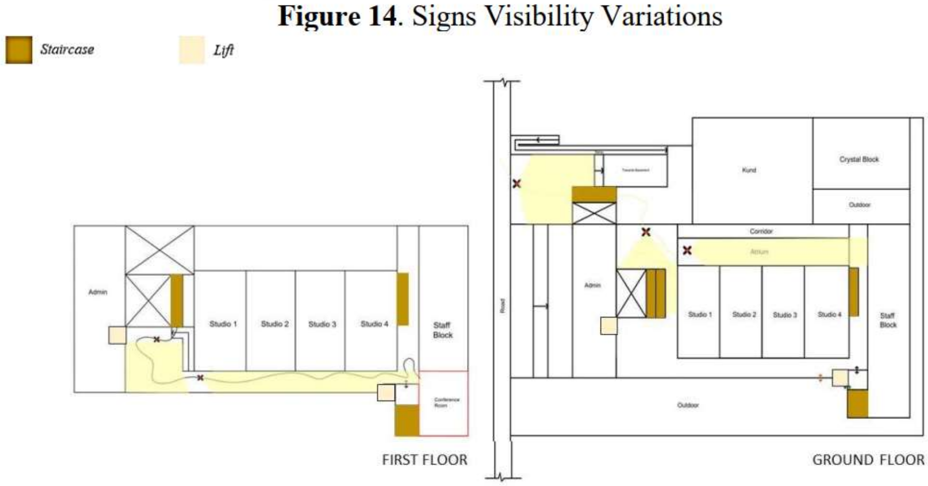


Figure 15. Visibility Map from the perspective of New Users

In figure 15, it was observed that every user, first perceives a new building visually. When the destination and elements to help identify the destination is visually clear, the users feel comfortable in wayfinding. In the current scenario, the staircase on the ground floor was used by most of the new users because of the clear visibility from the entrance lobby.

Observational Mapping:

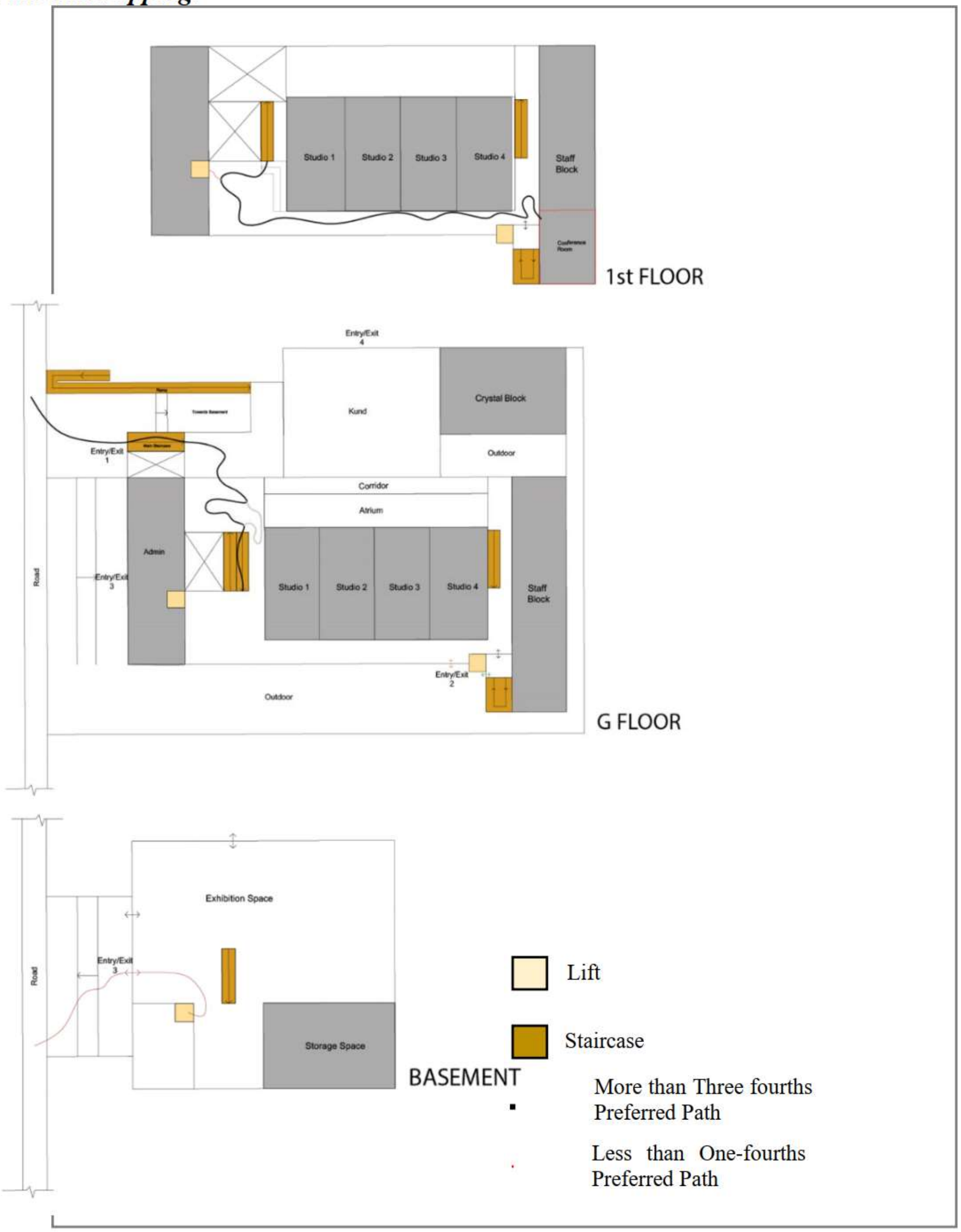


Figure 16 shows that both the New Individual and Group Users Preferred Paths to reach the destination (Point B). It is understood that Entry 1(main entrance) influences new users to enter and further navigate a new building. Although the study area had multiple entries, still more than three-fourths of new individuals and group users preferred the main entrance because of the big sign and grand entrance with a long staircase/Ramp. When there is a lack of signage in the lobby space, we can understand from the diagram, that the users get confused and prefer asking questions instead (Arthur and Passini, 1992).

CONCLUSION

The study shows some light on how different individuals and groups react and how architectural elements influence humanistic behavior. The Male and Female Variations indicate that factors like distance, time, and comfort affect them in wayfinding. It can be said that the path taken from Point A to Point B by New Individuals and Groups, there were slight deviations in between so it can be said that when space escapes in a building are good and easy to identify during emergencies, the users find it comfortable. The New Individual and Group users did not prefer the lifts as it wasn't easily visible and longer to reach when compared to Staircase 1 whereas most of the Frequent Individual and Group users tend to take the lift as they knew where it was placed, hence it can be said that the placement of the lift can help in saving electricity and promote people to walk more so in educational buildings or shopping malls or any other public places this placement of lifts and staircase can be adjusted to affect the users' movement and new users mainly dependent on signages, hence signages should be taken care to give the users an easy and hassle-free wayfinding which can save time and energy.

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ANALYSING THE SAFETY OF A CAMPUS USING SPATIAL SYNTAX

Sonika Raamanath Hegde[1], Rheethika Ramprasad[1], Pooja K[1], Abinaya J[2] , Subin Mathew Nesin[3]

[1] Student, School of Architecture, Christ (Deemed To Be University), sonika.raamanath@barch.christuniversity.in, rheetika.ramprasad@barch.christuniversity.in, pooja.k@barch.christuniversity.in
[2] Assistant Professor, School of Architecture, Christ (Deemed To Be University), abinaya.j@christuniversity.in
[3] Assistant Professor, Department of Psychology, Christ (Deemed To Be University), nesin.mathew@christuniversity.in

ABSTRACT

Everybody has been in campus environments and academic buildings at some point in their lives. The layout of these structures is crucial because it influences how a person behaves and presents themselves. The use of space syntax enables us to examine how individuals behave in relation to their surroundings and how places are used. The nature of the space and the way people move through it have improved because of the application of space syntax in campus planning.

A primary concern is safety, this paper is devoted to comprehending how various user groups navigate across a university. Here, we'll be looking at how students move around and behave in relation to how safe they feel on campus. Each user group's paths, nodes and gathering places will be recorded and we'll confirm both the original purposes and the current uses of the spaces. Additionally, several maps will be created to support the study that the campus is a safe place to be, including axial mapping and analysis mapping, convex mapping and grid analysis mapping. This with a combination of survey shall be used to understand safety with respect to space syntax.

INTRODUCTION

In the discipline of architecture, we develop innovative and creative concepts that we then translate into a tangible expression. As we progress past the concept stage, we frequently discover errors in the procedure and it is also how we develop solutions to them. However, the introduction of spatial syntax into academia, would be a crucial component for greater understanding and might help in simplifying the procedure. Space syntax is a collection of methods for examining the spatial arrangements and patterns of human activity in structures and cities. It also refers to a body of beliefs that connect society and space. Space syntax focuses on where people are, how they move, adapt, grow and communicate about it. This strategy is supported by a potent social theory of space and was established by Bill Hillier and his associates in the 1970s and 1980s.

The campus of Christ (Deemed-to-Be) University in Kengeri is a suitable location for this investigation as it is a 78.5-acre campus that is home to a number of deaneries and programs with diverse study methods and therefore, varying in occupant behaviour. The campus has a central square area where most of the buildings are while the front and the rear part of the campus are plantations maintained by the institution with a few congregation spaces.

The worldwide concern for quality and safety has created a need for a new method to improve safety in the workplace (Al-Hemoud and Al-Asfoor, 2006). Safety is one of the factors that determine whether a student feels comfortable studying at the said institution. Perceived safety is an important aspect of urban planning and is generally treated as an objective account of the personal sense of safety of each individual (Çamur, Roshani and Pirouzi, 2017). Institutions are small urban areas in themselves. They have their own inner dynamics and working. The level of safety in a campus can be understood using principles of space syntax. This can be done using measures like connectivity, axial integration, visibility field, lighting in area and usage of space.

LITERATURE STUDY

Space syntax was first introduced to the world at large with Bill Hillier's book "Space is the Machine" in the year 1987. Bill Hillier and Julienne Hanson observed that spatial syntax enables comprehension of a setting's social structure through a spatial configuration. It is one of the techniques for understanding space that combines tangible and intangible factors. Some of the theories that emerged due to these studies were the The theory of spatial combinatorics, Theory of natural urban transformation process, etc. (Yamu, Akkelies Van Nes and Chiara Garau, 2021). These help in evaluation of spaces depending on its core factor and the consequential study regarding the same. Theory of natural movement, for example, is useful to study the progress of a space depending on the time, hence relating it to change. This is useful to understand the prognosis of a city and helps analyse the socio-economic impacts of the urban design proposals. Space syntax has been used extensively in various fields like archaeology, architecture and urban planning, criminology, sociology, psychology and more. Factors like connectivity, axial integration, urban grid, Justified Graph etc. help understand the space in order to study them. (Yamu, Akkelies Van Nes and Chiara Garau, 2021)

Spatial syntax develops a different perspective on how to perceive any environment, bringing to light its prospects and visible habitation rhythms. This method of comprehending strengthens the debate on space design by making intangible features of spatial functioning more palpable. It combines scientific reasoning into the creative process. Architects extensively overlook this attribute since it is more analytical and mathematical since it associates study and architecture by providing a language for thought about and articulating the space experienced. However it broadens the line of thought and raises issues that prompt revision and effective design.

Understanding the complex relationship between the mind and the physical world is very important while designing for an urban area and this also is an important topic in terms of spatial syntax. Environmental stimulus, being a major part of the reaction that any human provides to any space is basically the response given, which is further followed by an activity. The built environment's visibility and mobility affordances, which allow for precise distance measurement based on human perception and cognition, too helps the human mind to map their preferred routes. The connections between a city's form and the type of emotions and aura it gives play a major role in the cognitive process and the options. A reduced nature in the pathway of any individual is said to lower emotional and cognitive thinking. This creates a new normal in the type of resources available. A sustainably designed urban outlook is thus required for any spatial syntax to stay in place with development. There is a conception of how people and their surroundings interact that keeps them in line with the modernist urbanism pattern. Thus cognitive affordance is achieved, which is both the result of human perception and their reaction to the design around them.

Despite having its advantages there are certain limitations to space syntax as well. It was mostly criticised for lacking 3D information and failing to consider factors influencing the urban structure, such as transportation hubs and commercial districts. There were also concerns regarding the metric properties not being taken into consideration for the calculations. But, Segment length, angular deviation, and metric radii were also added to the calculations during the 5th International Space Syntax Symposium, considerably resolving the issues. (Yamu, Akkelies Van Nes and Chiara Garau, 2021)

CONTEXT

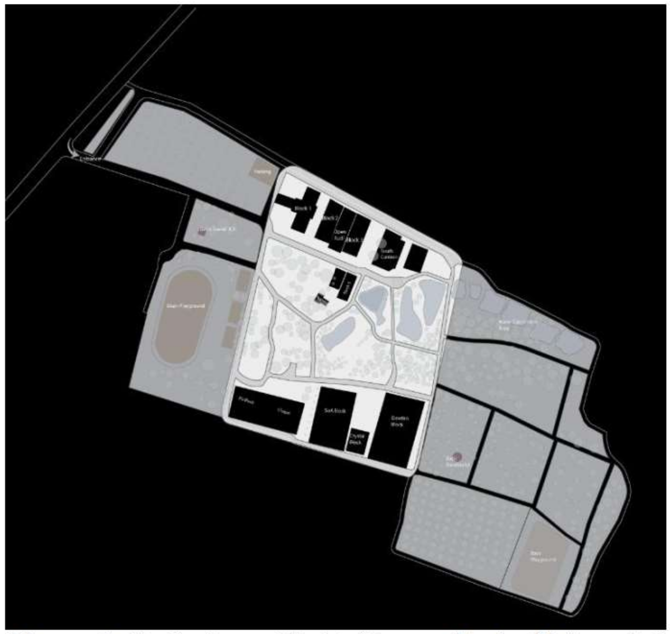


Figure 1. Study Area- Christ (Deemed to be University)

The case study chosen is Christ (Deemed to be University) in Kengeri, Bangalore. It is located in the outskirts of Bangalore, having ample transportation facilities. It is a spacious campus, offering courses in the areas of science, business, and arts. It is renowned for its structure and instructional methods. The campus location has distinct wet and dry seasons because it is situated in a tropical savannah climate zone.

However, the area provides plenty of room for relaxation and other recreational uses because it has a greener side. The individuals who access the campus, the students, and their modes of access, as well as their physical configuration and connectedness of various locations, will determine the study's setting. There has always been a trend in the decision the students make regarding their route plans, which is why this place was chosen. This study is done to identify the trends in these Movement patterns and safety of the campus by understanding the behavioural reasoning and the campus planning.

METHODOLOGY

The major methods that we shall be using to study the area are:

Axial analysis: It makes use of the topological space representation known as an axial line, based on the number of axial lines, distance from one line to the next, in steps (Charalambous and Mavridou, 2012). For Axial analysis, a set of maps with respect to to the context shall be made. They shall represent the major spatial usage of the area based on various parameters. Some of the major maps that shall be made are Axial Maps, the convex maps, Grid basis map for Visual Graphic analysis (VGA). The axial map can be used to do axial integration analysis while also creating a justified map of the same. The justified map shall show the connectivity and the depth of a node.

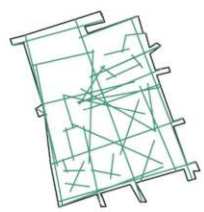


Figure 2. Axial Mapping

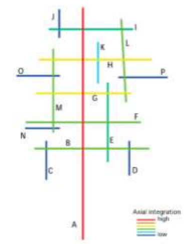


Figure 3. Axial Integration Map

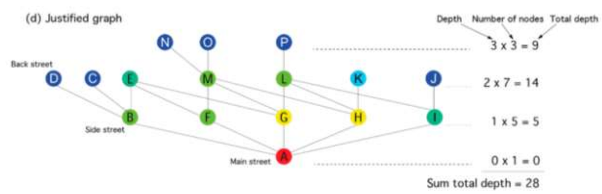


Figure 4. Justified map
Source: (Yamu, Akkelies Van Nes and Chiara Garau, 2021)

Student Survey: A set of 20 questions were asked in a form that was floated out to all the students who are using the campus. A sample of 260 student responses were received to be analysed.

Visual Mapping: As a part of this we went around the campus at different times to map the nodes and most used congregation spots. This data shall be assembled in a series of plans for better understanding.

Existing Safety Measures: Day lighting and artificial lighting along with the paths taken by the security guards on a patrol and location of surveillance areas in the vicinity help us understand the extra measures taken by the institution to maintain safety which goes slightly beyond campus planning.

All these data shall be put together and correlated to each other to have a better understanding and analyse it in an easier manner. By relating the axial Mapping to the visual apping we can understand the connectivity and visual fields in the campus. Other data collected manually by survey shall be linked to the data found by mapping to understand how the campus works as a system to maintain the safety as well.

DATA COLLECTION

Axial Analysis

As a part of axial analysis, axial mapping, connectivity, justified graph, integration chart, visibility field are done. Each of their description and analysis is as given below:

Axial Mapping

There are 75 roads in the campus. Most of them are interlinked and connect the major nodes to each other. This is a high resolution map, i.e., a high-resolution model, or pedestrian model, involves the study of the precise paths of pedestrian movement. (Yamu, Akkelies Van Nes and Chiara Garau, 2021). Through the map we can identify that the central area where the major structures are located, is very well connected by smaller pathways.

Figure 5. Axial Mapping

Axial Integration

This measure considers one way movement and estimates the degree of accessibility that a street has to all other streets in the urban system, taking into consideration the total number of direction changes (syntactic steps) of an urban entity (Yamu, Akkelies Van Nes and Chiara Garau, 2021). By using axial integration we can understand the depth and connectivity of an area. The length of the line shows the depth, and is directly proportional to the connectivity and the integration of the area. Figure 6 shows the axial integration mapping for the case study area. Here, the Darkness of the stroke of each path depicts its depth and connectivity, i.e., The Darkness is directly proportional to the depth.

Figure 6. Axial Integration Mapping

Connectivity

Connectivity is a static local measure and explains the number of connections that each street has to its direct neighbouring streets.(Yamu, Akkelies Van Nes and Chiara Garau, 2021) **Figure 7** attached below shows the connectivity of the paths in the campus. The red paths are well connected while blue paths are least connected. From this, we can see that the campus is well connected towards the entrance while the rear part is less connected. The central area of the campus where most student activities are conducted or happen, is the most well connected part of the campus.

Figure 7. Connectivity

Justified Graph

The relation between connectivity and integration can be verified using the justified graph as well. There are 5 levels or depths of paths in the campus as seen in **Figure 8**. On closer observation, it can be noticed that most of the connections are diamond or ring patterns. The branched pattern offers a definite set of potential relations between community and privacy and many more resources against intrusion. The idea of the diamond shape is that space use is normally concentrated within this diamond shape, the corners commonly being reserved for objects. (Hillier, 2017) The diamond rings configuration seen in the j-graph show the depth and the connectivity between spaces of the same depth. The huge number of rings as seen in the graph shows how well the paths are integrated as well.

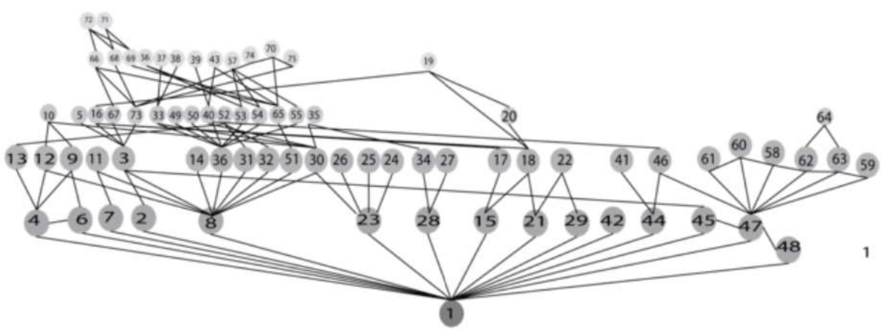


Figure 8. Justified Graph

Visual Mapping

Experts consider normal, or healthy, visual acuity to be 20/20 vision. That simply means that you can clearly see something 20 feet away that you should be able to see from that distance.(Harkin, 2012). Convex Maps are another type of map that can be used to show visible connectivity between areas. Since the campus chosen has high visibility across areas, a convex map could not be made.

The major nodes in the campus have a visibility of at least 20ft radius within the campus. All the green areas are trimmed and maintained regularly. A study conducted by Hillier and colleagues Eva Freidrich and Alain Chiaradia compare incidents of antisocial behaviour, measured in occurrences of violence, theft, graffiti, property damage and dumping, to axial map measures of integration and choice, and different block structures. The report concludes that the two factors; movement and inter-visibility effectively combat these incidents.(Ottenby, 2017) From the axial mapping analysis done above, we can conclude that the campus is very well integrated and connected at the central area and less connected towards the rear end. In Spite of the less connectivity, the visibility field is high. Figure 12 and 13 show the back playground and the back bandstand which are both noted as the loneliest spots in the campus. In these areas, the planning of the campus plays a minor role and the management of the area using additional security takes a major stand.

Figure 9. Bandstand

Figure 10. Through the doors of ground floor in Block 1.

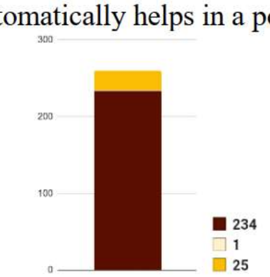
Figure 11. Back Playground

Figure 12. Back Bandstand

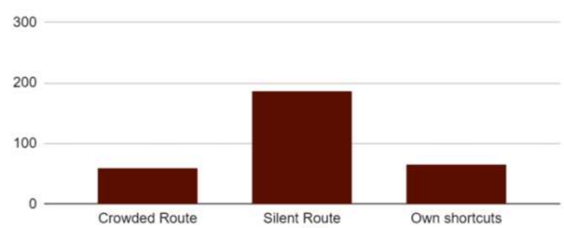
DATA ANALYSIS AND VISUAL MAPPING

The further analysis is regarding a survey, which was initiated by floating forms for the user groups- the students, from all programs and semesters. A total of 260 responses was received which is about 5% of the total population of the user group. The data collected was analysed as follows:

The initial safety, as per general awareness begins at the campus itself. **Figure 13. (i)** Shows the ratio of the likeness factor, taken from the 260 responses. The fondness scale is directly proportional to the safety scale, which automatically helps in a positive effect over mental health.(Yee, 2019)



(i)



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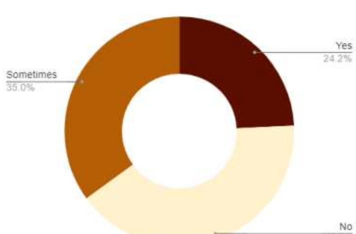
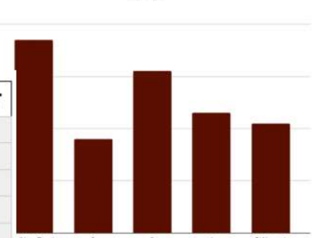


(iii)

SCALE	COUNT
1 (Very Rare)	74
2	36
3	62
4	46
5(Always)	42



(iv)

Figure 13(ii) shows the preference of the user groups regarding their choice in movement, whether they prefer going in groups, or moving around by themselves. **Figure 13(iii)** shows the route preference when it is dark either due to climatic factors or time period. By analysing the graphs, it is seen that people don't really prefer taking a different route during the night, or in the evenings. This shows how the user groups are very accustomed to the various existing routes. Along with the known factor of prevailing darkness in the locations where nature and a lot of greenery is prevalent, this gives an additional detail of an ample amount of light sources available in the roads, for a proper visual comfort and as an urban amenity.

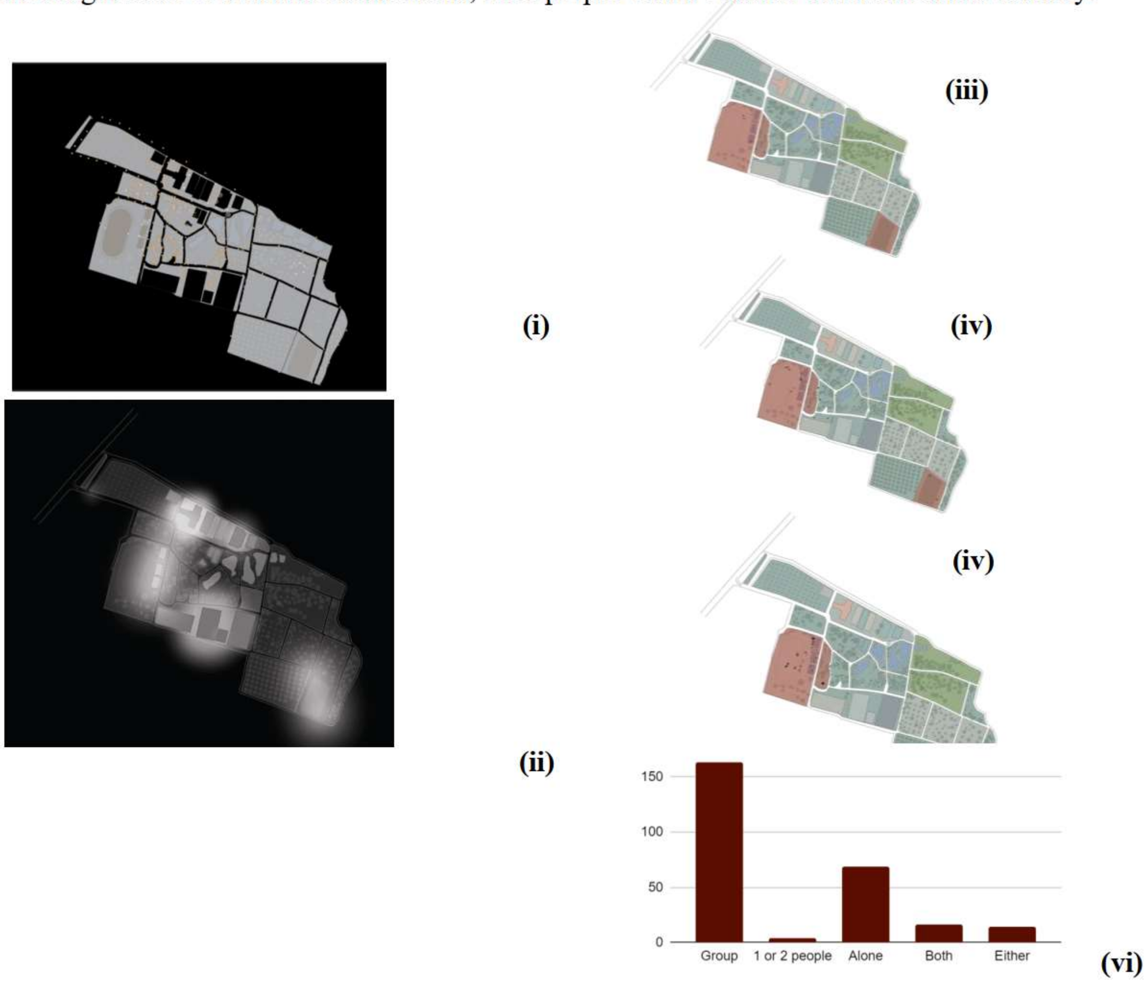


Figure 14(I) Street Light mapping; **Figure 14(ii)**Light intensity; **Figure 14(iii)** Visual Analysis at 9am; **Figure 14(iv)** Visual Analysis at 1pm; **Figure 14(v)** Visual Analysis at 4pm; **Figure 14(vi)** Visual Analysis at 6pm; **Figure 14(vii)**Graph of movement preference

Figure 14(i) shows the scattered nature of the street lights, providing good security and safety. It is located in every corner of the building, the pathways and even the unused spaces. Yet, the collected data shows a certain set of people avoiding the denser paths and preferring a well-lit route connecting the Level 1 roads, while accessing them just in groups. The more vibrant happenings in the main connectivity roads provide a sense of social belongingness, which might be a reason why few might choose it and have a better network with both the people and the events. In fact, various other researches prove that increased route familiarity results in increased automaticity and decreased attention towards the road, which would make the light source a necessity, rather than a need. (Harms, 2022) The front ground, the rear ground, and the vicinity around the PU block are three major areas of the campus that most individuals believe to be isolated, per the survey depicted in **Figure15**.

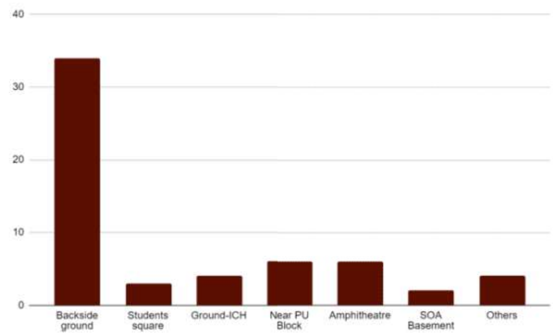


Figure 15. Isolated Areas

Many factors, some of which may be connected to spatial syntax, contribute to the particular feelings these environments evoke. Despite being situated close to the main building of the university, the front ground feels isolated, according to the survey. This is because the space's functionality differs greatly from that of the other building blocks, even though it is not necessary to operate at a specific time because it is a college campus and sporting events only happen during specific hours. As can be seen from the aforementioned statistics, the number of individuals visiting this spot fluctuates, leading most people to believe that it is lonely.

When it comes to the area around the pu block, it is once more thought to be lonesome due to the isolated nature of the building, the limited number of pupils that go there, and the degree to which those who are enrolled in the particular course are cut off from the rest of the campus. The area is primarily known for its spectacular views, and there aren't many things to do to keep people entertained here. There is no room for discussion when it comes to safety because the area is well-lit and guards actively safeguard it.

In terms of setting and layout, the area itself feels rather detached from the broader campus. Unless they have been wandering the campus for some time, individuals would not frequently be aware of the spot. The fact that a place for leisure that not many people visit is frequently adored by a large number of groups brings about both the positives and cons of such situations. In fact, students spend a lot of time doing sports by themselves in the evenings as a respite from the hectic college schedule. The disadvantage is that the area is open to the sky and has adequate illumination, but at night it appears to be under lit and less secure due to the amount of openness and the proximity of the other blocks in general, which gives a sense of less secured sensation, which is why individuals have dubbed the site solitary.

CONCLUSION

A campus has to be safe for students to feel comfortable using the areas in and around it and to study there peacefully. Safety of an area is not solely dependent on the planning but on the management as well. In this case, the additional safety precautions taken are in the form of proper artificial lighting during the evenings, security guards on patrol and surveillance cameras. The responses received in the survey and the data collected using axial and visual mapping are synonymous to each other. Hence, this proves that the case study chosen here proves to be adequately safe for the students. Space syntax is a tool that can not only be used to check the safety of a place but also used to design a safe place. The methods used in this study can be used to facilitate and make this process easier.

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from the students of various programs. So we sincerely thank them for spending their precious moments in filling our survey.

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EXPLORING THE IMPACT OF BUILDING DESIGN ON THE LEVEL OF STUDENTS' ENGAGEMENT WITH THE COURTYARD – A PILOT STUDY

Maali, Rua[1]; Al Niyadi, Sheikha[2]; Agiel, Ahmed[3,*]

[1] Master student, Architectural Engineering, United Arab Emirates University, UAE, 201640003@uaeu.ac.ae

[2] Master student, Architectural Engineering, United Arab Emirates University, UAE, 700038386@uaeu.ac.ae

[3] Assistant Professor, Architectural Engineering Department, United Arab Emirates University, UAE, a.agiel@uaeu.ac.ae

ABSTRACT

Students suffer a daily routine of pressure and stress while they are at a critical stage of development of their bodies and minds. In this regard, natural spaces can provide a suitable environment for users' engagement with nature. It can also create a health-supportive and sustainable environment to improve the quality of users' daily lives and promote educational quality. However, buildings are not always well integrated with the surrounding natural environment. We hypothesize that the arrangement of interior spaces surrounding the courtyards impact the level of users' engagement. The aim of this research is to study how university users perceive the campus' courtyard at the United Arab Emirates University (UAEU) and how those courtyards are beneficial for human's health and wellbeing. A sample of students was selected to examine three building courtyards in the UAEU campus. Participants were asked to make some choices regarding the outdoor spaces that they would enjoy visiting. Ethnographic interviews were used to trigger the emotional experience of the courtyard users. The study started with site description that was developed including sketch map of the courtyards. Two colour photographs of the area which helped in triggering the responses, and a descriptive text of the physical characteristics of the courtyards. The engagement of the participants was collected, reported, and analysed. Findings of this study showed that paying attention to the courtyard design and its surrounding space arrangements and how it can play a vital role in impacting users' engagement with the nature. The outcome of this study provides design feedbacks to architects and urban planners which will develop a better concept of the courtyards to enhance health benefits and create a healthier environment.

Keywords: Cognitive Engagement, Self-reported, Well-being, Ethnographic interviews

INTRODUCTION

Courtyards have existed for as long as people have been building houses from the countryside of Europe to ancient China due to their purpose of creating a relaxing space, inviting natural light, and encouraging air movement. A "Courtyard" is a building element that emerged not only in hot and dry climates for climate reasons but also for coulure and social activities. It is a fenced-in space that is open to the sky and is bordered by a building or wall. Courtyards were frequently used for various activities like as gardening, cooking, working, playing, sleeping, and even keeping animals in some situations. (Edwards at el.,2006). Mishra & Ramgopal (2013) also defined the courtyard as a room with a view of the sky, shaped like a square or rectangle and surrounded by several buildings or the most important rooms. Moreover, Reynolds (2002) defined courtyards as outside yet almost inside spaces that are open to the sky, usually in contact with the soil, but surrounded by rooms. The courtyards are deeply connected to the rooms around them, acting as a conduit and a filter for daylight, night darkness, wind, rain, and sound. The use of courtyards in the Arab world isn't only to bring some light and fresh air, but it's an architectural reflection of a rich culture that has influenced civilizations beyond their boundaries and has transcended decades.

Despite of the harsh weather conditions outside, the building should keep its people physiologically comfortable within the used spaces. In this regard, a courtyard within a building offers a lot of options in terms of establishing internal passive zones in buildings and hence passive architecture. A courtyard can give security, privacy, and a relaxing environment within the building. It does not only provide a pleasant environment and a lovely setting, but it also serves as a private and isolated place through which all the rooms clustered around it enjoy natural light, ventilation, and visual and physical communication. (Tabesh& Sertyesilisik, 2015)

Integrating a courtyard in a building can play a vital role in creating a connection between the outdoor and the indoor environment of a building. It allows for more flexibility in creating larger internal zones that benefit from natural ventilation and daylight. An outcome of this integration can be represented by the interior rooms and lobbies that will be provided by natural light and privacy from courtyards (Chahal at el., 2018). Hence, architects could include healing elements of nature into courtyards inside the building footprint, as well as windows at the ends of hallways to allow natural light to filter into public and private rooms. Lau & Yang (2009) concluded in their research that providing a courtyard enhances user experiences such as visual connection, privacy and security, and transparency from indoor to outdoor.

Architects frequently use the courtyard as an architectural design element in their buildings since a courtyard is a traditional design element that has been used for centuries. To establish a successful oriented courtyard that responds to human needs, design variables such as area, number of levels, orientation, exposure, types of walls, and many others must be incorporated (Almhafdy at el., 2013). In this study, we hypothesize that the arrangement of interior spaces surrounding the courtyards impacts the level of users' engagement.

METHODOLOGY

The research methodology includes testing sample of students that were selected to examine multiple building courtyards in the UAEU campus. The sampling method used in this study is the Convenience Sampling Method. Participants made some choices regarding the outdoor spaces that they would enjoy visiting. An Ethnographic Interview was used to trigger the emotional experience of the courtyard users see Table 1. The testing started with several site descriptions that were developed according to the UAEU campus map that shows the location of the courtyards see Figure 1. Then, photographs of the area were shown to the participants to help in triggering the responses along with a descriptive text of the physical characteristics of the courtyards. During that, several questions were asked regarding the participant's opinion on the privacy, type of activities they participate in, what they like and dislike about the design of the courtyard, etc. The engagement of the participants was collected, reported, and analyzed.

Figure 1: UAEU Map

Table 1: Methodology Stages

Methodology	
Stage 1	Photos of the courtyards were taken, and plans were collected.
Stage 2	Sample of 7 students were selected.
Stage 3	An interview was structured to elicit the participants' response.
Stage 4	Photos of the area were shown to the participants to help in triggering the responses while asking questions.
Stage 5	The feedback of the participants was collected, reported, and analyzed.
Stage 6	We produced the parameters that affect the user engagement.

Case study description

The Campus of the UAEU has several courtyards that are within its colleges' buildings. The addition of these courtyards was to harvest daylight, to improve visual comfort, and to reduce the electricity utilization coming from electrical lighting in the spaces that has a view to the courtyard. The courtyards in the UAEU female campus that were studied are the enclosed type. They don't have a specific shape, for instance, the C6 Building courtyard has a triangular shape as shown in figure 2 (a) while the courtyards in C4 and C5 buildings has a more of a rectangular shape as shown in figure 2 (b and c).

Figure 2 (a) C6 Building Courtyard

Figure 2 (b) C5 Building Courtyard

Figure 2 (c) C4 Building Courtyard

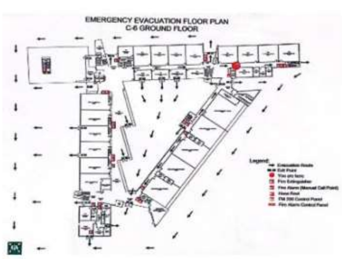

Figure 3 (a) C6 Building Plan

Figure 3 (b) C5 Building Plan

Figure 3 (c) C4 Building Plan

The C6 building courtyard space consists of grass surfaces, trees, walking paths, and shaded seating areas. As shown in Figure 3 (a), the building's plan shows that the triangular courtyard is surrounded by lobbies from all sides. On the other hands, the C4 and the C5 buildings' courtyards almost have the same structure and organization. They consist of grass surfaces, water features, walking paths, and very limited seating areas that aren't shaded. The rectangular courtyards are surrounded by classrooms and very short lobbies that consists of the entrance/exit doors as shown in figure 3 (b and c).

Data collection

For this study, online interviews were carried out at a duration of two weeks. Before performing the interview, interview questions were tested and revised several times for improvements to ensure getting more accurate responses from the participants. Moreover, during the interview, questions were translated to the local language when it was needed for proper execution. A total of 7 interviews were administrated to 7 voluntary female students.

Content of the interview

Since there were very limited previous papers studying in specific the impact of space arrangement of a building and its relationship with the courtyard, the interview questions were developed based on the literature that was grasped previously in the paper, which was reflected in the questions. The interview comprised of 20 questions that were divided into 4 sections based on their criteria as shown in Table 2.

Table 2: Interview questions.

(1) Space Recognition	
	Which Major did you study in this university?
	Have you taken classes at any of these 3 buildings?
	Do you recognize the courtyards that are shown in the pictures?
(2) Perception	
Users' perception of the physical design	Do the features of the courtyard communicate its function clearly?
	Are there enough seating areas for you to enjoy the experience of the courtyard?
	What do you like/ dislike about the design?
	Have you noticed any repeated patterns among the university's courtyards?
(3) Experience	
Users' experience in the UAEU courtyards	What's the shortest and longest period of time have you spent in the courtyard?
	What do you enjoy about visiting the university's courtyard?
	What kinds of activities do you enjoy from being part of while being in the courtyard?
(4) Satisfaction	
Users' satisfaction on the courtyards' design quality	Do you enjoy visiting the courtyard?
	Does the design of the courtyard meet your needs?
	What specific function does the courtyard fail to meet?
	Is there enough/ clear entrance/exist to the courtyards?
	Does the courtyard provide enough lighting to the surrounding spaces?
(5) Space Arrangement	
Users' perception of the engagement between the indoor and outdoor	What type of spaces are the buildings' courtyard surrounded with?
	Do you think that having the courtyard surrounded by a lobby provides more privacy? Or having a classroom/ office?
	What would you rate the level of engagement between the indoor spaces and the courtyard? (Low, Average, High)
	Is the barrier (Windows/curtain wall) between the indoor spaces and the courtyards provides enough transparency?
	What features can be added that can help in reducing heat gain inside the surrounding spaces of a courtyards?

FINDING AND DISCUSSION

Three courtyards were investigated to study the impact of space arrangement on the users' experience and their preferences in the UAEU female campus see figure 1 for interview questions summary.

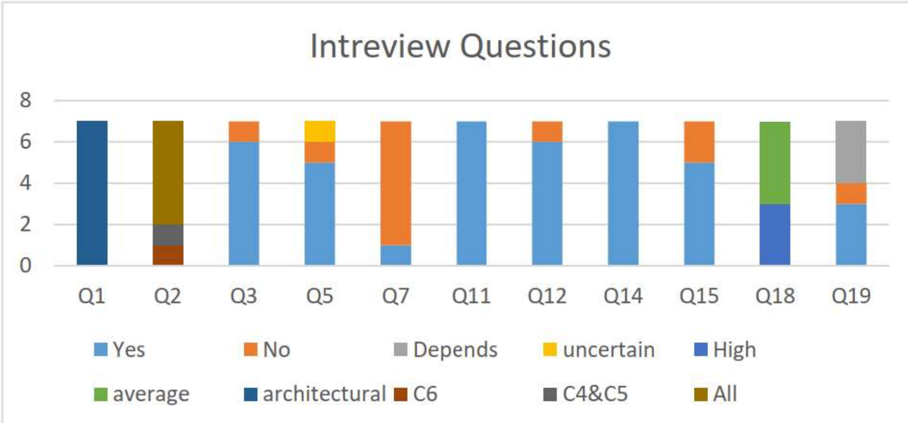

Figure 1. Interview Questions.

Space Recognition

For testing the knowledge of the participants and as an introduction to the interview, the students were asked several questions such as if they took any classes in the buildings surrounding the courtyards being studied or if they recognize the courtyards that were shown during the interview.

Through the detailed interview of 7 participants that were selected through a mutual relation with the interviewer, all of them stated that they are studying or studied architectural engineering in the UAEU female campus. After being asked if they had taken any classes in the 3 buildings that were selected for this study, (71.4 %, n=5 of total participants) answered that they had taken classes in all buildings, (14.3%, n=1 of total participants) had taken classes in only C5 and C6 buildings, and (14.3%, n=1) had taken classes only in the C6 building since she didn't take any general requirements. The final question in this section was asking about their recognition of these courtyards when they were only shown the UAEU courtyards' map. The result was that (85.7%, n=6 of all participants) did recognize the courtyards while only (14.3%, n=1 of total participants) was confused about where these courtyards were located within the campus, this can be related to the fact that she didn't take any classes in the C4 nor the C5 buildings.

Users' Perception of the Physical Design

For understanding the Users' perception of the physical design of the campus courtyards, several questions were asked among the users. This present study found that all participants think that the courtyards' features clearly communicate their function. To be specific the C6 courtyard had the most positive comments that circle around its use for college events, how its features clearly served student gatherings and activities, and the students using it for walking purposes instead of using the crowdy lobbies of the building. While the C4 and C5 were described as showing only features of greenery without a noticeable use of them. Another question that was asked during the interview was whether the students think there is enough seating areas for them to enjoy the experience of the courtyards and the answers were mostly positive. (71.4%, n=5 of total participants) stated that there are enough seating areas withing the 3 courtyards, (14.3%, n=1 of total participants) explained how she thinks that the C4 building courtyard doesn't have enough seating areas even though most students use that building, and (14.3%, n=1 of total participants) was uncertain of the seating situation since she spent most of her university years studying in the C6 building. The final question in this category is required more details about their thoughts on what they like and dislike about the design of the courtyards. The students' perspective of a good courtyard design was it having greenery, shaded seating areas, unique shapes like the triangular shaped courtyard within the C6 building. On the other hand, a bad courtyard design that not considering how uncomfortable it can get during the sunny timing of the day and not providing any solutions for that, not having well-divided spaces around it, limited seating areas, and a design that isn't suitable to be used for university events.

Users' experience in the UAEU courtyards

All respondents (N=7) who were spending time in the UAEU campus courtyards were asked about their feelings and experience. First, the students were asked about the time they spend there, and the range of answers was between 5min and up to an hour. As of what was noticed, their answered varied depending mostly on the weather and the time of the day. To be more specific, students tend to spend less time during summer season and during night-time since there aren't many lights available. Then they were asked about what they specifically go to the courtyard to enjoy, and the answers seem like they varied but in fact they were all connected. From their perception, the courtyard gives them a nice view since it consists of green areas. Some students like to take advantage of that and enjoy walking through its pathways, which also lifts the tension off their body and dissociate them from university stress. Then this category was concluded by asking them about the activities they like to be a part of while being in the courtyard. (42.9%, n=3 of total participants) enjoy walking to release stress and breathe some fresh air, and (57.1%, n=4 of total participants) enjoy sitting and spending time with their friends.

Users' Satisfaction on the Courtyards' Design Quality

In addition to their experience, the respondents were also asked about their satisfaction level on the courtyard design quality and how it can be improved. First, they were asked whether they enjoy visiting the courtyards, which was answered with a yes by all participants. They agreed that it enhances their communication with their friends since they can meet there, it is a nice addition to the university, and it acts like an escape space to get some fresh air. Some of them referred again to the weather as a factor that affects their enjoyment. The second question was testing whether the design of the courtyard meets their needs or not. (85.7%, n=6 of all participants) answered it by yes since it has seats, plants and flowers, nice air breeze, and it's easily accessible. On the other hand, (14.3%, n=1 of all participants) doesn't find the courtyards' design to be meeting their needs since it didn't help with the hot weather in the UAE which leads students to feel the need to use the courtyards in specific timings to avoid the burning sunrays. Having clear and noticeable entrances and exits to the courtyard can play a vital role in affecting the users' engagement. All participants agreed that the three courtyards have clear and enough entrances and exists. Furthermore, the participants were asked about what specific functions does the courtyard fail to meet, (57.1 %, n=4 of all participants) think that some of them lack privacy and shading, to be specific a participant mentioned how the lack of shading led to thermal discomfort because of the direct sunlight on the lobby which made it warmer, (28.6%, n=2 of all participants) think that the courtyard doesn't fail to meet any function, and (14.3%, n=1 of all participants) thinks that the lack of lights at night led to lack of usage. Finally, the participants were asked whether they think the courtyard provides enough lighting for the surrounding spaces, (71.4%, n=5 of all participants) answered it by yes with mentioning that the university still uses the artificial lighting even during the daytime. (28.6%, n=2 of all participants) think that there isn't enough lighting, it was explained that the C5 and C4 building are not that dependent on the natural lighting coming from the courtyard and she noticed that the lobby area isn't that well-lit.

Users' Perception of the Engagement Between the Indoor and Outdoor

For testing the main aim of this study, the participants were asked about their perception of the engagement between the indoor and the outdoor. They were first shown the buildings' plans and were asked whether they think having a courtyard surrounded by a lobby provides more privacy than when it's surrounded by classrooms. (85.7%, n=6 of all participants) believes that having a lobby would provide more privacy for the students. Having transparent windows will not provide privacy for the students inside the classrooms, a courtyard can be a distracting element during classes, and having classrooms surrounding the courtyard will make people feel like they're being watched while using the courtyard. On the other hand, (14.3%, n=1 of all participants) thinks that a classroom would be a more private option it also helps in changing the students' mood. Then, students rated the level of engagement between the indoor and outdoor, (57.1%, n=4 of all participants) rated it as "average" and (42.9%, n=3 of all participants) rated it as "high". Then, participants were asked a question for the sake of discussing whether the barrier (windows/curtain wall) between the indoor and courtyard provides enough transparency. (42.9%, n=3 of all participants) voted "yes", (42.9%, n=3 of all participants) voted that it depends on the time of the day, and (14.3%, n=1 of all participants) voted “no”. The final question of this interview was asked for the sake of improvements and the students suggested several ideas that the university can easily apply. The students suggested the university to add more water features to enhance the air temperature in the courtyard, add more plants near the curtain walls, to have less glass area to allow less heat and direct sunlight, more shading devices in the C4 and C5 buildings’ courtyards, and to use better windows/ curtain wall types like double glass.

User engagement parameters with courtyard.

The above data and discussions supported the user engagement parameters we reviewed in the literature and showed the important of the physical design and design quality of the spaces surrounding the courtyard could improve the user engagement with this space see table 3.

Table 3: User engagement parameters with courtyard.

Parameters	Literature Parameters	Interview Parameters
Greenery	✓	✓
Space Design and Arrangement	✓	✓
Design/Landscape Elements (flower boarders, textured plants, scented plants, and colorful plants)	✓	✓
Circulation	✓	✓
Privacy	✓	
Microclimate (temperature & light)	✓	✓
Engagement Between the Indoor and Outdoor	✓	✓
Physical Design		✓
Design Quality		✓

CONCLUSION

This paper illustrates a research effort that contributes toward understanding the impact of spaces arrangement located around the courtyards of the UAEU campus on the satisfaction level and users’ engagement. It concludes that understanding how the environment, including design and implementation, landscape elements, and space arrangement, impacted how users perceived and experienced the space and their expressed satisfaction levels. These findings offer architects and landscape architects insight into what to consider when designing future buildings with a large courtyard garden in a hot arid climate.

The findings of this research contribute to the design of campus courtyards in hot, dry regions. One of the courtyards’ purposes is to enhance the temperature for the building users. However, one of the more critical purposes is the users’ engagement with the space since it can affect their mental health and wellness.

Based on previous studies, the positive impact of courtyards on students’ learning performance is well reported. This study identified some fundamental courtyard physical and climatic factors that influence the users’ involvement in courtyard spaces. The impact of space arrangement can be noticed in the interview when students preferred a specific space surrounding the courtyard since it gave them a sense of privacy. The courtyard design demonstrated the importance of understanding the performance of the space depending on its surrounding spaces.

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EVALUATING THE ELEMENTS IN THE RECREATIONAL SPACE OF AN INSTITUTION

Eshitha Iyer[1], Ayra Badrudeen[1] Abinaya J[2], Nesin Sibin Mathew[3]

[1] Student, CHRIST University, Bangalore, India (eshitha.iyer@barch.christuniversity.in)
[1] Student, CHRIST University, Bangalore, India (ayra.badrudeen@barch.christuniversity.in)
[2] Assistant Professor, School of Architecture, CHRIST University, India (ar.abijay1011@gmail.com)
[3] Assistant Professor (Neurophysiology), Department of Psychology, CHRIST University, India (nesin.mathew@christuniversity.in)

ABSTRACT

The concept of 'Recreation' justifies the human need for satisfaction, leisure, and a state of pleasure. The elements involved in a recreational space impact the activities of the user in that space. Recreational spaces act as the in-between sojourns for formal pedagogy or andragogy. Spaces of recreation are essential, especially in educational institutions, where students spend most of their time. Public, semi-public, and private spaces are all included in the institutional design, with a large percentage used by students. Open public spaces, including recreational places, are measured in terms of their physical characteristics and connections to nature. The components of a recreational area influence the activities that users engage in there. This paper seeks to list and assess the many components that are present in a recreational space. This study will evaluate those elements and their types. Informal outdoor areas or other breakout areas promote interaction and provide the students with refreshments and leisure. The focus of this paper is to draw out the quality of leisure space synonymous with a productive environment for the student, where they feel rejuvenated. Five recreational spaces of CHRIST University were studied, and the elements that combine to form this place were also observed. A survey among the students who are frequent users of these spaces was conducted, and their responses were evaluated. The elements that majorly help students go to a place were assessed, and the element's significant role was concluded. The result of this study to design professionals is to understand the need to incorporate recreational spaces while designing an educational institution and design a student-oriented space.

Keywords: Recreational Space, Student Life, Institution Design, Open Space

INTRODUCTION

An institution is a place for the wholesome development of students. An institution provides a base for academic recognition of the student and motivates them to reach higher goals (van den Bogerd *et al.*, 2020a). Every campus needs open public spaces or break-out spaces accessible for leisure. The institutional design has public, semi-public, and private spaces, much of which involve areas utilized by students. The physical aspect and connection with nature quantify the open public spaces inclusive recreational spaces.

The mental well-being of the students is noted to enhance social behaviours. Informal outdoor spaces or breakout spaces help in interaction and create meaningful spaces for students. However, in a larger social context, open spaces are multi-useful spaces reflecting the people's culture and way of life (van den Bogerd *et al.*, 2020b). Open spaces have worked as people's way of connecting with other people through meeting and greeting, and have sparked conversations. It has been understood that open spaces and recreational spaces are sometimes used synonymously. Recreational spaces act as the in-between stops for formal pedagogy (Adedayo, 2018). Previously, when gadgets were not so popular among children, they would resort to spending their time outdoors. The ancient means of learning and teaching as brought in by the *gurukul system,* classes were conducted outdoors. The global pandemic of 2020, COVID-19, has densified stress levels in everyone, including students. Anxiety and other mental issues have started prevailing, hence the need to introduce a recreational space for relaxing and unwinding is unprecedented. The Covid-19 pandemic has substantially increased the demand for public open space in times of distress and fear brought on by household confinement, the economic downturn, and income losses (Marcelo *et al.*, 2022). People are exposed to worldly news and gather all types of information, and the fragile mind of a student tends to build upon the negative lumps. Recreational areas should offer green spaces where people can gather, fostering a sense of camaraderie among students and enhancing the social aspect of life. These facilities not only give students a great place to unwind with their groups, but they also tempt them to pick the areas closer to classrooms, or places of study. (Tambe, 2018)

The elements involved in a recreational space impact the activities of the user in that space. These recreational spaces should not be entirely disconnected from the formal learning spaces, yet be well connected to not be a distraction. How can an element play a role in defining a recreational space of an institution? This paper identifies and evaluates several elements that integrate and make up a recreational space. The paper aims to assess the features present in recreational spaces and the nature of such elements.
LITERATURE REVIEW

Outdoor Learning and Healthy Campus

Universities have spaces for recreation within the institution. In the digital era of education, it has become meaningful to design recreational spaces (Fournier and Grey, 2000), especially for students in the post-COVID era. Students could be seated with their gadgets wherever, but a break from studies is also required. However, such usage of gadgets has made learning in an institution multidimensional. (Ratnasari, D., and Haryanto, 2019). However, outdoor learning environments have significantly higher rates of improving a student's intellectual skills compared to a mundane indoor classroom environment.

The architecture of an open area greatly impacts how students feel about educational institutions, which is why it's so important for learning. Attractive open areas increase students' chances to mentally recharge in between lessons, improving their performance in the classroom. Additionally, open areas offer a location for physical movement and amusement that aids in reducing bad emotions brought on by the stress of continuous studying. (Farag, Badawi and Doheim, 2019).

Green Campus

Students can reflect on their experiences and perhaps gain a better sense of identity by spending time in nature. Natural environments give students a place to engage in social interactions, but they also encourage retreat behaviours by facilitating "being away" and freeing them from the constraints of school or college (Puhakka, 2021). Greenery decreases radiation, boosts the chemical composition of the air, and prevents surfaces paved in asphalt from scorching. It restores, regenerates, and rejuvenates man in both physical and mental dimensions through its colour and aroma (Mitkovic and Bogdanovic, 2004).

Many university campuses include open spaces as a fundamental component. Universities with beautiful green spaces frequently highlight these as qualities that enhance the student experience and the university's reputation(Speake, Edmondson, and Nawaz, 2013). Participation of students in outdoor activities other than the usual class contact hours has proven to alleviate stress levels. According to studies, giving youngsters access to elements of "nature," "refuge," and "prospect" in UGSs or Urban Green Spaces may have restorative effects and enhance their mental health. (Akpınar, 2021)

Recreation Spaces

The concept of 'Recreation' justifies the human need for satisfaction, leisure, and a state of pleasure. Recreation space is where a person would relax after a whole day's activity or any excursion. King et al., 2006 quoted that there are 2 main types of recreation: Passive and Active. The facilities such as playgrounds, fields, basketball courts, etc., are categorized under Active Recreational Spaces. The Passive Recreational

Spaces are natural forms and encourage activities like mountaineering, hiking, wildlife viewing, etc. It is recommended to have a landscape with a leisure setting since it not only offers time away from academics but also offers better environmental quality for the development of the campus image. These areas ought to be considered the primary ones as the university landscape develops. Additionally, by using the chosen spaces, a landscape design that takes into account students' preferences may boost their satisfaction and strengthen positive values. (Mt Akhir *et al.*, 2017)

Campus Life

These spaces can be both indoor and outdoor built spaces and facilities that enable communication and exchange of ideas. The preference of the user matters in the design of recreation space, especially, if the users are students. Most users tend to be relatively conservative and pragmatic to their preference of space to be used. The usage of various open spaces identifies why a space becomes meaningful to the users, simultaneously understanding the elements or the features contributing to this relatively conservative feature of the user to that space. (Hanan, 2013)

THE CONTEXTUAL STUDY: CASE OF CHRIST (DEEMED TO BE) UNIVERSITY, KENGERI CAMPUS

Location

Bangalore-Mysore highway, Karnataka, India

About

The Kengeri Campus of CHRIST (Deemed to be University) has a lush green campus of 78.5 acres. This modern campus has playgrounds and other sporting facilities. Several recreational spaces here include
Amphitheatre (Fig. 2a)
Basketball Court (Fig. 2b)
Open Air Auditorium (Fig. 2c)
Student's square (Fig. 2d)
The shade of the Tamarind Tree (Fig. 2e)

Fig. 2a. Amphitheatre

Fig. 2b. Basketball Court

Fig. 2c. The Open-Air Auditorium

Fig. 2d. Student's Square

Fig. 2e. Shade of the Tamarind Tree

The above-mentioned spaces are the "intended" recreational spaces. The need for a recreation space exists on any campus because of the mission of the institution.

E.g., the mission of CHRIST University is:

"CHRIST (Deemed to be University) is a nurturing ground for an individual's holistic development to make an effective contribution to society in a dynamic environment."

To have a "nurturing ground", the immediate need is to render learning facilities, and education and enhance the student-life experience.

METHODOLOGY

Data collection

The sites chosen around CHRIST University namely, the Amphitheatre, Open Air Auditorium, Basketball court, Student's square, and the Shade of Tamarind Tree are noticed to have been the hotspots where the students sit around and spend their time at. Each of the sites will be studied and surveyed efficiently. Students who spend their time in these spots were chosen to answer the questionnaire.

The typology of data collection is based on the Simple Random Sampling method. The questionnaire survey was conducted in a very conversational manner, simultaneously a google form was circulated among the students. The students were at liberty to choose the frequency of the visit to these sites for recreation.

The analysis of each question was done based on the responses received in the survey, and why students spend their time in the respective spots was understood. Certain elements in these spaces were identified, which are: Seating spaces, Nature, and Shade, and the student had to pick the element that draws them to that recreational space. Photographic evidence was taken during fieldwork, and sketches relating to the place were sketched on site. Google forms were created to record the responses, and Microsoft Excel was used to collect statistical data.

Development of Study

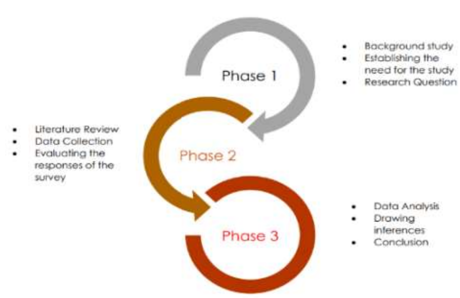
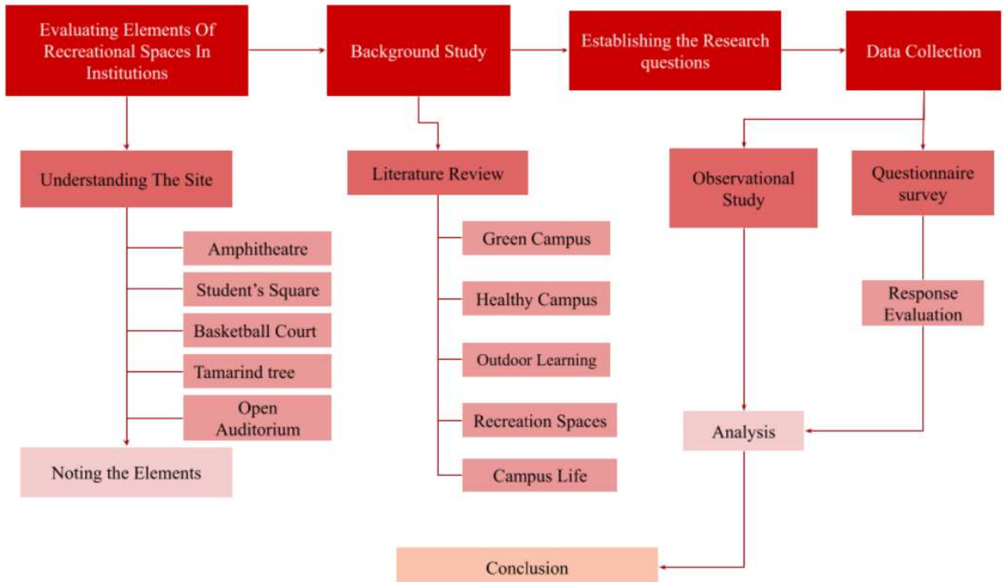


Fig 3. Different phases in the research

The First phase involves the background study and establishing the need for this study, including the research question. In the second phase, a Literature review was done by reading several journal papers. Data was collected, and the survey responses were analysed. The Third phase involved Data analysis and the conclusion of the paper.

Table 1: Research Methodology Chart



SURVEY ANALYSIS

The questionnaire survey was conducted among students from the First to the Fifth year of study. The questionnaire asked them about their frequently visited and least visited sites, out of the 5 sites. It was asked also whether the students prefer using these spaces before, during, or after class.
The responses and the data are as follows:

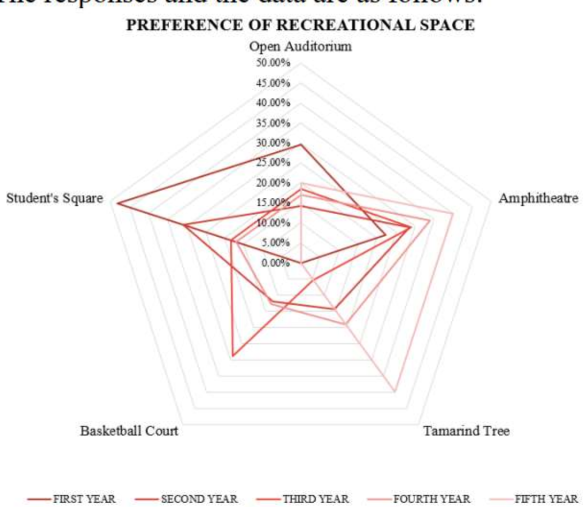


Fig. 4: Preference for recreational space across different years of study. Student's square is highly preferred by first-year students, whereas Amphitheatre is preferred by fifth-year students.

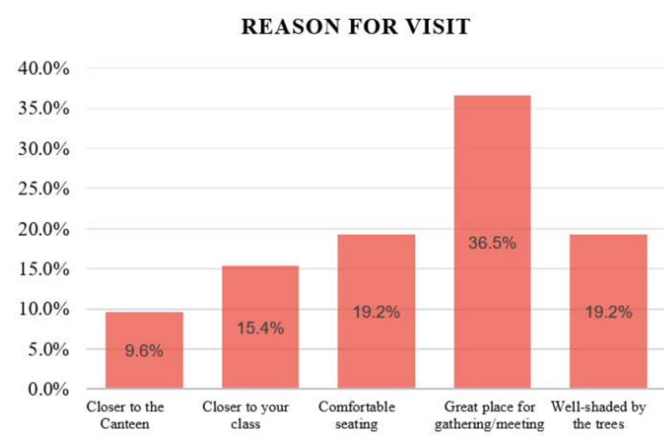


Fig. 5: Reason for visiting the Recreational Spot. Students tend to meet and gather in Recreational spots for socialising and interacting with each other.

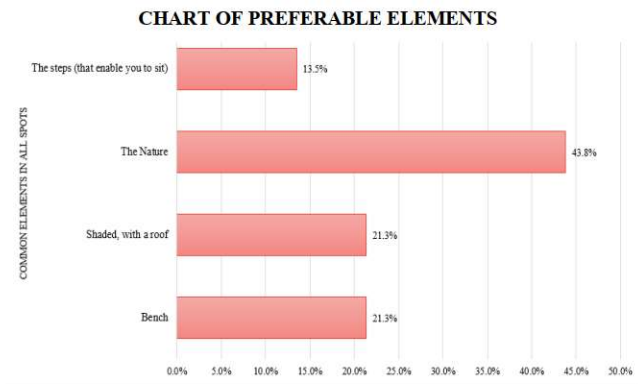


Fig. 6: Common elements present in all chosen spots that are favoured by students. Nature is the main element because of which the majority of the users go to their favoured Recreational places.

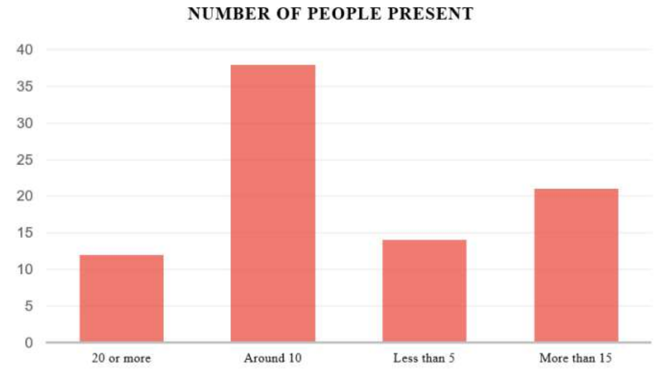


Fig. 7: Number of people present on average in the Recreational Spot. It is noted that around 10 people are always present in any given recreational Spot.

Fig. 8: Satisfaction Range from 1 to 5, when the user is in the Recreational spot

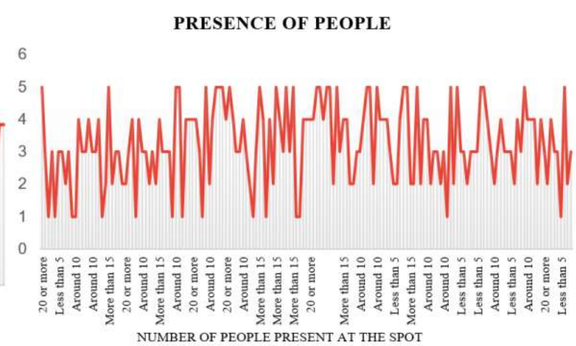


Fig. 9: Satisfaction Range (1-5) of the user when people are present in the Recreational Spot

RESULTS AND CONCLUSION

The analytics shows the transition in the occupancy of the Student's Square higher in the initial years, whereas it is non-preferable in the final years of study as much. It simultaneously shows that Amphitheatre is most visited by all across all years of study (according to Fig. 4). Recreational spaces preferred by the users are chosen in terms of proximity to their classrooms, as well as the need for socialising, and meeting other people. Simultaneous effects are noted in cognitive behaviour, as it unfolds friendships, peer-to-peer learning, and interaction with other students in the presence of nature. The feeling ranges from 3-5 (satisfied to happy) when the user is present in their favourite recreational spot, hence, it shows that their productivity in that space is high. Nature and greenery present in the chosen recreational space help students relax and unwind. In the design of recreational spaces, for an institution, in-depth planning and offering cross ventilation to the classroom with a greenery view composes a major whole. Green spaces demonstrate both environmental and educational features for learning. In addition, it serves as a more controlled and quiet private space than the outdoors, enabling students to thoroughly enjoy the academic curriculum. An ideal recreational space should also be designed with elements encouraging team building, and interaction areas. This could include, seating areas, such as multi-level seating, round tables etc. A focus object which could be an element of nature, such as a tree, can be highlighted, and the recreational space could revolve around that object.

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ECOLOGICAL DIMENSIONS FOR PUBLIC SPACES IN URBAN ARCHITECTURE

K S Gopal

Director, Centre for Environment Concerns, Hyderabad, India; ksgopal1952@gmail.com

ABSTRACT

This paper posits that ecology, ecosystem thinking, human-centred design, engineering, and architecture all are needed to flow into a confluence to create inhabitable spaces. The paper draws upon the experience of the author engaged in developmental work for 5 decades of working with marginalised sections of society, and dry-land marginal farmers and some solutions that he helped develop. The author shares learning's from poor women labourers and their rustic wisdom. The author shares about a pilot project where he and his team deployed all these learning's in creating a sustainable, resource-frugal, and human-centric solution to green available limited spaces in Bangalore.

BACKGROUND

I have been engaged in the development sector for more than 4 decades, working with women workers in rural areas, marginalised farmers in dry ecosystems and currently engaged in helping marginal farmers to develop assets with assured and frugal irrigation systems with an integrated approach.

I must confess, I am no researcher and am not trained as an academic to write overly rigorous research papers! I share here some humble learning's from one of the projects that we undertook recently. "Design Thinking" in recent times emerged as a major influencing perspective of organizations, products, processes, and even governments. Design thinking popularly uses a 5 step iterative model which involves Empathy, Design, Ideation, Prototyping, and Testing.

While many engineers focus on design and ideation, rarely do they prototype and do that iteratively from inputs from users. Empathy is a critical step that often is short-circuited or not exhibited by designers who focus a lot more on other dimensions.

LEARNING'S ABOUT HUMAN-CENTRIC DESIGN FROM THE GROUND

In 1983, I assisted the Andhra Pradesh government project to build weaker section housing in rural areas. Specifications such as plinth, size, roofing, materials, etc., were given by the government with a budget of Rs 5840. The extra cost was to come from beneficiaries who could not contribute money. I studied the literature on low-cost housing. One easy-to-do idea was to prefabricate the house and ship to integrate at the site. It had advantages: known costs, specifications met, and delivered on the schedule.

While getting the project executed, a group of women walked up to say their wages were low and made a demand to increase them. I empathized with their plight and then listed all costs of items - cement, steel, bricks, laterite stones, sand, skilled masons, etc, over whose prices I had no control. This neither convinced them nor me. I had a dilemma: is my job to improve the lives and livelihoods of the poor or deliver houses like a contractor, despite their value to the poor?

Multiple anecdotes were shared by the women and showed me ways to understand human-centric design suiting their labour, skill, and science. Their message was:" Design decides the Structure, Structure determines the Materials which must be led by choices *of whose Labour and knowledge is of value and must be at the heart of human-centric design".*

My solution to lower costs was: in situ fabrication of cement concrete slabs and then laying of the roof. Four houses share common walls. Desperate to meet housing targets, the government engineers reluctantly accepted. I am happy to share that the redesigned housing won a prize at the New York global housing competition, wages of women tripled enhancing their self-image and officials too were satisfied!

THE PROJECT

It's a known fact that urbanization is growing rapidly. There could be many reasons such as increasing employment opportunities, the anonymity of cities, the monetization of rural economies, shrinking share of the value of rural produce among others. As urban areas grow, in recent years thanks to advocacy and laudable work of many agencies people have become sensitive to ecology-related issues and see greening spaces as a way to reduce carbon emissions and pollution. We were given 350 meters of a road median to be greened as proof of the concept of a sustainable, resource-frugal greening solution for ecological gains.

LOCATION & PARTNERS

The pilot on the road median was implemented on a delineated 350 meter opposite Rajanakunte Panchayat on the Yellahanka-Dodddaballapur highway. It is our first effort. (The project was possible due to the generosity of Kailash Nadh and the Rainmatter Foundation founded by Zerodha Broking Limited, Bangalore) The Panchayat provided the water source from the nearby school bore well. It was fine as most water is required during summer when the school is closed. Work on the plantations began in mid-April 2021 and this paper is written in July 2022.

SOME PARAMETERS CONSIDERED FOR THE PILOT

Species chosen ought to be a mix of trees and shrubs which meet the following criteria: Native, bio-diverse, flora high on nectar, bright coloured, all-year-round blooming flowers, and spacing based and location based on select parameters. Planting in summer for the nursery using raised young saplings to adjust to a new environment amidst harsh conditions for fast plant growth in monsoon. Remove tar and dig pits for tree roots to find the anchor and shallow soil management in shrubs vide nutrient application and plant spacing. Cost-effective and synergistic organic practices to save and recycle water, healthy dynamic soils with biological inputs, young saplings, and Mycorrhizae for root growth and width.

Capture all rainwater with effective seepage and drainage to improve groundwater levels Automated measured moisture delivery at the plant root zone to save water and reduce weed growth, lane-closure, and accident risks to workers. Develop a manual on tasks, procedures, protocols, and practices, and for training to maintain and enhance ecological and human well-being gains. Explore wider participation and ownership compact in investment, integration, and incentives with maintenance and periodic assessments and improvements.

KEY DESIGN ELEMENTS ARE THE PLANTATION-WATER-SOIL-SUNLIGHT-AIR RELATIONSHIP TO HARVEST ECOLOGICAL GAINS

Plantations: Nursery-raised plants are normally bred in plastic bags and the growers are compelled to regularly cut the roots. Unlike two and three-year well-grown saplings we opted for six months for shrubs and one year for trees. To acclimatize upon transplantation, establish in the new ecosystem, and amidst harsh summer conditions plantations were done in April 2021.

The tree species chosen were Lagerstroemia Indica (Pride of India) and Cordia Sebestena while the shrubs were varying colours of Alamanda (dwarf), Ixora, and Russelia. 30% of the saplings had to be replanted within two months as they were stolen by people at night! I was told to put video cameras but refused as people take time to appreciate them. Six months later people stood on the median to take pictures, trampling the shrubs Officials said "fence the stretch". A year later people including car owners plucked the flowers. I learned citizens are desperate to enjoy nature, the first step that must ultimately lead to their nurturing of the planet and getting the others to successfully deliver on our ambition on ecology. It's one thing to protect it like some museum piece, it's another to let people feel ownership!

Soil: We removed the existing compacted highly acidic soils. We removed tar eight inches below the soil. For trees, we dug one square cubic meter pit to ensure it is well anchored, grows well, and mine the maximum soil nutrients. We added red and black soil with a locally prepared Living Compost (Microbes and Mycorrhizae inoculate developed by us) to dynamically multiply biological organisms for rich enhanced soil quality. Unlike vermicompost which uses foreign earthworms that move horizontally and only scavenge the top portion, Living Compost has native earthworms coming from the soil which plow and aerate the soil. Leaf litter serves as soil mulch and a regular food source for the microorganisms and reduces plant and soil nutrition costs. We had an issue with weeds with Living Compost as seeds were present in the farmyard manure used to prepare it.

Irrigation: Instead of water tanker supply and to reduce water quantity, we installed piped water supply with our innovative System of Water for Agriculture (SWAR) to deliver measured moisture at the plant root zone and serve as a rich system to foster soil organisms. We plan to embed root zone moisture sensors providing data to plan irrigation schedule and with remote control of the pump motor switch on and off and fit into the Smart City project in the near future. We propose to use water from treatment plants from multi-storied buildings facing a huge problem in treated waste-water disposal for plant nutrition which is a significant load on the waste disposal systems.

A circular grid of plant, water, and soil nutrition is at the heart to derive ecological gains to go beyond the situation we are caught challenged with.

Stakeholders' management: To succeed in delivering we must design a compact among stakeholders and manage the competition among implementing agencies.

Task: Ecological gain measurement is time-consuming. It must showcase the value and benefits of ecology-centred design to develop and offer solutions to problems faced by civic administration and citizens. It must go beyond just tree plantation to account for the offer of better air, no flooding, lower temperature, improved micro-climate, etc. Ecological dividends grow organically and exponentially over time through a natural process. Like many social goods and services, ecology needs patient capital – of both money and time.

THE OUTCOME

A year after the plantation, we asked common folks about their impressions. Car drivers: why you don't do an entire stretch of 20 kilometers, and in front of apartment complexes? Bikers said it will not work here: people will throw garbage or steal flowers. Street vendors saw the business grow as people stand longer watching the bloom. Rural folks opined that it offers them much hope and city people will learn to value rural ambiance. It was heartening to observe that within three months the bees arrived and occasionally sighted butterflies and await the birds and building of nests. Ecological gains by studies showed sighting of bees and butterflies, micro-climate, and joy and happiness to people passing by.

DESIGN FOR THE COMING FUTURE

Bangalore was once known as a prestigious and proud garden city in Peninsular India. Design thinking, ecological lens plus the creativity of its citizens will surely restore the city to its original pristine glory. I believe this can happen in just five years. Here are a few reasons why. Bangalore has the Smart City project for the efficient management of civic infrastructure. Hopefully, vehicle fumes will end with electric cars. Multi-storied apartments have water treatment plants to irrigate and enriched liquid household waste can serve as plant nutrients. Urban ecology management demands that links and tools be developed to landscape a sustainable circular economy to bring down anxieties to pursue innovation, creativity, and spirituality that nature can provide.

Low hanging fruits:
Bangalore Development Authority people took me to various sites. I found them laying new roads with old frameworks and sciences. To build ecological interventions later is difficult, expensive, and calls for compromises to introduce ecological factors, let alone maximize potential ecological harvests. Design-centric thinking must factor in ecologists' perspectives and develop new guidelines. It must build ecological measurements on what is to be monitored, paid for, and incentivized. It must make the task of implementing agencies easy and the responsibility to deliver high-quality roads to deliver on high speed with a smooth flow of traffic with the elegance greenery provides. I am confident that this will gain support and cooperation and a shared vision with the civil engineers, road concessionaires, contractors, and citizens.

Research needed to design architecture professionals to use public spaces in cities for ecological gains:
Where and how one should source and capture creative human-centric ideas on design?

Civil engineers and town planners offer structural and engineering solutions to address pain points, ecology must be localised and centred on happiness and harmony with nature. What are the gaps and how does one develop thriving ecological approaches amidst structural one-size-fits-all solutions? We must allow for myriad approaches which are flexible, local, and shine like a rainbow!

A talisman on urban ecological well-being to guide, influence, and onboard multiple players for shared goals akin to Gandhi's advice to J C Kumarappa on planning for India: "will what I propose to serve the well-being and self-image of the last person?"

THE EFFECT OF THE CONSTRUCTION SYSTEM ON THE ENVIRONMENTAL QUALITY DURING THE EXECUTION PHASE OF LARGE-SCALE HOUSING DEVELOPMENT PROJECTS IN ABU DHABI.

Muhammad Sami Ur Rehman[1], Mohammed Albattah[2], Latifa Khalid Almheiri[3], Mariam Ibrahim Alblooshi[3], Wadima Hamad Alrashdi[3], and Muneera Khalifa Alharazi[3]

[1] Ph.D. Candidate, Department of Architectural Engineering, College of Engineering, United Arab Emirates University, 15551, Al Ain, Abu Dhabi, UAE, 202090209@uaeu.ac.ae

[2] Assistant Professor, Department of Architectural Engineering, College of Engineering, United Arab Emirates University, 15551, Al Ain, Abu Dhabi, UAE, mohammed.battah@uaeu.ac.ae

[3] Undergraduate Students, Department of Architectural Engineering, College of Engineering, United Arab Emirates University, 15551, Al Ain, Abu Dhabi, UAE, 201711976@uaeu.ac.ae, 201702945@uaeu.ac.ae, 201717530@uaeu.ac.ae, and 201716961@uaeu.ac.ae

ABSTRACT

In most developed and developing countries, sustainability is an extremely important goal to reach. Construction and infrastructure sectors, in many of these countries, have been investigating various key factors regarding sustainability and improving existing practices in the industry to reach the objectives of sustainable cities and communities. The construction industry is highly resource-intensive and various aspects of its overall practice adversely impact the environment. The main objective of this study was to explore and understand the effect of three popular construction systems i.e., traditional Reinforced Cement Concrete (RCC), Precast Concrete (PC), and Light Gauge Steel (LGS) on the environmental quality during the execution phase of the construction projects. This research study chose a case study research method and selected three large-scale housing development projects being executed in Al Ain city of Abu Dhabi Emirate as the case study projects. The semi-structured interviews with Project Managers of these case study projects revealed several sustainability-related aspects associated with the construction systems under study and also identified harmful activities during the construction execution phase. Key factors were identified through the content analysis to discuss and compare these three construction methods based on the feedback gathered through the interviews. This research study concludes that the LGS system requires less time and equipment to complete, produces less noise and dust pollution, and possesses the highest potential for sustainability among the three construction systems.

Keywords: Light Gauge Steel; Precast; RCC; Sustainable Development Goals; SDG-11

INTRODUCTION

The United Arab Emirates (UAE) is considering all of the 17 Sustainable Development Goals (SDGs) presented by the United Nations General Assembly (UNGA). Several initiatives were implemented to meet these 17 goals. In Goal 11, sustainable cities and communities, the UAE intend to make the cities inclusive, safe, resilient, and sustainable (UAESDGs, 2021). The UAE has been launching many programs and projects that are aimed at fulfilling Goal 11. These programs include promoting and improving the sustainable infrastructure, building sustainable cities (i.e. MASDAR city), implementing and updating several laws to protect the environment, and enhancing sustainability in the cities, such as improving air quality, improving water quality, and maintaining human safety and wellbeing (UAEGP 2021). However, the construction industry is heavily reliant on its traditional practices and several construction processes are harmful to the environment and therefore a major hindrance in achieving sustainability. Many issues appeared during the execution, such as safety, low-skilled labor, shortage of recourses, cost and time overruns, poor quality, and construction waste. Following are different construction methods and technologies:

Traditional construction method (which is also known as reinforced concrete system): In this method, the substructure and the superstructure are built on-site (cast in place) using three major materials (plywood formwork, steel reinforcement, and concrete). The exterior enclosure and interior walls are non-structural activities and include Concrete Masonry Unit (CMU) and plastering (OKODI, 2012). All of the above activities and their related processes that are executed on-site generate waste of materials and water and also spreads noise and air pollution (i.e. dust). Moreover, this construction method requires a longer time to be finished, compared to the other systems and methods, which means more disturbance to the environment over the period (OKODI, 2012). However, they are easy to transport and flexible for the last-minute changes, which are considered some advantages of this system (Abdul Kadir et al., 2006; OKODI, 2012).

Precast Concrete: In this method, the substructure and superstructure, the exterior walls, the interior walls, floor slabs, and staircases are created as standardized elements in the factories and then delivered to the construction site. They are heavy elements, so they need mechanical lifting gear to assemble them and form the buildings (Li & Li, 2015; Nanyam et al., 2017). This method has several challenges, including the non-flexibility in future changes if the end-user desires to do so, and the rigidness in the appearance (Nanyam et al., 2017). In addition, this method requires unique transportation trucks and unique equipment on the construction site, which may consume more fuel, hence more CO2 emissions. However, this method has several advantages, including fewer workers on the construction site, reduced material and water waste, and fast construction time, which means less disturbance to the environment (Elkaftangui & Basem, 2018).

Steel structure: Recently, there are different types of buildings that widely use steel during the construction process such as multi-story residential buildings, skyscrapers, bridges, and commercial buildings. That is due to some characteristics of steel which are summarized as follows: strength, durability, usability, flexibility, aesthetics, and low weight (Aksel & Eren, 2015). In addition, there are different types of structural steelwork based on the steel structure construction method and the production of material for the steel elements. One of these materials is Light-Guage Steel (LGS) and the method is generally known as Light Guage Steel Construction (LGSC) or Light Guage Metal Framing (LGMF). This type is assembled mainly in the frames of the residential houses of the United States, Canada, and European countries and manufactured from cold-formed steel profiles generally C and U profiles. There are many advantages of the light-gauge steel system and it competes with other construction materials for its high strength and stiffness, ease of prefabrication and mass production, fast and easy erection and installation, and economy in transportation and handling (Vigneshkannan et al., 2017). On the contrary, the light-gauge system has disadvantages as well. The major one is the thermal bridging which will contribute to the moisture damage and heat transfer from the exterior to the interior in hot climates, like the GCC countries (Perkins, 2009).

The main objective of this study is to explore and measure the effect of different construction methods and technologies on the environment during the execution phase of the construction projects. This study focused on large-scale housing development projects by the Abu Dhabi Housing Development Authority (ADHA) in the Al Ain region of Abu Dhabi Emirate in the United Arab Emirates (UAE). These housing development projects deployed traditional RCC, Precast construction method, and LGS to deliver the ever-growing need for local and expatriates alike within the Emirate. This research study aimed at understanding the impact of these three construction systems and their associated activities on the environment of Abu Dhabi Emirate during the execution phase of said construction projects. The following sections will provide an overview of the chosen research methodology and findings in the form of a comparison between these three construction systems based on various factors which directly impact the environment during construction. Finally, conclusions are presented along with the limitations of this preliminary research study on this specific topic.

METHODOLOGY

To meet the objectives of this study, the authors implemented a case study research methodology. Initially, a comprehensive literature review was conducted to understand the topic and various aspects associated with the said research topic. Based on the findings of the literature review, a semi-structured interview questionnaire was prepared to act as a primary data collection tool which comprises 5 sections. The first section of the interview introduced the research topic, its aim, and objectives and collected demographic information of the interviewees. The second section aimed at understanding the purpose and scale of the project along with the reasons for implementing the chosen construction system to fulfill the objectives of the respective housing development projects. The third section aimed at inquiring about the harmful activities associated with the execution phase of any construction project and later on understanding the environmentally harmful activities associated with the specific construction system deployed. The fourth section of the interview questionnaire aimed at understanding the impact of various construction activities involved in all three construction systems and comparison between them regarding their effect on the local environment. The fifth and last section collected the opinions of the interviewees regarding the shortcomings associated with different construction systems and their suggestions to improve the overall situation.

Table 1: Details of the Interviewees

Sr. No.:	**Position**	**Organization**	**Years of Experience**	**Type of Construction**	**Interview Mode**
1	Project Manager	Contractor	30+	LGS	Face-to-Face
2	Project Director	Client	27+	RCC	Face-to-Face
3	Project Director	Client	27+	Precast	Face-to-Face

Figure 1: Case study projects in Al Ain

Data collection was planned by contacting the responsible organizations of selected case study projects and conducting a preliminary discussion on the aim and objectives of the research study. After the preliminary phase, the organizations provided the details of the most suitable interviewees for this research study and allowed the authors to visit their project sites. After a thorough visit, the interviewees arranged an introductory presentation at their camp/site offices regarding the case study project followed by an hour-long in-depth face-to-face interview. Thematic analysis was performed to analyze the qualitative data obtained through the interviews to identify prominent themes. Details of interviewees are presented in Table 1 followed by a brief description of case study projects. Three case study projects were selected for this research study based on their unique features. All case study projects are depicted on the map of Al Ain in Figure 1.

Case Study 1: Wadeema complex, a rental apartment attached to three different apartments as a part of a residential compound mainly for expatriates. The construction method used to build the 4 apartments is the LGS system. The official title of the project is Sheikha Wadeema Complex. The project site is located in Asharij, Al Ain, Abu Dhabi, and consists of 424 units.

Case Study 2: Al Shuaiba Residential Villas, an emirate national villa that is constructed using concrete brick wood infill with reinforced concrete for beams and post structures. As mentioned earlier, this is the most used construction method in Al Ain. The official title of the project is Al Shuaiba Residential Complex. The project site is located in Al Shuaiba, Al Ain, Abu Dhabi, and consists of 162 units.

Case Study 3: Jabel Hafeet Residential Villas, constructed using a precast concrete system, that represents the most used material for national houses. The precast concrete system market has been growing rapidly in UAE. The official title of the project is Emirati Housing Development. The project site is located in Jabel Hafeet District, Al Ain, Abu Dhabi, and consists of 3000 units.

FINDINGS

The deductive thematic analysis revealed several factors to compare the three construction systems. Key factors were project duration, cost-saving potential, required laborers, required equipment, water consumption, dust pollution, noise pollution, the potential for innovation, the potential for sustainability, and construction waste.

Project Duration: All interviewees identified that the total duration or the length of the project is the most important factor and impacts various factors associated with the construction project i.e., cost, time, quality, profitability, sustainability, etc. Traditional RCC structures require the longest time to complete whether the project is the construction of a single-detached house or a large-scale housing development project. As identified by the interviewees, the precast construction method provides an opportunity to reduce the overall project duration significantly providing an excellent pre-planning and coordination between the designer and the production facility. Furthermore, the LGS system significantly reduces the project execution time as one of the interviewees mentioned that the LGS system saves up to 70% of the execution time as compared to the traditional RCC construction method.

Cost Saving Potential: This factor was identified and ranked among the highest factors from the motivation perspective. The larger the cost-saving potential exists more attractive and obvious the choice it becomes. Interviewees identified that cost of traditional RCC and precast construction is comparable in small-scale construction projects. In large-scale housing development projects, the precast construction method provides a significant cost-saving potential. However, all interviewees agreed that the LGS system is among the most obvious choice in this case and Interviewee 1 identified that they had saved around 25% of the project cost as compared to the traditional RCC system for a similar housing development project.

Required Laborers: Since the traditional RCC construction method requires every aspect of the project to be done on-site, it required an increased number of laborers. The increased number of laborers calls for increased accommodation and transportation requirements as well. Although in a precast construction system, key structural elements are being built off-site the finishing process is similar to that of traditional RCC as per the interviewees which still requires a significant number of laborers. However, Interviewees 1 and 2 identified that the LGS system requires fewer laborers at every stage of construction as compared to the precast and traditional RCC systems. As per the interviewees' opinions, the fewer laborers for a shorter project duration will significantly reduce the need for transportation and accommodation which will save cost and poses a lesser threat to the environment of the locality.

Required Equipment: All interviewees identified the use of machinery and equipment as a major factor in polluting the environment since the majority of the equipment involved in the construction projects consumes diesel as a fuel. Interviewee 2 identified 23 pieces of equipment required to complete one villa/unit throughout the lifecycle of the project. All interviewees opinionated that the precast and LGS construction systems might require similar equipment but their use is less frequent in the case of precast construction and way lesser in the case of LGS systems. The lesser requirement of construction equipment and their use makes the LGS system the obvious choice of all the interviewees in preserving the environment as compared to the precast and traditional RCC construction systems.

Water Consumption: The construction industry is known to be the sector that utilizes a substantial amount of water throughout the lifecycle of the project. All the interviewees agreed with this fact and Interviewee 2 specifically mentioned the exorbitant amount of water being utilized in the traditional RCC construction system. In the case of a precast construction system, most of the concrete elements are being built in a controlled factory environment and only being erected at the project site, it also provides a potential to save water. However, Interviewee 1 identified and labeled the LGS construction system as a 'dry' system which requires a very less amount of water as compared to the precast and traditional RCC construction system which also reduces the discharge of polluted water into the environment from the construction sites.

Dust Pollution: Since most of the large-scale housing development projects are greenfield projects which means the development of a completely vacant site. Major construction activities i.e., land clearing, drilling, blasting, ground excavation, cut and fill operations, and many other activities throughout the lifecycle of the project cause significant dust pollution in the locality. All interviewees identified the traditional RCC construction method as the most harmful to the environment. However, since all the housing development projects require similar construction activities in the beginning, the interviewees ranked precast construction and LGS construction systems as moderately harmful to the environment as well.

Noise Pollution: Similar to dust pollution, noise pollution is also an inherent outcome of all the construction activities. As per the interviewees, the major contributor to noise pollution is the use of machinery and equipment throughout the lifecycle of the project. Since the traditional RCC require most of the activities to be conducted on-site and hence demands the increased use of equipment it ranked the most harmful system of construction for the environment. Furthermore, both precast construction and LGS construction systems were ranked moderately harmful as compared to the traditional RCC.

Potential for Innovation: All interviewees identified that innovation in prevailing construction methods and techniques is an important factor in achieving the aim of sustainable cities and communities. Precast concrete and LGS construction were ranked most suitable construction systems that are flexible enough to accommodate the innovations to improve life safety, fire resilience, improved design, environment friendliness, sustainability, and more. However, the traditional methods and techniques of construction are rigid and least susceptible to change hence less accommodating to modern innovations as opinionated by all the interviewees.

Potential for Sustainability: This factor was identified by all the interviewees from the perspective of recyclability of materials being used in construction projects. All interviewees identified that demolishing the facility built through the traditional RCC system is difficult and expensive to recycle as compared to the precast construction system. Also, the use of recycled material for producing concrete in the case of traditional RCC and precast concrete construction systems is non-existent in this context. However, Interviewee 1 identified the use of recycled material for producing the LGS panels and associated assemblies throughout the case study project. Furthermore, all the interviewees also agreed with the ease of demolition and recyclability of components involved in the LGS construction systems.

Construction Waste: The construction waste generated during the execution phase contributes significantly to the overall construction waste. All interviewees highlighted the importance of this specific factor and agreed on its significant contribution to polluting the environment of the locality. As opinionated by all the interviewees, the traditional RCC construction system generates the most construction waste due to the nature of construction activities involved in the process. Interviewee 3 also identified that the finishing phase of the traditional RCC and precast concrete construction is similar hence it has been ranked as moderate. However, all interviewees agreed that the precise design, proper planning, and careful execution of the LGS construction system has the potential to generate less than 1% of construction waste throughout the lifecycle of the project and hence ranked comparatively better for the environment as compared to traditional RCC and precast construction systems.

Table 2: Summary and comparison between three construction systems

Factors / Systems	**Project Duration**	**Cost-saving potential**	**Required Laborers**	**Required Equipment**	**Water consumption**	**Dust Pollution**	**Noise Pollution**	**Potential for Innovation**	**Potential for Sustainability**	**Construction Waste**
Traditional RCC										
Precast Concrete										
Light Gauge Steel										

Color Code: Good for Env. Moderate Harmful for Env.

CONCLUSION

Based on the expert opinion of the interviewees, the authors explore and understands the phenomenon. Starting from the understanding of the construction systems and their execution in the actual environment. As per their input, all those activities which increase the duration of the project will pose a significant threat to the environment. Traditional construction practices are rigid and offer the least room for innovation that allows for faster execution of the projects. Innovative construction systems like Precast and LGS produce the least amount of construction waste than Traditional RCC. Cement-based construction materials are tried and tested but are a major contributor to damaging the environment and unfortunately, the use of recycled concrete in the UAE is not common.

Based on the analysis of the data gathered through semi-structured interviews, this study presented the following conclusions. First, traditional construction practices make the RCC system least desirable for the environment during the execution phase. Second, the precast concrete system uses similar materials as RCC, hence ranked as moderate due to the limited use of recyclable materials. Lastly, LGS was the most favorable during the construction execution phase across most of the factors.

As the scope of this study was limited to the investigation and comparison between three construction systems during the execution phase of the project, future studies should investigate all phases of the project throughout its lifecycle. Furthermore, the quantification of embedded carbon associated with all three construction types will provide comprehensive feedback and will help in selecting the most useful construction system for preserving the environment and achieving the SDG goals as planned by the UAE government. Comprehensive ranking based on the range of factors must be performed based on the findings in the two future directions presented earlier.

ACKNOWLEDGEMENT

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THEME III

Sustainable Architecture and Energy Performance

EXAMINING VASTU PURUSHA MANDALA AS A SUSTAINABLE DESIGN TOOL

Tanushri Sharma[1], Shamala H.O.[2]

[1] Student, BMS School of Architecture, Avalahalli , Bengaluru, Karnataka, India, tanushrisharma200029@gmail.com
[2] Student, BMS School of Architecture, Avalahalli , Bengaluru, Karnataka, India, hoshamala@gmail.com

ABSTRACT

Vastu shastra is a time-honored Indian knowledge system of architecture and town planning. *Vastu purusha mandala* is one of its key tools which considers site conditions (type of *mandala*), orientation of building, orientation of activities and directional placement of openings among others. This paper attempts to proffer the argument that *vastu purusha mandala* as a design tool leads to better wellbeing of inhabitants in a sustainable manner through IGBC guidelines in terms of daylight and natural ventilation. The objective of the paper is to study the application of *vastu purusha mandala* through case studies of traditional residences from two different states (Tamil Nadu and Kerala) of India. The two residential case studies of *nalukettu* and *chettinad* houses have been selected for maximum application of *vastu purusha mandala* in their planning and design. The paper restricts itself to comparative analysis of the above mentioned case studies through perspective and simulation approach by analyzing *vastu purusha mandala* as a sustainabe design tool in terms of daylight and natural ventilation. But furthermore, significant examples can be explored wherein we find sustainable solutions being reached via application of *vastu purusha mandala.*

Keywords: Vastu Purusha Mandala, Sustainable Tool, Daylight, Natural Ventilation, IGBC Guidelines

INTRODUCTION AND METHODOLOGY

Vastu purusha mandala being a timeless and effective planning and design tool has been proffered through its application on different scales and typologies of projects ranging from *Madurai Meenakshi* temple (most ancient example) to *Jaipur* city (most recent example). This tool of planning and design has lost its essence over time due to the introduction of foreign planning systems in the Indian subcontinent. The revival of this vernacular knowledge system of sustainable design in built form is now necessary more than ever because of the current nature of human settlements drastically impacting their health and environment. Efficiency of planning is studied in terms of daylight and natural ventilation which are the most essential parameters required for building design. According to the present generation, a new terminology named sustainable design has entered India, which shares few parameters with *vastu purusha mandala* such as daylight and natural ventilation. This paper attempts to generate awareness that *vastu purusha mandala* can be sustainable and tries to examine this through the residential case studies of *nalukettu* and *chettinad* houses where *vastu purusha mandala* is applied in their planning compared with the recent sustainability parameters such as that of IGBC guidelines [1].

Vastu Purusha Mandala

The most precise representation of the universe is the *vastu purusha mandala*, which serves as the foundation for architectural design and is an important part of building construction. *Vastu purusha mandala* (*pada vinyasa*) is the process in which the site is divided into various numbers of squares. *Vastu purusha mandala* has many sub-categories of mandalas such as *sakala mandala, pechaka mandala, pitha mandala, mahapitha mandala, upapitha mandala, ugrapitha mandala, sthandiala mandala, chanditha mandala* (or *manduka mandala*) and *paramashaiyaka mandala*. For the purpose of this paper, *mahapitha mandala* has been used since it has been applied in the residential case studies of *chettinad* and *nalukettu* house.

Mahapitha Mandala-A Planning Tool

Mahapitha mandala is a design tool that guides in the site planning. This method has been efficiently integrated in the case studies which has significantly improved the sustainability of the design through daylight and natural ventilation. It consists of a square of 3x3 grid is superimposed on the site in which *Brahma* is in the center and occupies four plots. The plots adjacent to the boundaries of the plot of Brahma are occupied by various deities such as *Aparatsa* and *Aryaka* in the east, *Savitra* and *Vivasvat* in the south, *Indra* and *Mitra* in the west, and *Rudra* and *Bhudhara* in the north. The plots that are adjacent to the outermost boundary of the mandala, starting from the north-eastern plot in a clockwise order are ruled by *Isha, jayanta, Aditya, Bhrisha, Aani, Vitatha, Yama, Bhrinaaraja, Pitri, Sugriva, Varuna, Shosha, Maruta, Mukhja, Soma* and *Aditi*. The activity chart describes about the various attributes that are assigned to each activity space which are associated to a particular diety, and hence guides the planning of the space. *Vastu purusha mandala* being said to be sustainable is compared with the present IGBC parameters which talks about sustainability having a common ground through parameters of natural ventilation and daylight.

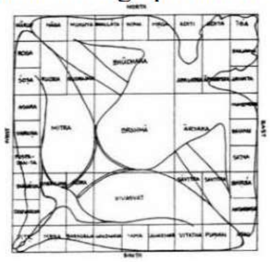


Figure 1: *Mahapitha mandala*
Source: Chakrabarti, Vibhuti, 1998. 'Survey of texts, ancient and modern', Indian architectural theory and contemporary uses of vastu vidya, *Curzon press*, fig.4, pp.7.

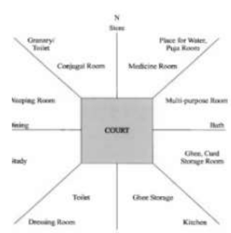


Figure 2: Activity chart
Source: Chakrabarti, Vibhuti, 1998. 'Survey of texts, ancient and modern', Indian architectural theory and contemporary uses of vastu vidya, *Curzon press*, fig.5, pp.7.

Climatic Strategies In Terms Of Daylight And Natural Ventilation Of Warm And Humid Climate

To allow cross-ventilation, buildings in warm and humid climate have open elongated plan forms with a single row of rooms. Open verandahs or galleries, which also give shade, may provide access to such rooms. Openings for doors and windows should be as large as possible to allow air to flow freely. Extended plans that go in the opposite direction of the prevailing wind provide little air resistance and are hence the best option. All vertical surfaces, including apertures and solid walls, should be shaded. If the building height is kept low, this process will be much easier. The roof will typically extend far beyond the line of the walls, with broad overhanging eaves providing needed shading for both openings and wall surfaces. Wind orientation is advisable in low-rise buildings when the walls do not receive much radiation. A structure cannot cool sufficiently at night to allow heat storage during the day since the outside air temperature is practically constant during the day and night. The influence of outside factors is reduced by opening the building to air movements and hence to outside conditions. The impact of indoor circumstances on structure is significantly reduced. To allow natural air flow through the indoor spaces at body level, openings must be set in accordance with the prevailing breezes (up to 2 m). It is vital to have ventilation, or air exchange. Thus, in this environment, both frequent air changes (ventilation) and sensible air flow across the body surface are required. The area between the roof and the ceiling will also require ventilation, and enough holes must be provided for this.[3]

Table 1: Common parameters of *Vastu Purusha Mandala* and sustainability
Source: IGBC Green New Buildings Rating System, September 2016, version 3.0, pp. 23-24, pp. 72-76, pp.105-121, pp.133 Annexure1.
Chakrabarti, Vibhuti, 1998. Indian architectural theory and contemporary uses of vastu vidya, *Curzon press*, fig.5, fig.4, pp.7., fig. 23, pp.66.

Vastu Purusha Mandala Parameters	***IGBC Parameters***	***Common Parameters of vastu purusha mandala and IGBC parameters***	***Approach for examining the Common Parameters***
Type of *mandala,* Orientation of building, Orientation of activities, openings.	Daylighting, Skylighting, Passive architecture	Daylight, Natural ventilation	Simulation approach (through andrewmarsh tool), Perspective approach (through case studies & sections)

CASE STUDIES

Chettinad House

Introduction To Chettinad House
The name *chettiar,* is derived from the generic term *'chetty'* which denotes business communities or trading groups. They were originally believed to be gem merchants in a town called *Santhyapuri* in *Naganad*, somewhere in the north of Tamil Nadu, which has a warm humid climate (2). The parameters used for this paper are daylight and natural ventilation, which are analyzed in relation to warm humid climate.

Chettinad House Planning According To Orientation Of Activities, Daylight And Natural Ventilation
Reception is located in front of the residence, has different levels, and is used not only to welcome people but also to relax. Males use the front *thinnai* and the *verandah* for casual talks, pawning and to greet visitors and guests. The double courtyard space is the main dining space, while the side rooms are also used as storage. The courtyard area is often used as a common area as well as a place to wash hands. Multipurpose central open space serves as the initial step of private spaces, as it is located among the rooms and close to frequently used semi-public as well as commercial spaces. The service area is divided into two courtyards, one at the front with four kitchens and the other at the back with four storage rooms (2 metres on each side). The women and the servants draw water from a well (*keni*) with in courtyard. The hallways surrounding the courtyards are used as preparation areas for celebratory events. The open-air courtyards solve the kitchen's ventilation and lighting concerns while also eliminating smoke and other impurities. On the first story, with a staircase, the entire concept is duplicated. *Bhojana* hall is a common dining area shared by the two dwellings with a street entry. The main courtyard is encircled by aisles with roofs that slope into the courtyard. The open courtyard offered both lighting and ventilation, improving the space's quality. The

central courtyard is where paddy is dried, and the aisles are where people talk and sleep. *Chettinad* roofs are quite helpful in conditioning the air. The organisation of the homes in consecutive courtyards, the hierarchy of the pavilions with sloped and terraced roofs, and the recurrence of rectangular plots oriented in accordance with primary axis east/west and north/south have developed a distinct roofscape, distinctive to *chettinad* houses which aids in allowing daylight and natural ventilation to enter the building.

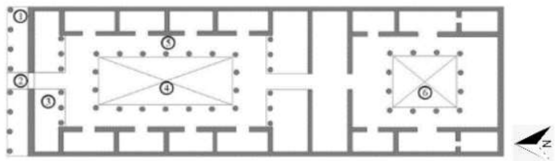


Figure 3: Plan of *chettinad* house, *1. Thinnai*, 2. Entrance Door, 3. *Pattgasali*, 4. *Courtyard*, 5. Aisles, 6. Service Courtyard

Source: Patwardhan, A., 2018. "Architecture: An Heirloom in the Context of *Chettinad,* India", *Athens Institute for Education and Research [ATINER], ATINER's Conference Paper Series*, ARC 2017-2393, Fig. 8, pp.10.

Analysis Of Application Of Vastu Purusha Mandala In Chettinad House Plan

The following observations were made when *chettinad* house plan was superimposed on *mahapitha mandala.* Furthermore, the organization of spaces were compared with the activity chart described for *mahapitha mandala* to examine that *chettinad* planning has been influenced by *mahapitha mandala* planning.

1) The plan of *chettinad* house has courtyard at the center of the main house and service area which represents *brahma* from the activity chart.

2) In the activity chart, north direction is meant for trade and south is meant for storage which is reflected in the plan of *chettinad* house where store room is in north direction whereas storage area for services is in southern direction.

This proves that *chettinad* house has an influence from the *mahapitha mandala* and its activity chart.

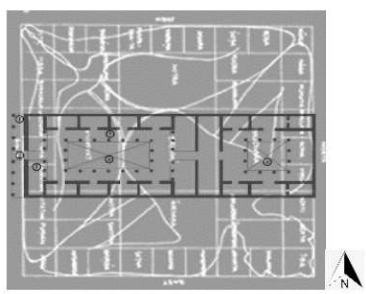


Figure 5: *Mandala* superimposed over *chettinad* house plan

Source: Chakrabarti, Vibhuti, 1998. 'Survey of texts, ancient and modern', Indian architectural theory and contemporary uses of vastu vidya, *Curzon press*, fig.4, pp.7

Patwardhan, A., 2018. "Architecture: An Heirloom in the Context of *Chettinad,* India", *Athens Institute for Education and Research [ATINER], ATINER's Conference Paper Series*, ARC 2017-2393, Fig. 8, pp.10.

Nalukettu House

Introduction To Nalukettu House

Kerala has a warm humid climate [2], *nalukettu* house has long been a desirable and well-known traditional courtyard house. Brahmins, landlords, and royalty's residences are often courtyard mansions known as *nalukettu* (*nalu*-four; *kettu*-hall in Malayalam). Following the needs of space expansions, the *nalukettu* can be expanded to form a double *nalukettu* having two courtyards (*ettukettu*) and sometimes a fourfold *nalukettu* with four courtyards (*patinyarukettu*). Several layouts adopt *vastu* prescribed principles in their spatial constraints.

Nalukettu House Planning According To Orientation Of Activities, Daylight And Natural Ventilation

Nalukettu house has a north-south orientation. The north as well as east are given precedence, hence a family temple or some religious artefacts are placed here. The ladies room is normally located on the north side of the building, and is facing south. Alternatively, the access can be on the south or west corner. (Page 9). Daily routine and religious practices are guided by the directions suggested by *mahapitha mandala*. In the morning, the entire family gathers in the dining room, which is located on the north or northwestern side of the house, adjacent to the kitchen, which is located on the northeastern side. The toilet is usually a separate entity on the northwest corner of the residence. In hot summers, the north or north-eastern side of the house remains relatively cool, making it ideal for women to rest and work throughout the day. Guests are usually hosted in the living room, which is usually on the south-eastern side. Another space is the *"ara,"* or granary, that is used to store harvested rice in a wooden tank known as a "*pathayam*." This is usually positioned on the courtyard's western or southern side. Because of the optimum temperature and air flow, the kept food is not harmed by fungus as a result of this orientation. The front *verandah* is where men spend time reading in the early hours. These *verandahs* face east, where the sun shines delicately in the morning. The bedrooms are in the southwest and west. Summers have a primary wind direction of southwest or west at night, unless another microclimatic variable modifies its course.

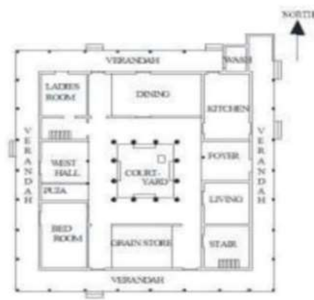


Figure 4: Plan of *nalukettu* house

Source: Choyimanikandiyil, K., 2018. Functional adaptability essence of hindu rituals and architectural elements of traditional domestic buildings in kerala: excerpt from the vedas. International Journal of Engineering & Technology, vol.7, no.3.34, 624-630.

Analysis Of Application Of Vastu Purusha Mandala In Nalekettu House Plan

The following observations were made when *nalukettu* house plan was superimposed on *mahapitha mandala.* Furthermore, the organization of spaces were compared with the activity chart described for *mahapitha mandala* to examine that *nalukettu* planning has been influenced by *mahapitha mandala* planning.

1) The plan of *nalukettu* house has courtyard at the center of the house which represents *brahma* from the activity chart.

2) The activity chart suggests that the kitchen should be placed in the southeastern direction, but when compared with the *nalukettu* house plan, the kitchen is placed in northeastern direction. This representation may be influenced by unknown local site factors, but it showcases that the kitchen is essentially placed in eastern direction in the activity chart as well as the residential case study of *nalukettu* house plan.

3) The plan of the *nalukettu* house has southwestern placement of bedroom, which when compared with the activity chart is similar as it is placed in the same direction along with the spaces such as dressing room and toilet which have attached functions to bedroom. This suggests that bedroom has been placed in the similar direction to the function of that in the activity chart.

This proves that *nalukettu* house has an influence from the *mahapitha mandala* and its activity chart.

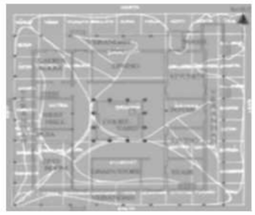


Figure 6: *Mandala* superimposed over *nalukettu* house plan
Source: Choyimanikandiyil, K., 2018. Functional adaptability essence of hindu rituals and architectural elements of traditional domestic buildings in kerala: excerpt from the vedas. International Journal of Engineering & Technology, vol.7, no.3.34, 624-630.
Chakrabarti, Vibhuti, 1998. 'Survey of texts, ancient and modern', Indian architectural theory and contemporary uses of vastu vidya, *Curzon press*, fig.4, pp.7.

SIMULATION ANALYSIS OF DAYLIGHT

The following tables studies the daylight parameter through the case studies of *chettinad* and *nalukettu* traditional housing by simulation approach.

Table 2: *Chettinad* House

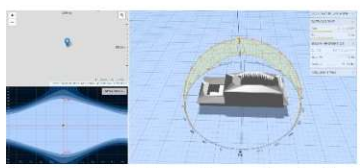
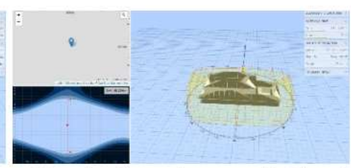
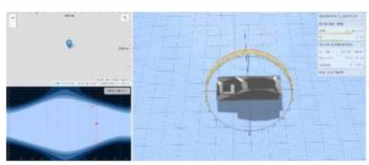
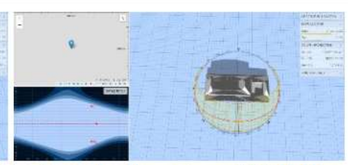
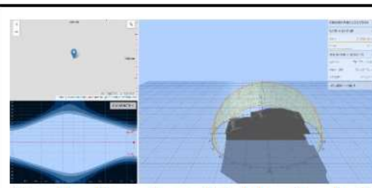
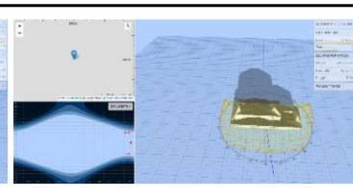
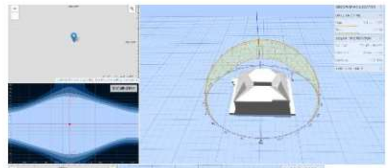
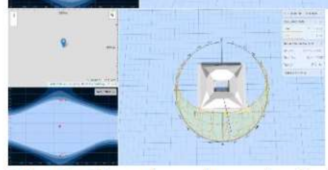
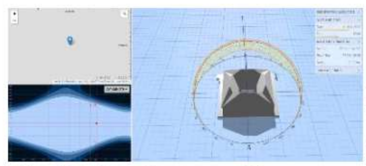
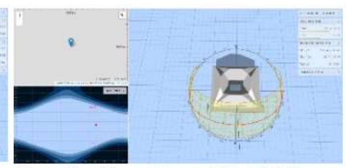
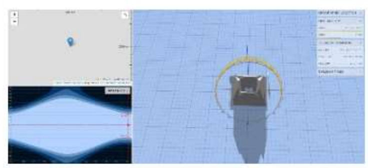
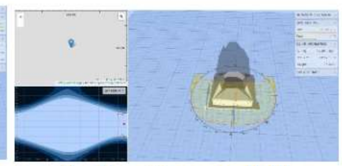
Solstices	Timings	Directions	Simulation Analysis	
Summer Solstice (21^{st} June)	12 Noon	North, East	 North direction: low shaded zone	 South direction: well-lit with low shade
Equinox (21^{st} September)	12 Noon	North, East	 North direction: medium shaded zone	 South direction: Well lit daylighting
Winter Solstice (21^{st} December)	12 Noon	North, East	 North direction: highly shaded zone	 South direction: well-lit daylighting

Table 3: *Nalukettu* House

Solstices	Timings	Directions	Simulation Analysis
Summer Solstice (21st June)	12 Noon	North, East	  North direction: low shaded zone South direction: Well lit daylighting
Equinox (21st September)	12 Noon	North, East	  North direction: medium shaded zone South direction: Well lit daylighting
Winter Solstice (21st December)	12 Noon	North, East	  North direction: highly shaded zone South direction: well lit daylighting

From the above analysis it is found that the sunrays are entering the courtyards and the verandahs but the spaces of higher occupancy such as bedrooms do not have direct sunlight entering and often have reflected light providing ambient lighting throughout the year. During the summer months, the sun's position is at a higher angle which is prevented from entering as direct sunlight to exterior portion of the structure and is often reflected from roof surfaces to light up the interiors providing ambient lighting and high shade, whereas a significant amount of sunlight enters the courtyard. During the equinox the sun's position is lower than that of the summer sun which allows a little sunlight to enter the interiors of the house providing well-lit and partially shaded areas. During the winter months the sunlight enters the external portion of the structures at a lower angle providing the higher amount of sunlight to enter the interiors with low shade, whereas in the courtyard, least amount of sunlight enters and ambient light conditions are maintained.

PERSPECTIVE APPROACH FOR NATURAL VENTILATION

In *chettinad* and *nalukettu* house use of *chajja* projections, extended roofs supported by columns, and integration of courtyards and attic spaces aids in the building efficiency through natural ventilation and stack effect. The residence's principal source of ventilation is the central courtyard which enhances stack ventilation. A garden on the western side of the house serves as a primary source of fresh air, which helps to keep the house warm during the day and radiates the heat out through the courtyard at night. The courtyard acts as a regulator, regulating the temperature of the house. As it is enclosed by rooms and is less exposed,

the courtyard creates negative pressure, because of which more air is drawn towards it. The lightest wind could be caught by using a flat roof encircled by a balustrade. *Jaali* helps in increasing the speed of the wind which helps in diffusion and reduces the intensity of glare through sunlight in interiors.
The structure hid the sun's rays while allowing the breeze to pass through, keeping the core apartments cool and fresh.

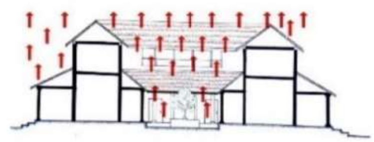


Figure 7: *Night analysis of courtyard house*

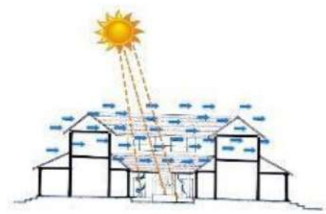


Figure 8: *Day analysis of courtyard house*

CONCLUSION

The main intention of this paper is to convey the knowledge of *vastu purusha mandala* as a sustainable design tool, where *vastu purusha mandala* is often attached to mystical and superstitious beliefs. But through this paper the term sustainability was defined with comparison to *vastu purusha mandala* through technical (simulation analysis) and theoretical (perspective analysis) approach. Though *vastu purusha mandala* cannot be followed to its fullest in any design and planning, applying it results in significant changes for the betterment of design in terms of sustainability. In this paper both qualitative and quantitative approach has been applied resulting in *vastu purusha mandala* being sustainable in terms of daylight and natural ventilation. Further the topic could be explored on larger scales and various other parameters of sustainability.

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A STUDY ON THE DISTINCTIVE USAGE OF COURTYARDS AND ITS COMPONENTS IN FIVE DIFFERENT LANDFORMS OF SOUTH INDIA AS QUOTED IN THE SANGAM LITERATURE

Praveenkumar P[1], Ananthi T[1], Grace Trivena J[1], Jeni R[1], Vigneswaran A[2].

[1] Student, Marg Institute of Design and Architecture Swarnabhoomi, Chengalpattu, India, ppraveenkumar300@gmail.com, ar.ananthi.tr@gmail.com, gracetrivena71152@gmail.com, jenithomas0101@gmail.com.
[2] Assistant Professor, Marg Institute of Design and Architecture Swarnabhoomi, Chengalpattu, India, vigneswaran@midas.ac.in.

ABSTRACT

Courtyard is the living part of a dwelling. The study aims to provide a better understanding of the courtyards found in different landforms. The research revolves around the Sangam age of the South India and its culture. This paper consists of the historical study and comparative analysis of the 5-thinais (physiographic divisions as mentioned in the Sangam literature). It provides a detailed analysis of courtyards in Kurinji (mountain), Mullai (forest), Marudham (agricultural land), Neidhal (coastal) and Palai (arid zone), which is carried out based on the components of courtyards such as their geometry, aspect ratio, vegetation and water body. It further mentions the exceptional usage of the components of courtyards found in different regions. This study establishes a well-balanced interpretation of their underlying culture, emotions and habits. It provides a detailed analysis on the evolution and usage of the courtyards with respect to their culture, climate and lifestyles. In addition, it discusses the lack of its implementation due to depreciation of spatial values and modern technologies. It concludes by providing a comparative analysis on the evolution of the spatial usage and the outcomes of the rudimentary methods.

Keywords: Courtyards, Sangam Literature, Culture, Landforms.

INTRODUCTION

Courtyard is considered to be one of the Primitive forms of Architectural Styles, it can be opted in various styles of buildings. Courtyard is one of the spaces in the house which connects it to the outdoor landform and climate of the region. It is one of the Efficient and Traditional features of Houses with Sustainable values. Reynolds says, "…a special place that are actually outside but yet almost inside to the building, open to the sky, usually in touch with the earth in many cases, but fully surrounded by the room". The Concept of Courtyard is carried over by people as part of cultural Heritage in South India, but Scientific studies shows they are also one of the most sustainable ways of constructing a house.

Sangam Landforms

The traditional treasury of the Tamil literature, the Sangam poems reflects on the concept of deploying nature and its surrounding landscape as a framework to express human love. The Sangam literature is classified into literatures of "aham" and "puram". "Aham" (interior) deals with the personal or human emotions like love in a metaphorical and abstract manner where "Puram" (exterior) deals with the contexts of people's lifestyle. The landscape of a place is divided into different types based on their geographical location. Their flora, fauna, climatic conditions, their culture and their location are correlated with each other. This classification is called as thinai. There are five thinais, namely Kurinji, Mullai, Marudham, Neidhal and Palai. (Kuruntokai, 2007)

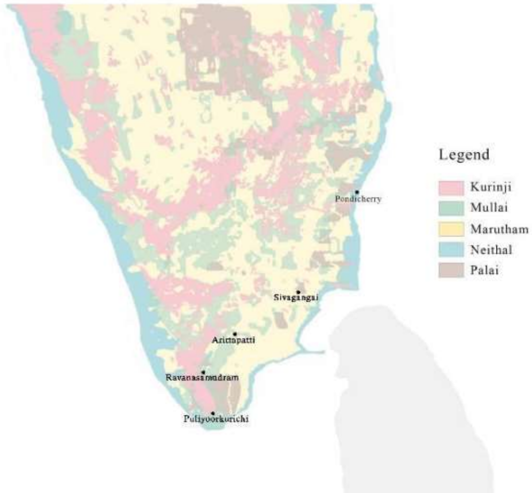

Figure 1. Five Landforms Topography and their Mapping as mentioned in Literature
Source: Author

"மாயோன் மேய காடுறை உலகமும்
சேயோன் மேய மைவரை உலகமும்
வேந்தன் மேய தீம்புனல் உலகமும்
வருணன் மேய பெருமணல் உலகமும்
முல்லை குறிஞ்சி மருதம் நெய்தலெனச்
சொல்லிய முறையாற் சொல்லவும் படுமே"
-Tolkāppiyam, Agham-5

These lines from the ancient tamil grammatical literature Tolkāppiyam illustrates, the analogy of gods and landforms, which is considered as one of the major references from the sangam literature.

Kurinji is the cool mountainous region with water in abundance. There grows a special flower, kurinji that blossoms only once in every twelve years. Elephants, monkeys and bull are some of the commonly found in this location along with bamboos, jack fruit trees and 'Venkai' maram. The tribal people living here, hunt and gather honey.

Mullai is the land of the forests where the soil is red and fertile due to the presence of rivers. This paves the way for the farmers to yield rich cultivations. The specific flower found in this thinai is jasmine and the animal is deer. The region is filled with' Konrai' maram.

Marudham is agricultural lands and the areas surrounding them which has ponds brimming with water. Agriculture is the main occupation of the people living in this area. The fresh water fish, water buffaloes and mango trees are abundant here.

Neidhal covers the seashore and is usually full of sandy soil. The place is filled with waterlily, 'punnai' maram, sharks and crocodiles. The fisher folks living here go deep into the sea to catch fish.

Palai is the desert or wasteland which is associated with the scorching summer sun. Many animals wander in this area but only cactus can be seen in this dry land. The bandits in this area steal food and other things from the travelers. (Kuruntokai, 2007).

METHODOLOGY:

In this Paper, the identification and usage of the Courtyards of five different landforms with respect to their climatic is identified. These Analysis will be on basis on the courtyard's basic dimension, positioning, orientation to their site axis and the materials used in their specific region. In traditional Indian architecture, harmony with nature was an important. In ancient days, bringing the natural elements inside a dwelling unit was done effortlessly by the builders.

The size and scale of the courtyard may vary depending on the climate zone and social culture in which it is located. The main goal is to achieve or create a pleasant frame of light and air. Courtyards traditionally served as a central space between houses/rooms owned by individual families. It acts as the focal point of the unit, which increased social interactions and strengthened internal relationships.

On the Basis of the comparative analysis done in the five landforms of the southern region, we can co-relate the connecting factors or the similarities in their distinctive elements which can obtain the people maximum comfort both in climatic and cultural aspect.

CASE STUDIES

The Case study of five different housing type courtyards in different landforms as mentioned in ancient literature are taken as an example. The analysis will be done by comparing the elements and functions of the courtyards in the given types.

Courtyard In Puliyoorkurichi, Kanyakumari (KURINJI)

In Kerala, courtyard is called nalukettu, which means 4 (four)-halls-house encircling an inner-yard. An abstract grid, a mandala, guides the configuration of the naluketta. The pattern demonstrates a concentric arrangement that places the supreme deity at the center of the mandala, where no erected form is permitted. The central order is superimposed by a diagonal hierarchical orientation, gradually sloping from the northeast to the southwest corner. This location of the rooms corresponds to this orientation.

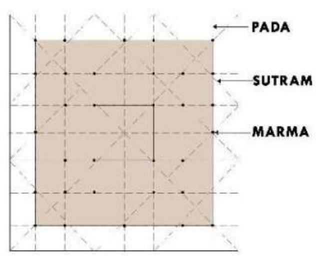

Figure 2. Marmam and Principle (Geometrical orientation Principles of Nalukettu)
Source: Author

Puliyoorkurichi is located in 10km away Nanguneri and 42km away from Tirunelveli. This village has a 700-year-old Esaki Amman temple, which was built along the fort wall. This area highlights the traditional functionality of Hindu culture and mannerism of medley zones. The geographical location of the village is such that the area experiences a pleasant weather all around the year.

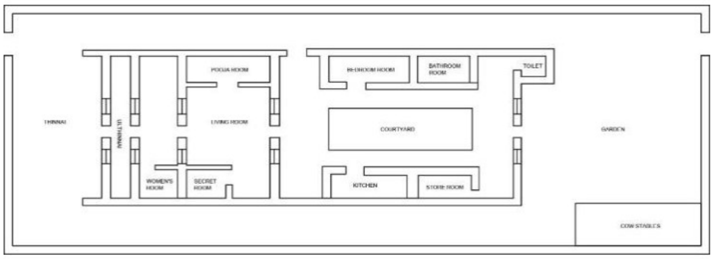

Figure 3. Spatial Zoning
Source: Author

The house is north-south oriented, facing the southern direction. The dwelling consists of a Thinnai, a central courtyard, a living hall and a few private rooms including a kitchen and room for storage. The house abuts the wide street to the front and an open yard in its rear side. Each room in the dwelling opens to the central courtyard.

Vaastu, a balanced state of positive effect and an unbalanced state of negative effect, plays a vital role in traditional Agraharam houses. The living spaces are arranged around the courtyard to allow sufficient air movement in all seasons. Balancing spaces such as Thinnai and Thazhvaram (passage around the court) allow for a gradual, smooth transition and movement of spaces. It also encourages and facilitates social interaction that leads to stronger social bonds.

Figure 4. Tulsi plant in the Central Courtyard
Source: Author

The use of the courtyard in the house has a noticeable effect on the dwelling, because it changes the thermal performance of the building. The courtyard is one foot deep, which is used as a water reservoir during rainy days. During normal days, this space is used for socializing and washing. Pitched roofs are used because the area receives a significant amount of rainfall. Mangalore tile over concrete is used on the roof to help water flow directly into the ground. Semi-covered courtyards promote sufficient ventilation and sunlight in the structure.

Courtyard in Ravanasamudram, Tirunelveli (MULLAI):
To the west of the village about 5 miles, lies the Western Ghats which is full of evergreen trees. As Ramanadhi winds along the village, it flourishes all year round. It originates from Western Ghats near Sivasailam and flows through the village until it joins the Varahanadhi. All these natural features add picturesque scenes to the village. The village has a sea of paddy fields dotted with palm trees.

The village experiences a pleasant weather all around the year as it lies at the foot of the hill. During the months of July to September, the temperature ranges from 23-26°C. November to December is the coolest months of the year where the temperature falls below 26°C. The temperature in the hottest during April and May which is below 37°C. The climate decides the calendar around which agriculture activities of the village revolve, mainly the setting-in of the northeast monsoons. The average rainfall received by this place ranges from 50 to 60 days.

Courtyard has a great impact on the thermal performance of the residences by providing comfortable living conditions for the families. Figure 3, shows the effect of openings and clerestory in courtyards, which acts as a light well, air shaft and brings both daylight and air circulation in rooms. As streets had row housing, windows are not provided in the side walls of the structures. All the windows are of the same size. The front and back door alignment enhance the wind flow. These factors allow cool air to sink and warm air to rise up. Shadow of a house during different and the minimum number of openings in the houses, minimizes the heat and allows light to enter. The shading devices, projected with eaves protects the exposed surface from direct radiation.

Materials: The brick walls are well plastered with lime-mortar, which reflect the incoming heat. To reflect heat and to get a glossy finish, jaggery or molasses, nutmeg (kadukkai) and amla are grounded to go along with the soil mortar. Fermented lime is sometimes mixed with jaggery, nutmeg and amla for construction. (IJA, 2020)

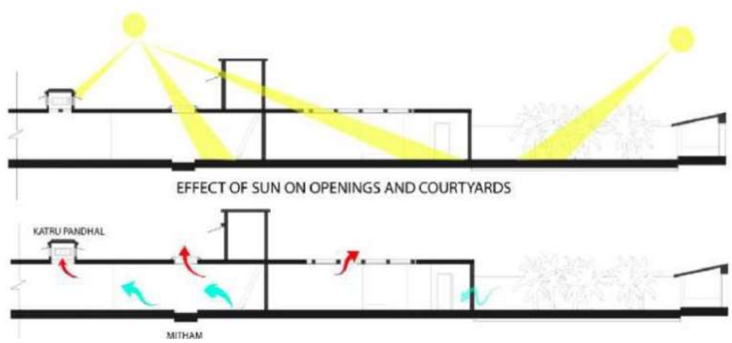

Figure 5. Effects of Openings and Courtyards
Source: IJA, (2020)

Courtyard in Arittapatti, Madurai (MARUDHAM):
Arittapatti is located near a rocky hill, which is about 24 km northeast of Madurai. This potential heritage village has an 8th century rock-cut temple of Lord Siva and Jain vestiges. It is home to many rare flora and fauna.

The selected dwelling was built in 1960, which belongs to an agricultural family of 6 members. The house is north-south oriented, facing the southern direction. It is a small 7.5m x 6.5m double roofed structure. The dwelling consists of a small courtyard, measuring 3m x 1.5m, a kitchen, a bedroom and a room for storage. The house abuts the wide street to the front and an open yard in its rear side. Each room in the dwelling opens to the central courtyard.

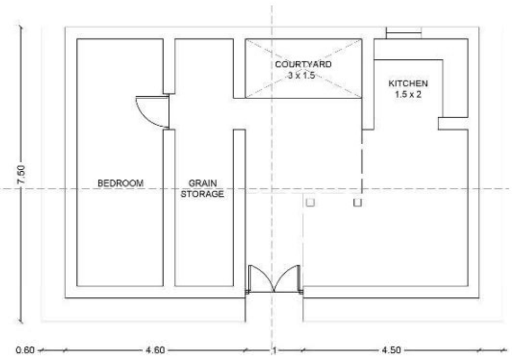

Figure 6. Plan of the mud dwelling
Source: Author

The effectiveness of passive solar features is explained based on the building's planning, its orientation, the building components, spatial design and the inhabitant's activities. The building is constructed using locally available materials like mud, wood and stone. The foundation is made of stone. Slope roof is one of the major climate responsive elements in vernacular setting. It plays a significant role in reducing the incident heat on the surface and maximum heat reflection due its angle of slope (30°-35°).

Figure 7. Courtyard of the mud dwelling
Source: Author

Though the size of the courtyard is small, it helps in providing natural diffused day light to the entire house which reduces the energy consumption to a greater extent. The habitable spaces are arranged around the courtyard to permit adequate air movement in all seasons. The buffer spaces like Thinnai and Thazhvaram (passage around the court) allows gradual, smooth transition and movement of spaces. It also encourages and facilitates social interaction which leads to stronger social bonding.

***Courtyard in Sivagangai (PALAI)*:**
Sivagangai district experiences dry climate with an average temperature of maximum 36 degree. The terrain is mostly flat. Chettinad is home to the prosperous Nattukottai Chettiars, whose affluence is seen in their palatial houses with carved teak wood doors, door frames, Mangalore tiles, decorative pillars and unique Athangudi floor tiles. In the typical traditional Chettinad house, the courtyard is the central, primary element of the house as all the rooms are built around the courtyard. The entrance of the house is east facing. Light enters mainly through the central courtyard. The opening provides fresh cool air during the day. The heat absorbed during the day is radiated out by the courtyard. The house temperature is controlled by the courtyard as its thermostatic in nature. The orientation of the building is by the cardinal directions.

Figure 8. Palatial Mansion of the Chettinad House
Source: Author

The courtyard connects the interior and exterior of the house and brings both light and cool air into the dwelling. A house with a courtyard acts as a protective envelope by keeping the outside heat at a certain distance and providing a microclimate for the house with proper shading and cooler areas, which will be the basic requirements of the inhabitants in response to the daytime temperatures due to solar radiation.

Figure 9. Palatial Mansion of the Chettinad House
Source: Author

Courtyard in Pondicherry, (NEITHAL)

The study done is the INTACH Pondicherry building, a residential converted commercial building. The rectangular building has two courtyards of dimension 4.9m x 3.7m x 4.9m x 3.2m. They are surrounded by a U–shaped corridor. The height of the courtyard is 2.3 m from the finished floor level.

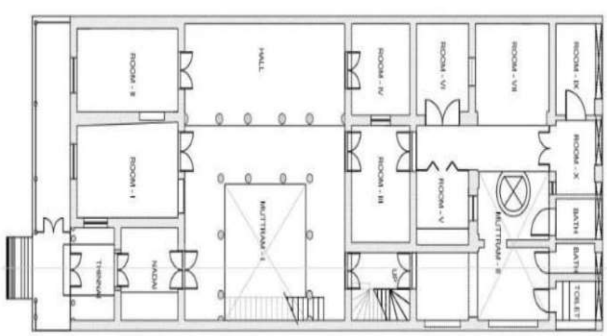

Figure 10. INTACH Building Ground floor plan
Source: Author

Figure 11. INTACH Building Ground floor plan
Source: Author

The courtyard was equipped with both functional and ornamental landscape features which purifies and freshens the air circulated inside and as shown in figure.11. The courtyard can facilitate enough natural lighting for the whole structure without any other opening in the hall.

ANALYSIS OF THE STUDY:

The study of five different courtyards in various landforms located in south India which deals with climatic conditions of their own will be analysed on the comparison basis which includes dimensions of the courtyard, Positioning of the courtyard, Usage of the courtyard, Geometry of the courtyard, etc.

Table 1. Comparison of factors in five Courtyards
Source: Author

Factors for Consideration	**Kurinji (Puliyoorkurichi)**	**Mullai (Ravanasamudram)**	**Marudham (Arittapatti)**	**Neidhal (Pondicherry)**	**Palai (Sivagangai)**
Position of Courtyard	Centre of the Dwelling	Towards the Entry and the backyard	Adjoins towards upper central Portion of the House	Adjoins towards anyone of the boundary walls	Centre of the residential unit
No. of Courtyards	More courtyards are used like nalukettu, ettukettu, pathinarukettu	Two Courtyards are provided. one for the visitors and one for the family	Only one courtyard is provided with a Minimal Aspect ratio	Two courtyards are provided with different usages and dimensions	One or more courtyards are provided with massive dimension
Ratio of courtyard space to other spaces	1:4 As they are the focal element Nalukettu principle	1:6 They are minimally used in coverage of space	1:6 Dimensions of courtyards are much smaller and oriented at center	1:5 Considered as a major interaction space, separated with corridors	1:4 Single large or multiple courtyards were used according to the climate

Climatic Aspect	The average rainfall of the Kurinji regions is very high so these courtyards act as rainwater colleting ducts and some even store them as a Temporary water body	The courtyards in this region mostly used for source of lighting and ventilation and for other cultural aspects.	In the Plains, they are used as an Element of vent ilation and connecting space of indoor to the open sky or Microcosmos	Neidhal region, as they fall over coastal zones the courtyards are considered to be a cutout for circulation of air and also reduce humidity of the indoor space	In Hot and dry climatic condition courtyards are irreplaceable, the stack effect increases airflow throughout every room that are connected to courtyard.

The comparative analysis shows that the courtyards usage in the five regions is unique and different in their own way. In terms of social aspects, they are used as a functional space depending upon their work done in their landforms such as drying fish in Neidhal, washing utensils, used as a sleeping space. Some regions use this as a worship zone with a tulsi plant at the center. The variable usage of the courtyard makes it an inevitable element of the structure and carried over from Sangam age till now.

CONCLUSION

The comparative analysis study shows that the courtyard's usage and its components in the five landforms of Southern part of India are inter related in usage and sustained till now from the Sangam age which dated back from 100 BC. Though the topography, geometry, orientation and the materials used in the courtyard vary, the purpose of maintaining a comfortable environment inside the house remains the same. Courtyards are connected with our culture very much as they become a communal space of families and social activities in most of the houses. The usage of courtyards in modern days are reduced due to the influence of Contemporary style but, the Importance of courtyard which has travelled with us from the past till now must be taken into consideration to make the dwelling sustainable and retain the cultural values of our Region.

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EVALUATION OF THERMAL PERFORMANCE OF BUILDING ENVELOPES OF NATURAL VENTILATED RESIDENTIAL BUILDINGS IN WARM HUMID CLIMATES

Madhumathi A[1], Sivakumar Paraman[2], Masa Noguchi[3] and SudhakaraPandian R[3]

[1]School of Architecture, Vellore Institute of Technology, Vellore, India; madhumathi.a@vit.ac.in
[2]Landscape Architecture Department, College of Architecture and Planning, Imam Abdulrahman Bin Faisal University, Dammam, 31441, Saudi Arabia; sparaman@iau.edu.sa
[3]ZEMCH EXD Lab, Faculty of Architecture, Building and Planning, The University of Melbourne; masa.noguchi@unimelb.edu.au
[4]School of Mechanical Engineering, Vellore Institute of Technology, Vellore, India; sudhakarapandian.r@vit.ac.in

ABSTRACT

This study compares the thermal performance of three distinct types of building envelopes used in residential buildings in Madurai, Tamil Nadu, a culturally and architecturally significant city in South India. The study's goal was to examine the thermal characteristics envelope of buildings constructed from a variety of traditional and modern materials to determine which type responded to the prevailing climate better than others and what factors or techniques may have contributed to its improved performances. The thermal behaviour, comfort, and suitability of various building techniques and materials are investigated, compared, and discussed. An experimental investigation was performed to analyse how a building envelope influences indoor conditions. Numerical modelling and software simulation was used to understand the performance of materials that are not common in the experimental location but have the potential to provide improved thermal comfort, To summarise, the study aims to identify optimal combinations of walls and roofs that provide excellent thermal comfort levels for residential buildings without the use of air conditioning equipment. The study's findings will be used to build methodological foundations for the design, construction, operation, and repair of energy-efficient Residential Building Envelopes.

Keywords: Building Envelope, Thermal performance, Experimental Investigation, Indoor thermal comfort, Optimum envelope combinations

INTRODUCTION

In most countries, residential buildings consume the majority of energy in the construction sector. (Report "Buildings and Climate Change: Status, Challenges and Opportunities", 2007). The design of residential buildings has a significant impact on people's daily lives. The majority of the energy used in buildings is used to provide thermal comfort. Building envelopes that are designed to be energy efficient can save energy in a building (Sozer, 2010). The climatic response of a building envelope is determined by the selection of building materials and their thermophysical qualities. Understanding the thermal performance of the building envelope on the indoor environment is critical for reducing energy usage in buildings. The envelope's materials influence its capacity to passively thermo-regulate indoor thermal comfort. (Balaji, NC et.al. 2013). This study concretely fixates on assessing the role of the building envelope, in cognation to comfortable air conditioning systems and appliances, in achieving energy efficiency in houses in the Indian residential sector.

Thermal performance refers to the approach of modelling the energy transfer between a building and its surroundings. (Victor Jose, 2015). These calculations enable one to evaluate the success of a building's design and contribute to the creation of improved designs for energy-efficient constructions with comfortable indoor environments. The current study seeks to evaluate a variety of building envelopes, spanning from traditional to contemporary, in terms of thermal comfort offered to the built environment. The study's purpose is to identify the best wall and roof combinations for good thermal comfort in residential buildings with natural ventilation in Warm humid climates.

RESEARCH METHODS

This investigation is divided into three stages: First, the Thermal Transmittance Value (U-value) is calculated numerically, and the results are compared to standards. The maximum value of overall thermal transmittance (U-value) of a roof in hot-dry, warm, and humid climates should not exceed 2.33 W/m2-K (EN ISO 6946-2007), whilst the U-values of exposed walls in warm and humid climates should not exceed 2.91 W/m2 -K.

The second step involved taking field measurements in residential buildings with different building envelopes - traditional, conventional, and alternative construction techniques - to assess their thermal performance. Research was done to compare the direct impact of different envelope materials on indoor thermal comfort while keeping the outdoor ambient environment constant.. During the field measurements, the residences were completely occupied, and no mechanical cooling was used. The internal and outdoor microclimates of a test room with various types of building materials in the walls and roof were measured for six days during the summer overheated period in Madurai, from April 15 to April 19, 2020. The house comparative study was carried out by conducting experimental research in rooms with uniform room sizes, ceiling heights, and window sizes. A data acquisition system (Temperature (T) /Relative Humidity (RH) data logger) was placed in the test room of houses in Madurai. The parameters that determine interior thermal comfort, such as outdoor air temperature, indoor air temperature, and indoor humidity, were measured during the experiment. At the time, the weather in Madurai was clear, and the outside air temperature in the shade ranged from 31 to 39°C. At various periods of the day, the air velocities within and outside the house were monitored with a portable anemometer. According to the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc (ASHRAE) Standard 55-2004, occupants would be comfortable at 27 degrees Celsius Operational Temperature and 75 percent Relative Humidity (with 0.27 Clo and 1 Met) if the air velocity was at least 1 m/s. A person's thermal comfort in India is between 25 C and 30 C, with an ideal temperature of 27.5 C, according to the National Building Code (NBC) 2005 (NBC 2016). Temperatures up to 35 degrees Celsius are appropriate when there is a reasonable air circulation of 1.5 m/s.

The third stage involves using a computer simulation to determine the best combination of wall and roof materials for naturally ventilated buildings in terms of internal thermal comfort. This section of the study was carried out utilising an analytical technique and the computer application SOLIDWORKS. This component of the research aims to find the best possible configurations with high thermal performance for usage in Madurai residential buildings. The results reveal that different roof and wall combinations have significant thermal effects.

DESCRIPTION OF THE STUDY AREA

Madurai is one of the world's oldest continually inhabited cities, having been a prominent settlement for two millennia (Jacob Biakkunga, 2011). Madurai's traditional city centre retains parts of its heritage characteristics/features, including traditional settlements still inhabited today. The majority of modern building envelopes are constructed of brick walls and reinforced concrete roofs. Architects are also experimenting with sustainable and alternative construction strategies. Madurai has a Warm humid climate.

Summer temperatures frequently reach a maximum of 40 °C and a minimum of 26 °C, with highs of 42 °C not uncommon. Temperatures in the winter range from 29.6°C to 18 °C. The maximum wind speed is around 8 kmph in June and July, and it is around 4-5 kmph in the other months.

DESCRIPTION OF ENVELOPE CHARACTERISTICS OF SELECTED TRADITIONAL HOUSE IN MADURAI

The research was carried out in a 150-year-old traditional residential building located within the historic community in the concentric streets of the city core. Madurai's original settlement design features small alleys and common wall systems, resulting in a dense urban fabric. Narrow street layout and wall-to-wall construction decrease direct solar radiation impacted on house walls. The colonial architectural treatment on the facades and balconies of the houses not only created visual harmony for the street architecture, but also facilitated air movement within the buildings and avoided direct radiation on the main wall of the houses.

Thermal insulation in traditional buildings in Madurai is achieved by the efficient use of materials and techniques in the construction of walls and roofs (Table 1). The experimental house's walls were up to 750 mm thick, with rows of small bricks put with lime mortar and lime plastering (Figure 2). As a result, the exterior wall is highly insulating. To achieve thermal insulation from the roof, a Madras terrace roof, which is a characteristic roof of traditional structures in south India, was erected (Figure 2).Because of its high thermal mass, the Madras terrace roof provides heat insulation, keeping the building cool and comfortable throughout the year.

Figure 1: Traditional House with natural building materials in the envelope

Table 1: Traditional House - Envelope Thermal properties

Envelope components		**Thermal Transmittance value (U)**
Brick wall -750 mm thick lime mortar and lime plastering		0.7 W/m²K
Madras Terrace roof		1.59 W/m²K
Average indoor AT, RH of Madras Terrace roof		
Parameters measured	Outdoor	Indoor
Average AT	34.5°C	26.75°C
Average Relative Humidity	46.97 %	58.92%
Wind Velocity	1-3 m/sec	0-1.5m/sec

DESCRIPTION OF ENVELOPE CHARACTERISTICS OF SELECTED CONVENTIONAL HOUSE IN MADURAI

The modern conventional house selected for experimental studies is around 10 years old. The selected case example is a one storey (with a ground floor) detached building. The choice of the house was made such that similar climatic conditions prevail for both the traditional and conventional house for a logical comparative study.

Buildings typically in warm humid conditions are built with a concrete structural system, brick walls 125 - 225mm thick with cement plaster (Figure 4), and a Reinforced Cement Concrete (RCC) roof slab (150mm thickness) with weather proofing tile terracing (Figure 4). Roof receives the most intense heat, which, along with the roof element's low thermal resistance, results in maximum heat gain through this element, which can account for up to 40% of total heat acquired into the building. The heat is then transferred to the interior spaces, producing thermal discomfort even at night for building residents. This type of roof is extensively utilised in most Tamilnadu houses and is used as a study reference roof.

Figure 2: Conventional House with Reinforced Cement Concrete Roof / Brick wall with cement mortar

Table 2: Conventional House- Envelope Thermal Properties

Envelope components		**Thermal Transmittance value (U),**
Brick wall -225 mm thick cement plastering		2.2 W/m²K
Reinforced Cement Concrete Slab with lime concrete terracing		3.09 W/m²K
Average indoor AT, RH of RCC roof/ Brick wall with cement Mortar		
Parameters measured	Outdoor	Indoor
Average AT	34.5°C	33.54°C
Average Relative Humidity	55.75%	55.17%
Wind Velocity	3-5 m/sec	1-1.5 m/sec

DESCRIPTION OF ENVELOPE CHARACTERISTICS OF SELECTED CONTEMPORARY HOUSE WITH ALTERNATIVE CONSTRUCTION TECHNIQUES

The experimental building is an architect's private residence in which the architect attempted to develop an appropriate reaction to the natural environment as well as an emotive and inspirational level design that represents his commitment to ecologically sensitive architecture. The house serves as an artefact, with a collection of alternative building envelope and Passive Cooling techniques that serve as a wonderful example for the current study.

Figure 6: Contemporary House with Sustainable Construction Techniques

The architect was inspired by traditional Chettinad architecture and attempted to recreate it in a modern manner. Chettinad's magnificent mansions exhibit a fusion of vernacular architecture and Southeast and European architectural styles. Chettinad architecture is distinguished by the utilisation of enormous spaces in halls and courtyards, as well as the construction materials, ornamental elements, and furnishings.

The traditional Chettinadu homes in Tamil Nadu, India, embody the concepts of climate responsive architecture.

The house chosen for examination is aligned east-west, with the main entrance on the east. The entire structure is three stories tall and covers an area of 750m2. The house's spatial planning adheres to a grid structure (Figure 6). All of the spaces are organised around a central courtyard, which is typical of Chettinad architecture.

The walls of the front façade, which faces east, were created as an interplay of stone, brick with stone cladding, and brick with brick cladding, making the front a highly intriguing artefact (Figure 7). These materials are thermally resistant, have a high heat capacity, and absorb solar radiation through their external surfaces. Interior walls are plastered with a particular sort of plaster known as 'Chettinad plaster,' which is made using egg plastering and numerous layers of lime base, jaggery and spices, powdered white seashells, and other materials. (See Figure 7) This mixture lasts a lifetime and keeps the area cool during the hot and humid Indian summers.

For the house's passive climatic management, several roof technologies and ceiling finishes were utilised, which also contributed to its distinct visual appearance. The roof was primarily made of the filler slab. The filler slab is a mechanism that refills the concrete in the tension zone of the RCC roof slab. The cost of the roof decreases as the quantity and weight of the concrete material are reduced while keeping the strength of the conventional slab. Lightweight, inert, and low-cost components can be used to create filler materials.

Figure 7: Envelope materials used in contemporary house with sustainable construction techniques

In the selected case scenario, two types of filler slabs were used. The first is a filler slab with a filling material of Mangalore clay tiles and an outermost layer of lime concrete terracing and clay tile. The roof's insulating capacity is improved further by completing the ceiling with a layer of clay tile (Figure 7). In the second kind, the filler slab is made of inverted earthen pots, and heat gain is further decreased by roof shade (Figure 7). When earthen pots are put on the roof slab, several air pockets form inside the container. Air gaps are always used to insulate heat. Because the air inside is lighter and rises, the contact surface of the roof should be clear of air and no heat should come into touch with the mother surface of the roof. The windows were mostly confined to the northern and southern walls. Balconies adjoin the windows on the eastern wall, preventing direct rays from striking on the windows. The windows on the western wall have been avoided.

Table 3: Modern house with alternative construction techniques- Envelope thermal properties

Envelope components		**Thermal Transmittance value (U)**
Brick wall 220 mm thick - stone cladding		1.1 W/m²K
Filler Slab - earthern pots as fillers		2.04 W/m²K
Filler Slab –Clay tiles as fillers		2.21 W/m²K
Average Indoor AT, RH of Filler slab with exposed clay tile roof		
Parameters measured	Outdoor	Indoor
Average AT	34.5°C	29.76°C
Average Relative Humidity	65.85%	55.16%
Wind Velocity	2-5 m/sec	1-2 m/sec
Average Indoor AT, RH of Roof Shading technique with Brick wall and interior Egg plastering		
Parameters measured	Outdoor	Indoor
Average AT	34.5°C	28.76°C
Average Relative Humidity	65.85%	50.99%
Wind Velocity	3-5 m/sec	1-2 m/sec

RESULTS AND DISCUSSION:

Thermal Transmittance Value Analysis

In warmer regions, low U-values are desired because they can greatly reduce heat gain and cooling loads. The thermal parameters of the examined structures (Tables 1, 2, and 3) show that, with the exception of conventional construction methods, both traditional and modern sustainable building strategies have U values that are lower than the permitted limit. Traditional building techniques, in particular, have low u values and are hence preferred. In dense urban areas, the roof is the most vulnerable to the effects of solar radiation because it receives sunlight for nearly the whole day. The walls eventually acquire temperatures close to the ambient temperature when shaded by overhanging eaves, verandas, or a green setting. Innovative Roof technology can significantly reduce energy consumption in cooled buildings while improving internal thermal conditions in non-cooled buildings (Zinzi and Agnoli, 2012). To achieve enough heat storage capacity and consequently ideal thermal characteristics, the roof can be designed as a single or multi-layered construction. A roof design with a high heat storage capacity may be advised for spaces that are used for lengthy periods of time throughout the day. Multi-layered roof forms created by combining different low conductive materials to obtain appropriate heat storage capacity may be the best choice for buildings that are used throughout the day (such as houses).

Results of Indoor Thermal Performance Analysis

The traditional building envelope of the Madras Terrace roof and the brick wall with lime mortar and lime plastering is considered an excellent thermal insulator in the experimental investigation carried out to test the thermal performance of the built environment because it has a high unit-mass. The high thermal capacity of traditional materials aids in retaining absorbed heat for a longer period of time and releasing it more slowly into the surrounding space than the other conventional materials. During hot summer days, the average internal temperature reading of the Traditional building with Madras Terrace roof (Figure 3) is 26.5°C, which is almost equivalent to the Thermal comfort level mentioned in ASHRAE guidelines (ASHRAE Handbook, 2005). The relative humidity of the tested traditional building was similarly within acceptable limits..

When the average interior air temperature measured in a house with a typical Reinforced concrete roof slab was compared to the ASHRAE criterion, it was determined that the indoor temperature does not fall inside the comfort zone. The indoor temperature is higher than the outside temperature at night. In conventional buildings, the discomfort is caused by a lack of proper thermal insulation in the walls and roofing. A room in a contemporary house built with sustainable techniques (filler slab and brick wall with stone cladding) has an average interior temperature of 29.6°C (Figure 8). The filler slab clearly outperforms regular RCC slabs in terms of thermal performance. Filler slab increases thermal comfort inside the building due to the insulating capabilities of the filler materials. The average indoor temperature of the contemporary residence's room (filler slab with earthen pots and roof shading by earthen pots and brick wall with stone cladding) ranges from 28°C to 29°C (Figure 9 and Table 3), with a diurnal variation of only about 1°C, implying that a stable indoor temperature is maintained throughout the monitored period. The average indoor temperature is 28.76 °C, which is within the tolerance threshold of thermal comfort standards. Roof shading is a simple architectural strategy for minimizing heat input on an existing roof slab.

DESIGNING FOR OPTIMUM PERFORMANCE: ROOF AND WALL COMBINATIONS

The optimal combination of the wall and the roof frequently offers the designer with unique challenges. Although the majority of heat gain in buildings occurs through the roof, the thermal comfort of the interior area is also influenced by the thermal characteristics of the walls, the size of the window openings, and the ventilation rate. The purpose of the research is to evaluate the thermal performance of various roof and wall configurations. The investigation is carried out using an analytical technique and the computer programme SOLIDWORKS.

Three types of walls (Figure 10): 1. conventional brick wall (0.23m) with cement plaster, 2.Brick wall with rat trap bond, 3.Cavity wall with double layer of brick, have been chosen to evaluate the performance of various roof types. The U values of all the roof and wall types that were tested were determined numerically. The widest used typology in Warm Humid regions was used to choose the range of wall and roof types, which was gathered through literature research and surveys. SOLIDWORKS software was used to create a three-dimensional prototype. The material properties (U Value) of the unit building's walls and roofs were altered for each run to determine the direct effect of materials on the thermal behaviour of the building (Figure 12). The model's orientation was chosen for the worst climatic conditions since the experimental study area's south west side has the highest heat gain zone. As most performance indicators, such as time lag, decrement factor, thermal damping, thermal performance index, heat flux, and heat flow rate, use surface temperature as an input criterion, the ceiling temperature was chosen as the evaluating parameter for the comparative evaluation of various roofs and wall combinations. To reduce the radiant heat load on the occupants, the roof should have a lower internal surface temperature. The ceiling temperature should not rise more than 4.5 °C above the air temperature, according to (Koenigsberger, O & Lynn, R 1965).

Assumed conditions:

Average Environmental Air Temperature (outside)	= 32.5°C
Average Internal Air Temperature (Inside)	= 25°C
Simulations run for	= 15 May 2015
Inlet air velocity	= 1.5 m/sec
Heat transfer co-efficient	= 21.3 W/m^{2}K
Intensity of incident solar radiation	= 5.59 W/m^2

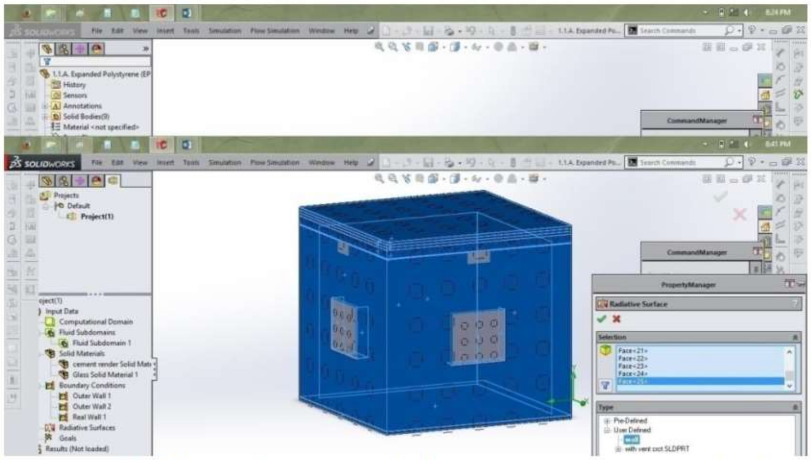

Figure 12: Assignment of thermal properties to the prototype model created for simulation of wall and roof thermal performance

Table 4: Difference in ceiling temperature (°C) and optimum indoor Air Temperature (°C) of Wall and roof combinations

	Types of roofs	U – Value (W/m2K)	Brick wall U value: 2.7	Brick Wall with rat trap bond U value: 1.42	Brick wall with air cavity U value: 1.36
	Madras terrace	0.035	8.48	8.92	6.92
	RCC-A*	1.59	10.93	11.25	11.37
	RCC-B*	3.07	9.75	10.88	10.78
	RCC-C*	2.59	12.22	12.62	13.29
	RCC-D*	3.51	6.22	1.71	0.63
	Filler slab with cement render both sides	1.4	11.03	11.32	11.32
	Roof shading in over deck and air space in between	2.14	3.83	4.48	4.48
	Roof shading by clay tile	2.15	4.15	4.21	4.21
	Green roof	2.21	1.64	1.42	-0.68
	Cool roof	2.04	11.36	11.73	11.73
	RCC with Expanded Polystyrene	1.36	3.03	3.16	3.77
	RCC with Extruded Poystyrene	0.4	8.16	2.56	3.35
	RCC with Perlite concrete	0.526	11.94	9.9	10.58
	RCC with Elastopor Insulation	0.358	1.94	1.82	2.3
	RCC with Elastospray	1.47	1.94	1.81	1.75
	RCC with Gypboard	0.425	4.6	0.57	0.67
	RCC with Wooden false ceiling	0.401	4.61	0.51	-0.33
	RCC with Bamboo ceiling	2.09	0.62	0.45	0.54
	RCC with Plaster of Paris	1.6	0.64	0.63	0.69
	RCC with Thermocol	1.89	0.64	0.05	0.67
	Roofs with phase change materials (PCMs)	1.344	6.63	4.63	4

RCC-A*	0.1m RCC + 0.05 m lime concrete (brick bats) + 0.02 m clay tile (RCC-A)

RCC-B*	0.1 m RCC + 0.075 m lime concrete (brick bats) + 0.02 m clay tile (RCC-B)
RCC-C*	0.05 m RCC + 0.015 m lime concrete (brick bats) +0.0 25 m mortar + 0.015 m terracotta tiles (RCC-C)
RCC-D*	0.025 m Clay tile +0. 125 m cement vermiculite (1:6) + 0.0 5 m RCC + 0.050 m lime concrete (brick bats) + broken ceramic tiles (RCC-D)

RESULTS AND DISCUSSIONS OF CEILING TEMPERATURES OF VARIOUS ROOF AND WALL COMBINATIONS

When the performances of the roofs with different wall combinations were compared (Table 4), it was discovered that when the wall combinations were changed, there were not too many variances in the performances of these 21 roofs. This demonstrates that, of all the building envelope components, the roof contributes the most heat gain. However, there are significant variances in the performance of various roof types. The ceiling surface temperature was compared to the permitted limit established by Koenigsberger et al. (the ceiling temperature should not rise above 4. 5 degrees Celsius above the indoor air temperature). The air temperature limit has been established at 27.5°C because, according to the National Building Code (NBC) 2005, a person's thermal comfort ranges between 25°C and 30°C, with 27.5°C being the ideal temperature. Furthermore, occupants would feel comfortable at 27°C operating temperature and 75 percent RH (with 0.27 Clo and 1 Met) provided the air velocity was at least 1 m/s, according to ASHRAE Standard 55-2004.

When compared to normal brick walls, the walls with rat trap bond and double layer brick wall with cavity performed better in terms of thermal performance. When coupled with all three types of walls, the green roof has the most acceptable ceiling temperature. When combined with modern wall techniques, the traditional Madras Terrace roof has a ceiling temperature slightly above the acceptability limit, indicating that the optimum combination of Madras terrace roof should be thick insulative walls, such as traditional brick walls of 0.45m thick with lime mortar. When paired with all three wall combinations, the basic RCC roof and its modifications, such as altering the thickness of RCC slabs or laying the weathering course (lime concrete with brick bats), failed to offer an acceptable ceiling temperature.

CONCLUSION

This study comprehensively analyzed the design principles used in the construction of a variety of building envelopes for naturally ventilated residential buildings in Madurai, Tamil Nadu, and their usefulness in providing indoor microclimate control by quantitatively analyzing their thermal performance. Traditional and vernacular architecture are brimming with climate-appropriate constructed answers. Traditional architecture contributes to the social and cultural character of a location. It is critical that this architecture maintains its integrity. This Traditional Architecture has survived to the present day. Contemporary architecture should be effectively integrated with conventional architecture lessons. The envelope built of reinforced concrete roof, often known as RCC, and brick wall with cement plastering has possibly grown as the most common envelope solution in India in recent decades, relegating traditional alternatives. While greater raw material availability, building flexibility, and the capacity to cover larger spaces have propelled RCC and brick walls with cement plastering to the top of the list, whether it is truly the best alternative remains debatable. Knowledge of previous generations' traditional wisdom through traditional building lessons can be a highly powerful tool for enhancing future buildings. Traditional building, on the other hand, involves more complex construction process and may necessitate the engagement of more skilled designers and builders. Traditional materials may no longer be available in the modern period. “Passive and Low Energy Architecture”, which takes the essence of traditional architecture and presents it in a modern sustainable way, may be the ultimate solution to the energy demanding architecture of today.

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A REVIEW ON THERMAL PERFORMANCE OF TRADITIONAL RESIDENTIAL BUILDINGS ON THE EAST COAST OF SOUTH INDIA- TAMIL NADU

Gayathri S Shivakumar[1], Sophia M[2]

[1]Associate Professor, BMS School of Architecture, Bengaluru, India. ashagayathri@gmail.com
[1]Research Scholar, Department of Civil Engineering, CMR University, Bengaluru, India
[2] Assistant Professor, Department of Civil Engineering, CMR Institute of Technology, Bengaluru, India. sophia.m@cmrit.ac.in

ABSTRACT

East Coast of South India- Tamil Nadu, experiences a warm and humid climate. Traditional residential buildings have been constructed on concepts of bioclimate design which were evolved centuries ago. The design includes effective and efficient use of natural methods and passive methods to increase the indoor thermal comfort level.
The thermal comfort performances of vernacular residential buildings have to be analyzed to evaluate the measures viz., solar passive techniques, natural ventilation, construction methodology, sustainable materials, etc. to balance the outdoor and indoor climatic conditions. Identification of sustainable architectural features provides a great insight into the thermal performance of the vernacular architecture along the coastal area of South India. Also, the comparative study of the various techniques of passive cooling in traditional and modern residential buildings in this climate zone brings out the basic requirements of thermal comfort in day-to-day life.
This review revives the principles such as climate responsiveness, sustainable features adapted in the bioclimatic architecture design of residential buildings to provide a comfortable indoor thermal environment in the warm – humid climate zone and to blend the findings with the modern residential buildings to help in the reduction of the energy consumption due to usage of electromechanical devices.

Keywords: Bioclimate, solar passive techniques, natural ventilation, sustainable materials.

INTRODUCTION

East Coast of South India – Tamil Nadu experiences warm and humid climate [1](Figure 1). The temperatures ranges from 28-41^0 with the cool breeze from the sea providing relief [2]. Rainfall received from NorthEast Monsoon is about 60% annually[3]. Winters have moderate temperatures with high moisture content in the atmosphere for most parts of the year causeing thermal discomfort due to less evaporation, resulting in sweating [2].

The vernacular structures are the fine representation of the tradition and bioclimate architecture design which shows the adaptability to tradition, culture and climate [4]. The techniques adopted are simple and practical with out sophistication [5]. This paper reviews some of the techniques used in the coastal traditional buildings. It also shows the absence of electromechanical devices in a subtle way. The focus is on the natural way of implementination of bioclimate design.

BIOCLIMATE DESIGN

Bioclimatic design is an approach to design the buildings and its landscape based on the local climate by using simple design techniques such as day lighting , sunshades, natural ventilation, passive heating and cooling etc, to create a comfortable living conditions in a building[7]. Integrating passive systems in building helps in the utilizing natural resources for thermal comfort and ventilation, depending on the local climate and other environmental sources [6].

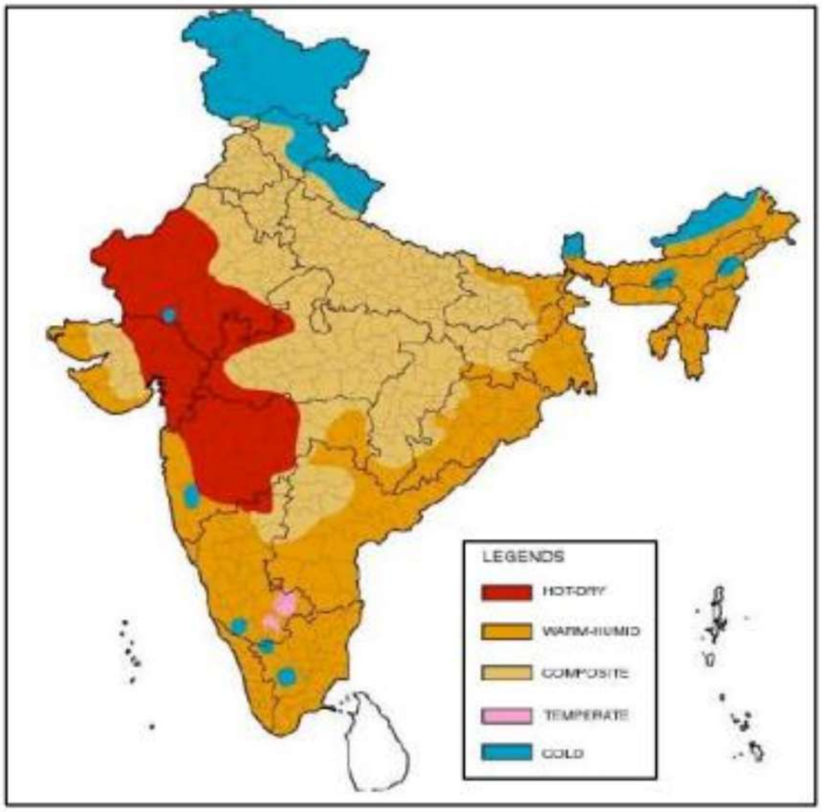

Fig. 1 NBC Climatic Region – Bureau of Indian Standard, 2016

Brenta Maria (2012) presented that the bioclimatic design improves the energy efficiency of buildings by rational usage of energy, utilization of re-newable resources, reduces environmental impact and use of eco-friendly materials, The energy benefits are obtained due to the reduction in heat losses, direct or indirect passive solar techniques and indoor thermal comfort conditions in the buildings. The indoor air-temperature are maintained during the different climates and creating a favorable micro-climatic conditions around the buildings to reduce the energy requirements [8].

Implementing the bioclimatic design in the usage of efficient energy technology, extended applied systems and avoidance of complex passive systems creates a thermal comfort in the hot and humid climate area of the coastal land [9]. Many studies have been conducted on the study of energy savings using the traditiona and passive methods in order to maintain the thermal comfort in buildings comparing with the modern techniques[13]. The traditional buildings along the east coast of India -Tamil Nadu are designed with the bioclimate concept centuries ago. These buildings provided rationalised usage of natural energy, maximum usage of renewable resourses, reduced the impacts on the environment by using the eco friendly sustainable materials. The quality of the indoor environment were improved by the usage of natural and passive cooling methods in the buildings considering the thermal comfort and energy demand[10].

SOLAR PASSIVE TECHNIQUES

Natural resourses – wind & solar are utilized as passive systems to heat or cool the building without the usage of mechanical equipments [11] and are usually combined with the shading systems with the possibilities of ventilation.

The solar passive systems are categorized as follows[8] :

Direct Solar Gain Systems	**Indirect Solar Gain**	**Isolated Solar Gain**	**Cooling systems**
Dominant Axis Openings facing the coast line Roof Openings	Thermal walls Thermosiphonic panel	Sunspaces, green houses Isolated storage wall Thermosiphonic air panel Transmission Loop	Natural ventilation Intensity of the prevailing wind directions

The working is based on the concept of exchange of energy along with the envi-ronment; including energy storage, distribution to different locations in a building. The passive systems are the components of the buildings which are integrated in the bioc-limatic design. The passive system choice targets the improvement of thermal comfort along with the highest energy savings. The passive systems require South orientation. They have to be com-bined with the proper insulation and the thermal mass[8].

The bioclimate building design which was used in the traditional buildings has benefitted in thermal and visual comfort along with durability and stability of the structures. It has been reported bu Kranti Kumar Mynani [12],[15]. that the large open spaces provides cooler indoor temperature during day time creating better living conditions. These designs provide high levels of thermal comfort during the warm and humid climates. The bioclimatic design can be implemented in the contemporary buildings – reduces the excessive usage of cooling devices and reduces the energy consumption and make the buildings energy efficient.

The buildings along the coastal region of south India traditionally have incorporated solar systems: (i) *Thalvaram* – verandah is a transition space between the street and the house; and also long extension of the house which provides shade and protects the building walls from the exposure to sun and rain, and it has a raised platform – Thinnai which is used to sit and relax[11]. (ii) Large courtyards at the centre of the building which is used socializing activities is surrounded with corridors which leads to other rooms[10]. (iii) Rear side Verandah – at the rear part of the house has a roof which provides shaded space for utility and other activities[11].

Fig. 2 Courtyards in Large Houses [16]

NATURAL VENTILATION

A simple concept to cool a building is by natural ventilation- the shape, orientation, openess,vertical shafts, ventilation/ louvered wall openings [7]. Priya et al. (2012) [9] repoted that linear pattern was followed in the construction of the houses which had east-west direction orientation facing towards the coast line; the linear design has functionally arranged rooms for various activities on the either side of the dominant axis starting from the front door to the rear door connecting the courtyards and corridors. This pattern facilitates the free flow of air and sunlight to enter the house from different points in the building.

Additional features such as Open spaces and semi open spaces as courtyards and balconies, jalli walls- provides ventilation and privacy in certain parts of the house, high ceilings with ventilators near the roof helps good air movement, large doors and windows with louvered shutters not provides ventilation but also visual connection to the surroundings. Special features such as wind catchers, are placed at the top of the courtyard for free circulation of hot and cold air in to building [9], [17].

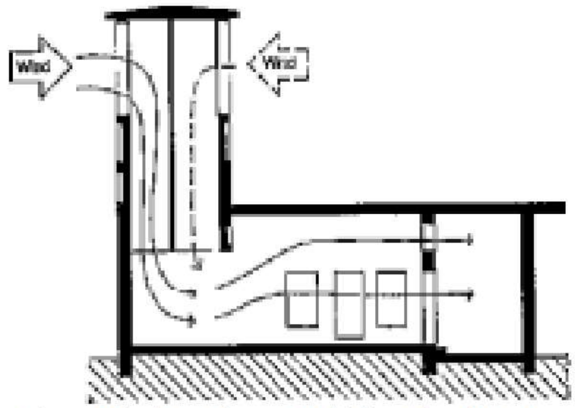

Fig. 3 Wind Catcher – Multidirectional [17]

CONSTRUCTION METHODOLOGY

Traditional construction materials like mud, brick, lime mortar, thatch roofing, country roof tiles, timber, bamboo, etc. are used as natural thermal insulators; the thickness of walls varies from 230mm to 600mm depending on the materials used, large openings for doors and windows with extended lintels and sunshades provides relief during soaring temperatures in summers; the buildings have hig roofs upto 4.5m – helps in air circulation, louvered ventilators reduces the entrapped heat in the rooms and the floorings tiles are usually made of tempered clay mix - this increases the absorption of heat and reduces the radiation too. The open spaces and courtyards have either mud/ stone flooring, which also contributes to the thermal comfort in the building. In some buildings, the roofs are provided with air void cement – vermiculite thermal insulation[14].

Fig 4 Athangudi Tiles – Locally made for flooring

SUSTAINABLE MATERIALS

Materials such as earthern bricks/ burnt bricks with lime mortar as binding materials are locally available and are economical too. The building blocks are sometimes mixed with straw/reeds to increase the strength and durability. Mud Plastering /Lime mortar plastering helps in the reduction of transmission of heat through the walls, hence its much cooler than the outside temperature. Lime plastering is also self healing hence it recues the formation of cracks due to excess heat during transmission. The walls are periodically white washed using liquid lime. This reduces the moisture absorption [11]. Locally available timber or bamboo are usually preferred for roof frames with country tiles until and unless the owner of the building prefers to lavish materials[16].

CONCLUSION

It can be concluded from this review that the traditional buildings along the eastern coast of India-Tamil Nadu provides a comfortable thermal comfort in the warm and humid climate by incorporating the bioclimate architecture design, solar passive techniques, natural ventilation, the construction methodology and the eco-friendly sustainable materials used, all these pointing out the less usage of electro – mechanical devices , leading to Energy Efficient Buildings.

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THERMAL COMFORT AND ENERGY PERFORMANCE OF RESIDENTIAL BUILDINGS IN RUSSIA

Ioana Predescu [1], Arman Hashemi[1*], Alex Scott-Whitby[1], Guy Eames[2], Svetlana Alekseyevna Zabelina[3], Kirill Borisovich Zubkov[3], Narguess Khatami[4]

[1] University of East London, School of Architecture, Commuting and Engineering, London, UK
[2] Planet 2030 Ltd., Peterborough, UK
[3] MASI University, Moscow, Russia
[4] Mott McDonald, London, UK
[*] Correspondence: a.hashemi@uel.ac.uk

ABSTRACT

Currently, around 50% of the Russian housing stock needs renovation. Although the annual energy consumption for residential buildings in Russia seems to be within the recommend good practice ranges, they may not provide a thermally comfortable environment for their occupants, due to the significantly lower heating set points compared to the UK. This paper investigates the current conditions and methods to improve energy performance and thermal comfort in residential buildings in Russia. Dynamic thermal simulations are conducted using IES(VE) to assess thermal comfort and energy performance in a multi-story residential case study building. CIBSE TM59 and PMV assessment methods were used to investigate the thermal comfort conditions during summer and winter, respectively. Different combination scenarios for heating setpoints, external shading strategies and refurbishment strategies were considered to assess the effects of these strategies on energy and comfort in the building. The results reveal that energy consumption was significantly reduced by over 94% for the high-performing refurbishment strategies, while thermal comfort was marginally improved.

Keywords: Residential Buildings, Retrofit, Energy Performance, Thermal Comfort, Russia.

INTRODUCTION AND RESEARCH CONTEXT

According to (С.В. Корниенко, 2018), currently, 50% of the Russian housing stock is in need of renovation, this is because the housing percentage was constructed during an industrial era, where thermal comfort in buildings wasn't the main focus, leading to the currently unsatisfactory Russian housing stock. During the Soviet Union, the main construction method was masonry, or precast concrete panels with no insulation (Satu Paiho Å. H., 2013). Currently, modern construction still practices the use of precast concrete panels with either an exterior concrete surface or ceramic tiles with little or no insulation (Satu Paiho Å. H., 2013). This method of construction leads to poor thermal insulation which does not meet modern standards (Satu Paiho Å. H., 2013). The poor construction is one of the reasons why Russian construction is unable to reach its full energy potential. Additionally, the ineffective energy infrastructure, does not adequately meet the requirements of the long heating season (Satu Paiho Å. H., 2013), which degrades the energy efficiency even more. According to (Satu Paiho I. P., 2015), 60% of Russian multi-family apartment buildings require renovations or repairs, and this is rising to 93-95% in apartments less than 25 years old. The lack of renovation is also affecting the residential buildings and their compliance with modern standard requirements for the thermal insulation of the building envelope, which have been increasing since 2000 (Modin, 2020). Russia is considered to have a big potential for energy conservation; however, due to the knowledge gap and the rather old infrastructures, 40-45% of the consumed energy is related to household needs, 10% of which is wasted. Other sources indicate that, compared to other developed countries that use half of the energy construction, Russian buildings account for 38% of the primary energy consumption (Bashmakov, 2017); (A I Gabitov, 2019). According to, (Sirvio Anu, 2015) and (Modin, 2020) the main source of energy and heat losses are related to the outer walls, windows, air leakage through joints, holes, and ducts. Therefore, to reduce the share of heat losses, some design changes should be considered; including insulation of walls from the outside, replacement of low-performing windows and doors, and thermal insulation of structural elements (Modin, 2020). When it comes to climates, such as in Russia, breathable insulation such as mineral wool is recommended (Modin, 2020). A few solutions that could be applied to improve energy efficiency in residential buildings, include the improvement of space heating, water heating, improvement of water delivery systems, increased thermal resistance of building envelopes, using Low-E coated windows, reduced air infiltration, optimized fuel and energy consumption (T Lychuk, 2012) and (Korniyenko, 2018).

According to (A I Gabitov, 2019) Russia, for the second half of the 20th, century, has annually used 350-380 kWh/m^2 purely for heating residential buildings, which is 5-7 times higher compared to other European counties. Other sources indicate that the heating energy consumption during heating seasons in old buildings is 150-200 kW/m^2, (С.В. Корниенко, 2018). Retrofitting these buildings would decrease energy consumption by half. During the initial analysis, a major gap in the knowledge was identified in terms of thermal comfort, energy efficiency benchmarks, and the internal comfortable temperatures in buildings. To this end, this paper aims to assess the current conditions of the residential buildings in Russia, based on an existing case study. The assessment will be undertaken using existing Russian data, with the aim of using a parametric design method where four main scenarios are simulated and analysed including insulation, infiltration rates and shading strategies to understand how thermal comfort and energy consumption are influenced by these.

RESEACRH METHODOLOGY

Dynamic thermal simulations are done in IES(VE) to assess comfort and energy performance in a case study residential building in Kazan, Russia (Figures 1 &2). The current and optimal U-Values for the Russian construction as well as the UK (CIBSE Guide A) (CIBSE, 2021) and Russian set points are used. Thermal comfort assessment will be based on CIBSE TM59 (TM59, 2017) for the summer period (Table 1), and PMV for the winter period, to understand the current thermal comfort and energy consumption conditions in Russia.

Four main fabric scenarios are considered, aiming to understand how different u-values, setpoints and air change rates affect the thermal comfort and energy consumption as follows.
Building Fabric:

- The scenarios will be: Base Case (worst scenario),
- Basic Renovation Case,
- Improved Case and Passive house case (best scenario).
- Passive house
- Shading on south facade:
- No shading
- 0.5m
- 1m.

Heating set points (CIBSE, 2021) as shown in Table 2:

- Russia
- UK

A total of 24 combination scenarios therefore are simulated for four different fabric standards, two types of shading systems on the south façade and two heating set points.

Table 1: Criteria for TM59 (CIBSE TM59 2017)

Naturally ventilated dwellings	Criteria 1	Criteria 2
Location	Living rooms, Kitchen, bedroom	Bedroom
Degree	time greater or equal to 1	not exceed 26
Action		Sleeping
Time	May to September	10PM to 7AM
Percentage	no more than 3% occupier hours	no more 1% of annual hours

Table 2: Building Fabric Data for simulation

Building Fabric			
	Wall W/m2 K	Window W/m2 K	Air Change n50 (1/h)
Base Case	1.1	2.9	0.325
Basic Renovation Case	0.5	1.85	0.2
Improved Renovation Case	0.32	1.5	0.1
Passive House Case	0.1	0.8	0.05
Heating setpoints			
Russian Scenario	16 °C		
UK Scenario	18°C Bed- 22.5°C Living - 18 °C Kitchen		
Shading			
Shading 1	No Shading		
Shading 2	0.5 Meter		
Shading 3	1 Meter		

The occupancy levels were taken from the TM59 template (Table 3). For the PMV assessments, the heating system was considered to be on from October to March and off from April to September. Also for the TM59 thermal comfort assessments during summer time the heating was off during the summer period from April to September (TM59, 2017). Additionally, during summer time a window opening schedule was applied to open the windows every time the temperature in the room exceeded 22 C to meet the TM59 Criteria.

Table 3: Occupancy Profiles (CIBSE TM59 2017)

Occupancy Profiles	
Unit/room type	Occupancy
Studio	2 People at all times
1-Bedroom: Living room /Kitchen	1 Person from 9am to 10 pm
1-Bedroom: Living room	1 Person at 75% gains from 9am to 10 pm
1-Bedroom: Kitchen	1 Person at 25% gains from 9am to 10 pm
2-Bedroom: Living room	2 Person at 75% gains from 9am to 10 pm
2-Bedroom: Kitchen	2 Person at 25% gains from 9am to 10 pm
Double Bedroom	2 Person at 70% gains from 11pm to 8 am
	2 People at full gains from 8am to 9am from 10pm to 11pm
	1 person at full gain in the bedroom from 9am to 10pm

DATA ANALYSIS AND DISCUSSION

The results are reported for Flat 1 (64.9644 m2) located on the first floor with two bedrooms, a living room and an open kitchen. The results are divided into 3 parts for the PMV and TM59 for thermal comfort and the overall Energy consumption of the case study building.

PMV Thermal Comfort (winter time)

Figure 3 shows the PMV results for the Base Case scenario, where thermal comfort has been achieved during the winter period in the bedroom but not for the open plan for the UK set points whereas for the Russian heating set point the temperatures are significantly lower resulting in thermal discomfort. Additionally, in Figure 3 it can also be noticed that the 0.5m or the 1m shading does not have a meaningful effect on the PMV results. Additionally, after careful analysis, it is noticed , that in April and October, before the season change, temperatures decrease significantly in April resulting in a PMV between 0.4 and -0.4. In figure 4, where the condition of the external envelop was improved it is noticeable that the PMV in the UK and Russia cases, has improved, making the rooms thermally comfortable. Compared to the previous results, Figure 5 has significantly improved the results, with the improved case the rooms are fully meeting PMV reaching 0.5 results in the UK case where the set point is higher. Figure 6 shows the Passive House case, where the thermal comfort is comfortable in both Russian and UK case point cases, the reason is due to the high insulated envelope, which offers a very comfortable building during the winter period. In all figures, it is noticeable that at the end of the winter season, April tends to be overheated, especially in the passive house case (Figure 6) the rooms are reached a 1.0 PMV in the UK case and a 0.6 for the Russian setpoint case. Implying that the heating should be closed at the begging of April to keep the building thermally comfortable. Overall, not even one of the four fabric scenarios has been majorly affected by shading.

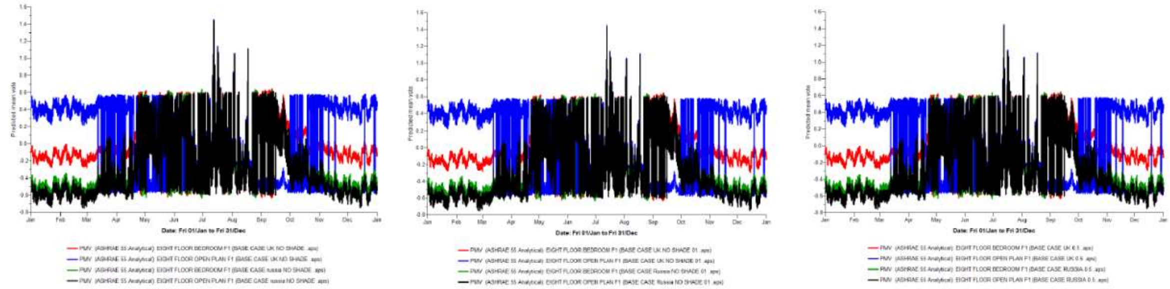

Figure 3: PMV results BASE case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

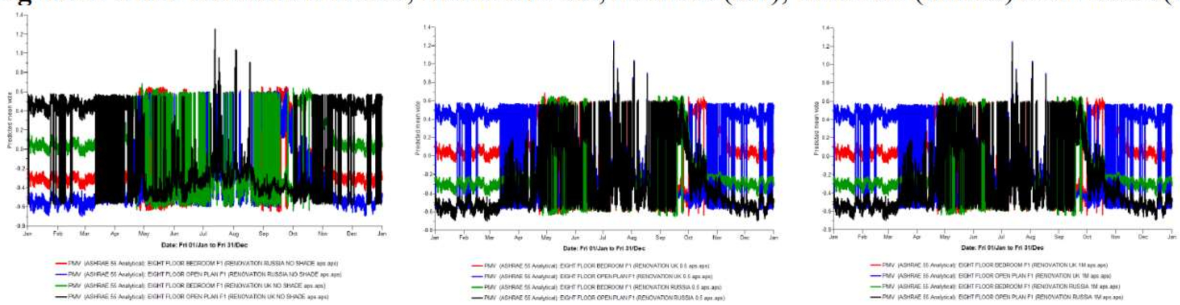

Figure 4: PMV results BASIC RENOVATION case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

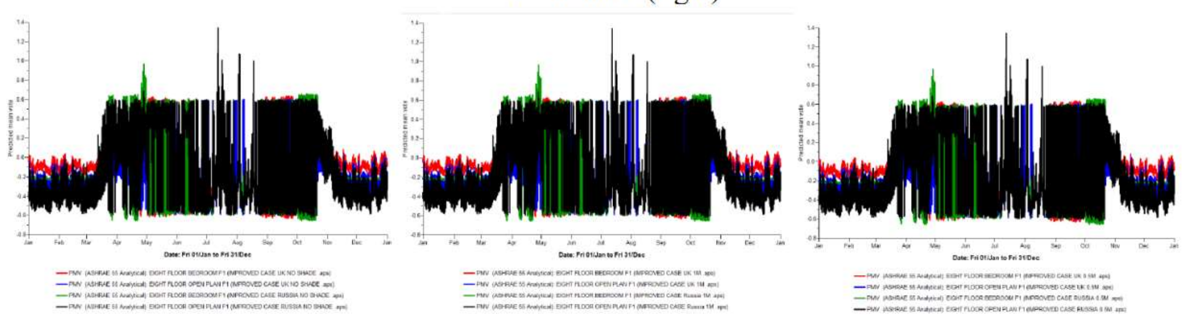

Figure 5: PMV results IMPROVED case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

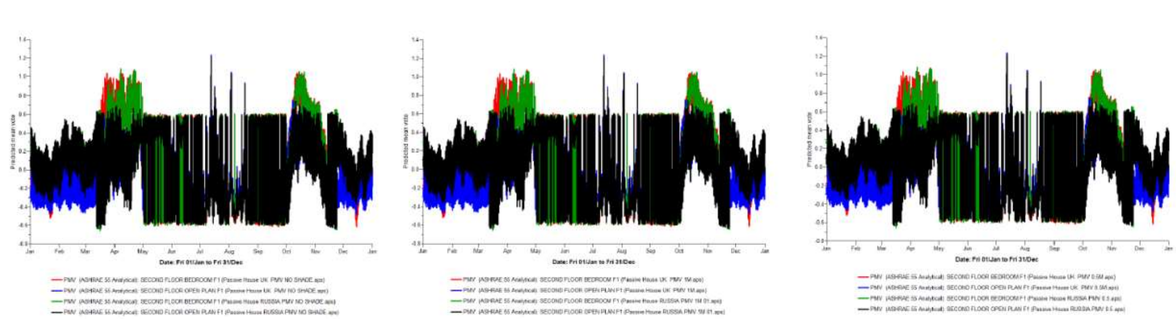

Figure 6: PMV results PASSIVE HOUSE case, Russia and UK, no shade (left), 1m shade (middle) 0.5m shade (right)

Table 4, shows the percentage of occupied hours when PMV was met during winter in Fat 1. II. This shows that the this flat has passed PMV requirements in all four scenarios with an average of 80.12%

for the UK and 71.61% for the Russian setpoint. As expected in the Russian case, where the set point is lower, PMV is less achieved compared to the higher set points used in the UK. For the base case scenario, thermal comfort conditions in the Russian case are below 55% and 78% for the open plan and bedrooms respectively, demonstrating the excessive thermal discomfort during winter. When the construction was poorer and with a better set point, the building reached a higher thermal comfort during winter. For the improved case and passive house cases the results improved significantly; however, for the basic renovation thermal comfort deteriorated. The latter requires more investigation to identify the reasons.

Table 4: UK % Occupied hours meeting PMV

	UK Setpoint%	Russia Setpoint%
Base Case % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	74.8	53.8
First Floor Bedroom F1	86.5	77.7
Basic Renovation % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	71.7	56.9
First Floor Bedroom F1	81.5	83
Improved Case % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	84.9	76.9
First Floor Bedroom F1	81.1	78.5
Passive House Case % occupied hours meeting PMV +/- 0.5		
First Floor Open Plan F1	94.8	77.6
First Floor Bedroom F1	65.7	68.5

Energy Consumption

The annual energy consumption has been assessed based on four different fabric scenarios each having different U-values for the external envelope of the building and different air change rates. Table 5 shows the final results representing how much energy has been used annually for the Russian and the UK setpoints. The results show that the annual energy consumption is reduced in every scenario in the Russian case; going down from 124.2193 MW/h with the base case scenario, which has the worse construction, to 4.4598 MW/h with the passive house. This is a reduction of over 94% in energy consumption. The addition of shading did not have a meaningful influence on energy consumption.

Similar to the Russian case, the energy consumption for the UK condition is reduced for the improved fabrics. Another comparison that can be observed is in the UK scenario the energy levels tend to be four times higher compared to the Russian data results, this is caused by the higher sets points used in the UK which will lead to higher consumption of energy to heat the room and reach a thermally comfortable room.

Table 5: Total Annual Energy Consumption

	Total Nat. Gas (MWh)	KW.h.m-2
Base Case -Russia	124.2193	75.02
Base Case -UK	168.7592	101.92
Basic Renovation -Russia	58.6319	35.44
Basic Renovation -UK	90.2058	54.48
Improved Case -Russia	28.0184	16.92
Improved Case -UK	59.3530	35.84
Passive House Case -Russia	4.4598	2.69
Passive House Case -UK	13.3217	8.24

The UK residential energy benchmarks (CIBSE GUIDE F, Table 20.1), identifies an energy consumption of 247 (kW·h·m–2) as the good practice and 417 (kW·h·m–2) as the typical practice. Table 5 shows that the UK benchmarks are met in all four scenarios, for both the UK and the Russian setpoints. Given that the simulations are based on the analysis of an intermediate floor, since the assessed flats are generally exposed to external weather conditions on one or two sides, the average energy consumption per square meter of the flats is meeting the benchmarks and in fact significantly lower than the UK benchmarks. It should also be noted that the lower energy consumption in Russia is due to the lower heating setpoints compared to the UK.

Adaptive TM59 Thermal Comfort (summertime)

Figures 7,8,9,10 illustrate the operative temperatures achieved in Flat 1. The results show that Flat 1 is passing the criteria set by CIBSE TM59 because the temperatures did not exceed the maximum of 26 degrees. These results show that the construction and the different U-values and air change rates as well as the addition of a shading system do not significantly influence thermal comfort in the building during summertime. For improved construction types, the lowest temperature that Flat 1 is between 19-20 degrees, in comparison with Figure 8, where the temperature can go as low as 16 in May. The 5 C degrees difference may be due to the construction of the building which has been significantly improved in the Passive House scenario.

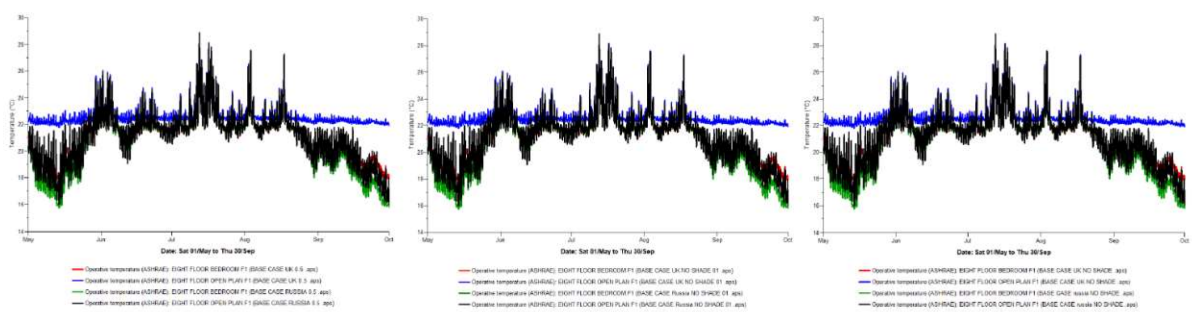

Figure 7: Operative Temperature Base Case Russia + UK 1/0.5m and NO shade Flat 1

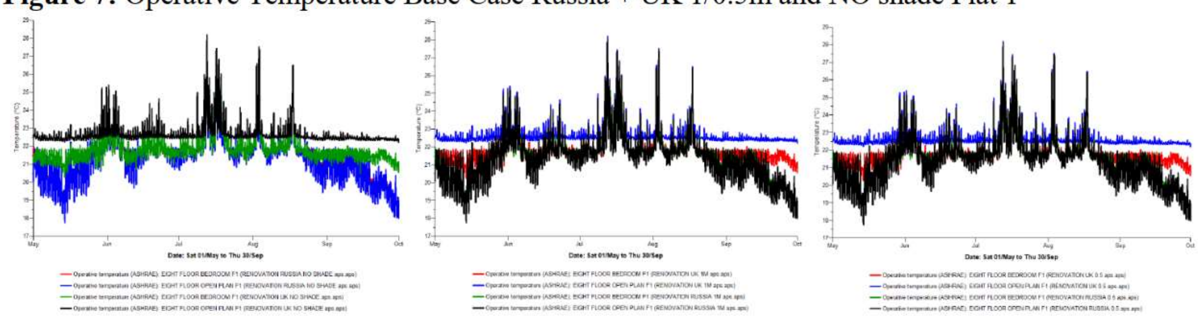

Figure 8: Operative Temperature Basic Renovation Case Russia + UK 1/0.5m and NO shade Flat 1

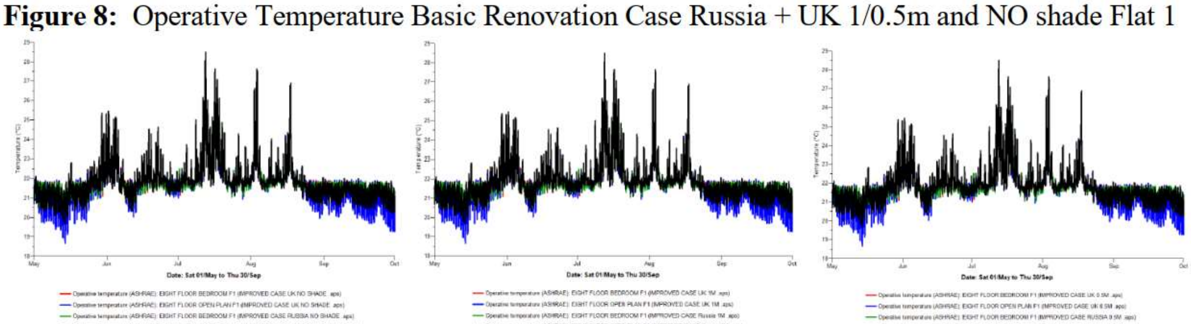

Figure 9: Operative Temperature Improved Case Russia + UK 1/0.5m and NO shade Flat 1

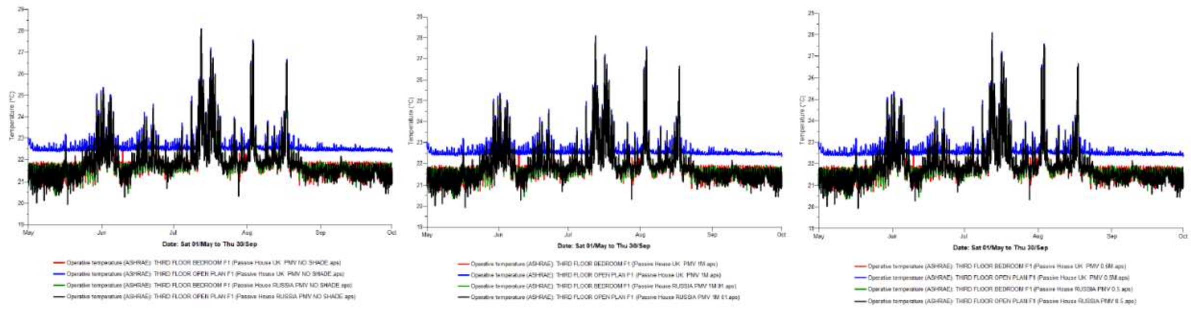

Figure 10: Operative Temperature Passive House Case Russia + UK 1/0.5m and NO shade Flat 1

DISCUSSION

Overall, the PMV results show a major difference between the Base Case and the Passive House scenarios, implying that the differences in U-values have a major impact on thermal comfort during winter. Generally, the PMV results indicate that thermal comfort has been achieved at 76% on average in all 24 scenarios. On the other hand, CIBSE TM59 requirements have been successfully achieved during the summertime. This implies that the comfort conditions have not been influenced by the construction of the building; however, improved construction has been effective in keeping the temperatures high during the winter to summer transition. As for the operative temperature, PMV has not been affected by the addition of shading. The reason for this may be due to the building orientates (west and east) and the size of the glazing/windows. In terms of the energy consumption of the building, assessed and compared against the UK's benchmarks for residential buildings, the UK and Russian scenarios successfully meet the benchmarks. While the benchmarks are met, it is noticeable that energy consumption in Russia has reduced by over 94% for the passive house condition compared to the base case. For the UK case with higher heating setpoints, the improvement has been over 92%. This indicates a significant potential for energy saving if the existing buildings in Russia are retrofitted to the passive house standards.

CONCLUSION

This paper analysed energy performance and thermal comfort in a typical multi-story case study building in Russia. A discrete amount of information concerning energy consumption and construction methods gives a clear understanding of how Russia is approaching industry development and the new sustainable implementations required worldwide. This said, despite meeting the UK benchmarks in terms of energy performance, the current situation (lower heating set points and defective construction methods) means that thermal comfort is dramatically failing in many residential buildings particularly during winter making them too cold. This could affect the health and well-being of the occupants of these buildings in the long term. The effects of different U-Values, airtightness, shading and heating setpoints were assessed in 24 different combination scenarios. The results showed that thermal comfort was marginally affected by the construction type and shading. In contrast, there was a strong correlation between energy consumption, the building fabric quality (in terms of U-Values and airtightness) and the different heating setpoints. These had a significant impact on the annual energy consumption resulting in a reduction of over 94% for energy consumption in the passive house case. Retrofitting the existing buildings to achieve higher energy efficiency standards could therefore significantly reduce energy consumption and Green House Gas emissions in Russia. Additionally, a better-insulated envelope would result in a thermally comfortable space for the occupants by keeping the heat inside. This said the current internal temperature norms of 16 C in Russian residential buildings is open to question as to whether this could achieve a thermally comfortable space without affecting the occupants' health and wellbeing. More research is required on the effects of various issues such as the inefficient infrastructure and various retrofitting strategies on energy performance in Russian buildings.

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IMPACT ON CLIMATE CHANGE DUE TO REDUCTION OF CARBON EMISSION BY ADOPTING LOCALISED ADAPTIVE THERMAL COMFORT MODEL: A CASE OF MUMBAI, INDIA

Anand Achari[1], Trupti Mishra[2], Bakul Rao[2]

[1] VES College of Architecture, India (anandachari@gmail.com)
[2] IIT Bombay, India

ABSTRACT

As cities become economic hub, they attract higher population looking for better economic opportunities and become main contributor to global warming (KeTTHA, 2011). Cities are also great places to cut carbon emissions due to their centralised facilities, large population size, and rational use of land (Chan et al., 2013). Every third house in Indian cities will have an air conditioner by the year 2030, this brings along great challenges of carbon emissions due to largely coal reliant energy. Highest use of energy in building sector is for thermal control. Mumbai city is fast growing market for residential apartments, and is on a similar path of experiencing energy consumption and carbon emissions due to cooling requirements in the warm and humid climate.

Impact of using localised adaptive thermal comfort model on Mumbai city's CO_2 emissions was observed in this study. The change in cooling degree days (CDD) and corresponding energy consumption-based CO_2 emissions were calculated for various future scenarios and compared with the present conditions.
The use of set point of 28°C as suggested in present study immediately will drop the CO_2 emissions to about 1/6th, and the future CO_2 emission will drop to 3/5th. Almost 696 GWh annual energy consumption can be reduced if LATC is used. This saving is enough to power residences of about 2008 average Indian villages (assumption of 1826 kWh/day/village and 52% used for residential) (Smart power India, 2019). The reduction of 337 Kilotons annual of CO_2 emission is possible if LATC and aggressive mitigation strategies implemented, which is equivalent to that absorbed by 19 forests of the size of Sanjay Gandhi National Park (SGNP) in Mumbai (CPCB, 2021).

Keywords: Localised Adaptive comfort, Warm and humid, Cooling Energy, Carbon emission, Climate change.

INTRODUCTION

In most of the tropics and subtropics which are home to a large majority of the world's population and characterised by increased densities, maximum temperatures in summer are now 40 degrees Celsius or more, and are predicted to rise further. (Lundgren & Kjellstrom, 2013). Residential stock historically was built based on the need for comfort. However today, most of the existing stock is designed based on the mass – produced easily available materials and standard layouts leading to a poor design in relation to the climate. Inadequate surface–volume ratios, bad building orientation, and poor natural ventilation all contribute to a rise in indoor heat levels, which has significant repercussions for occupants' physiological comfort and health (Isaac & Vuuren, 2009; Lundgren & Kjellstrom, 2013).

The repercussions of this is an increasing need for mechanically induced ventilation and space cooling. Air conditioning, in an effort to make their living more comfortable is likely to be increasingly used all year around. High-income countries are not driving growth, but middle-income countries, particularly emerging economies like India and China (Isaac & Vuuren, 2009; Lundgren & Kjellstrom, 2013; Davis & Gertler, 2015). Air conditioners keep a building cool on the inside, but release a lot of waste heat to the atmosphere leading to an increase in atmospheric temperature and overall warming

(Nuruzzaman, 2015; De Munck, et al., 2013; Lundgren & Kjellstrom, 2013; Kikegawa, Genchi, Kondo, & Hanaki, 2006; Hsieh, Aramaki, & Hanaki, 2007). This further increases the street air temperatures at the night-time causing additional electricity consumption due to night-time usage of Air-conditioners (De Munck, et al., 2013; Lundgren & Kjellstrom, 2013; Hsieh, Aramaki, & Hanaki, 2007).

All indicators project an ever-increasing trend of urbanization that will in turn lead to an exponential growth in the energy sector. Households consume 33% of all end-use energy globally (Isaac & Vuuren, 2009). There are three main reasons cited for the increase in Residential energy consumption (REC) as per Prayas's report, 2016. The first is that India is aiming to provide uninterrupted electricity to all its households. The second is, with the increasing income over time and growing aspirations people will opt for high electricity consuming appliances. New- technology, though may be energy-efficient when developed well adds to the affordability of the appliances (Chunekar, Varshney, & Dixit, 2016).

Energy consumption for cooling:

Out of all the electrical appliances air-conditioners are the biggest electricity guzzlers (Phadke, Abhyankar, & Shah, 2014, Chunekar, Varshney, & Dixit, 2016). This drastically contributes to the growing energy demand and hence has a negative impact on the climate. In many cities, electric air-conditioning consumes 30–50 percent of total electric energy utilised during the summer, and in certain commercially developed cities, this proportion even exceeds 50 percent (Li, et al., 2014). The additional air-conditioning use due by the increase in urban air temperature accounts for 5–10% of peak energy demand in cities (Akbari, 2005). Residential air conditioning energy demand is expected to increase more than 40 times in 2100 compared to 2000, with an average annual growth rate of 7%. This development is without the additional effects of climate change, which could result in an additional 50% increase in consumption (Lundgren & Kjellstrom, 2013). Global energy consumption for air conditioning is expected to rise from about 300 TWh in 2000 to 4000 TWh in 2050 unless more mitigating initiatives are implemented (Chalmers, 2014) India has 300% the population of the United States, but more than 300% cooling degree days (CDDs) per person. If India adopts an American cooling standard, its entire potential cooling demand will be 14 times that of the United States (Sivak, 2013).

Scenario in India:

India is at a unique crossroads where 70% of building stock required in the year 2030 is yet to be built (Kumar, Rawal, Seth, & Walia, 2010). As per UN projections The population of India is expected to expand for several decades, reaching over 1.5 billion in 2030 and surpassing 1.66 billion in 2050 (Department of Economic and Social Affairs, Population Division , UN, 2017). According to most assessments, India's overall residential floor space will be far more than its entire commercial floor area (Global Buildings Performance Network (GBPN), CEPT, 2014). Mumbai follows the same trend with a rise in residential numbers indicating a projected population of 33 Million in 2030 (McKinsey and Company, 2010). The rise in the residential numbers and an increase in the owning capacity indicate a further rise in the penetration of AC's in the near future in India unless design interventions leading to a better layout focussing on a natural mode of ventilation are made. According to ICAP, India's cooling demand will become 8 times by 2037-38, and 11 times for Building Sector compared to the baseline 2017-18. It is also noted that 30% reduction is possible due to intervention from better design and technology. India Cooling Action Plan (ICAP) aims at reduction of cooling, refrigerant, and cooling energy demand across sectors by 20-25%, 25-30%, and 25-40% respectively by 2037-38. It also recognizes "cooling and related areas" as a thrust area of research. (ICAP, 2019)

Current building trends and dynamics – population growth, growing floor area, significant increases in new construction, and a big inefficient existing building stock, to mention a few – all contribute rapidly to CO_2 emissions (Global Buildings Performance Network (GBPN), 2013). If the energy source is not renewable, increasing AC use increases power consumption and urban heat island effect (Lundgren & Kjellstrom, 2013). Air - conditioning apart from producing large amounts of waste heat and an increase in fuel consumption, increases the emissions of CO_2, SO_2 and NOx leading to air pollution and carbon emission thus contributing to global warming. (Li, et al., 2014)

Globally, buildings account for over 30% of all energy-related CO_2 emissions (GBPN, 2013). At the regional scale, according to Issac and Vurrens' research, India would be the most severely affected region in the long term, accounting for more than 66% of world's carbon emissions related with increasing cooling and heating requirements due to climate change. (Isaac & Vuuren, 2009). CO_2 emissions increased almost two-and-a-half times in India between 1990 and 2014. Coal is India's main energy source, with resources of around 186 billion tonnes compared to 221 million tonnes produced in 1990-91. Coal will continue to meet more than 60% of India's energy requirements. Coal, on the other hand, has the greatest CO_2 emission coefficient. Indian per capita emissions will rise from 1.7 in 2012 to 3.7 tons/capita in 2030, and further to 5.8 tons/capita for the supply mix. (NITI Ayog, 2015).

An analysis of the growing demand in the cooling sector shall help understand its impacts on the energy demand and thus the subsequent emission increase. The objective of this study is to identify the impact of change in set-point temperature of air-conditioning on climate change in Mumbai. Calculating the energy consumption of air-conditioning in the residential sector in Mumbai shall help analyse the demand and understand the CO_2 emissions from this sector.

METHODOLOGY

Impact of using localised adaptive thermal comfort model on city's CO_2 emissions was observed in this study. The change in cooling degree days (CDD) and corresponding energy consumption-based CO_2 emissions were calculated for various future scenarios and compared with the present conditions. For this study, the area under Mumbai and Mumbai Suburbs has been considered. This study analyses the data for the year 2011 and a future projection for the year 2030. The forecast for 2030 is based on two of the IPCC's Representative Concentration Pathway (RCP) trajectories for potential climate futures, RCP 4.5 (aggressive mitigation) and RCP 8.5 (moderate mitigation) (Business as usual). Energy use is a function of climate, specifically the heating and cooling degree days. As per Schipper and Meyers, 1992, end-use wise energy demand can be represented based on three basic elements as given in Eq. 1 (Isaac & Vuuren, 2009)

$$E = A \times S \times I \tag{1}$$

Here, Activity (A) expresses the under lying driving force of energy demand for a service or sector i.e. population. Structure (S) refers to other elements that determine energy demand which in this context is climate—for which we use cooling degree days (CDD) and heating degree days (HDD), and Energy intensity (I) refers to the amount of energy used per unit of activity (Isaac & Vuuren, 2009).
Air conditioners are often treated as appliances, with ownership based on household and energy consumption based on unit. The model used to calculate the Energy consumption due to Air – conditioners is as follows (Isaac & Vuuren, 2009).

$$Cooling\ Energy = \frac{Households \times Penetration \times UEC}{Efficiency} \tag{2}$$

Based on the model by McNeil and Letschert (2007), the total cooling energy of the city will depend on number of households using air conditioners, the household unit energy consumption (UEC) (kWh per Household per year), and the efficiency of the equipment. Here the Activity indicator used is No. of Households, Penetration is the structural parameter considered and UEC is the intensity with the climate parameter of CDD (Isaac & Vuuren, 2009). Eq. 2 is considered for the Mumbai and Mumbai Suburbs. The data required for each of these have been obtained from various sources. All the data is obtained for 2011 and the future projections have been obtained or interpolated for the year 2030.

Number of Households:

Households is the number of urban residential houses and households in the area. The number of households in an urban region has a direct impact on the amount of air conditioning used in that location. This data for Mumbai and Mumbai Suburbs was obtained from the census 2011 of Mumbai. The household numbers for 2030 is not obtained directly. It is derived using arithmetical increase method using the historic decadal Primary census abstract data. The number of household for greater Mumbai in each decade from 1971 to 2011 were arranged chronologically to calculate increment every decade. An arithmetic average of these increments was calculated to use in Eq. 3 for estimating number of households in the year 2030.

Appliance penetration:

Increasing consumption of air conditioners can be estimated by the percentage of Air conditioners in the urban households as given by the penetration rates. The appliance ownership patterns of cooling devices were refered from the report India Energy Security Scenarios, 2047 (NITI Ayog,2015). In this report, the data available were for every 5 years starting from the year 2012 to 2047. From this, the general penetration rate of AC's for urban areas for 2011 and 2030 is extrapolated using Eq. 4 and Eq. 5. This penetration rate is assumed to be the penetration rate for Mumbai and Mumbai Suburbs.

$$Penetration_{2011} = Penetration_{2012} + \left[\left(\frac{Penetration_{2017} - Penetration_{2012}}{t_{2017} - t_{2012}}\right)\right] \quad (4)$$

$$Penetration_{2030} = Penetration_{2027} + \left[\left(\frac{Penetration_{2032} - Penetration_{2027}}{t_{2032} - t_{2027}}\right) \times (t_{2030} - t_{2027})\right] \quad (5)$$

Unit Energy Consumption (UEC)

The unit energy consumption (UEC) is the total energy used by appliances yearly, given by kWh/household/yr. UEC in this study was calculated by using Eq. 6 modelled by McNeil & Letschert, 2007.

$$UEC = (0.345 \times Income) + (1.44 \times CDD) - 823 \quad (6)$$

Here the Income value is in USD, and CDD are represented in number of hours in the year when cooling will be needed as per base temperature. The GDP data for the year 1999-00 to 2010-11 was obtained from government data website, and for the year 2011-12 to 2016-17 is obtained from the Economic Survey of Maharashtra 2017-18 Report. The Data obtained in Crore Rupees is converted to $ using conversion rates of the respective years from RBI. The GDP and INR to USD reference rates are exponentially projected for 2030 from historic data by using log linear regression method as shown in Eq. 7 and Eq. 8. The monthly household income was estimated by using using Eq. 9.

$$Ln(GDP) = 0.12555 \times (Year) - 240.30996 \quad (7)$$

$$Ln(USD\ rate) = 0.02156 \times (Years) - 39.41879 \quad (8)$$

$$Monthly\ Income = \frac{GDP}{No.of\ HouseHolds \times 12} \quad (9)$$

For calculating cooling degree days (CDD), differences between the base temperature and hourly temperature measurements were calculated. The hourly weather data for the year 2011 and 2030 are required for this study, however the freely available TMY of the location is developed from data of the year 1975 to 2005. The "present" and "future" hourly weather data (2005, 2035) for Mumbai for two emission scenarios (RCP 8.5, RCP 4.5) were calculated using weather shift online tool. These temperature values for each hour of the year were then linearly interpolated using MS Excel to derive hourly temperatures for the year 2011 and 2030 using Eq. 10. This method was used for both years (2011 and 2030) and for both emission scenarios (RCP 8.5, RCP 4.5).

$$y = y_0 + (x - x_0)\frac{(y_1 - y_0)}{(x_1 - x_0)} \quad (10)$$

Where, y = required temperature (hourly DBT for the required , y_0 = Temperature of the year 2005 (hourly DBT), y_1 = Temperature of the year 2035 (hourly DBT), x = the required year (2011 or 2030) (for which the hourly DBT is to be found), x_0 = the year 2005 (for which the hourly DBT is available), x_1 = the year 2035 (for which the hourly DBT is available)

National building code (NBC) of India earlier suggested using 24°C to 26°C as the set point temperature, and the air conditioners are expected to be working if the outdoor temperature goes beyond it. However, the adaptive thermal comfort studies show that in the warm and humid climate it is found that occupants are thermally comfortable at temperatures higher than 26°C. Various base temperatures were explored to calculate CDD in this study as per Table 1. The neutral temperature of the respective models is considered as the set point in this study to calculate CDD. The neutral temperatures given by various ATC models are in terms of operative temperature and new effective temperature, but they are assumed as dry bulb temperatures so that the CDD could be calculated by comparing them with hourly outdoor DBT.

Table 1: Base temperatures considered for calculating CDD using different models.
Source: Author

Neutral temperature			**Base temp. (°C)**	**Source**
ATC Mumbai	(Tn ET*)	(Local)	28.00	(Author)
IMAC	(Tn TOP)	(India)	24.75	(Manu, Shukla, Rawal, Thomas, & de Dear, 2016)
ASHRAE 55 2010	(Tn TOP)	(International)	24.60	(ASHRAE, 1998)
ASHRAE 2001	(Tn ET*)	(International)	18.00	(ASHRAE, 2001)

Efficiency

Energy efficiency ratio (EER) is the ratio of the cooling capacity (in British thermal units [Btu] per hour) and power input (in watts). As per the report – Adaptive Thermal comfort standards in 2030 BEE data indicates that Three Star ACs are most widely utilized. Hence for this study the efficiency has been taken as 2.7 considering a 3-star AC. (CEPT University, AEEE & Lawrence Berkeley National Laboratory (LBNL), 2018) The Energy efficiency of AC's in India is extrapolated for 2 scenarios the BAU and the Accelerated efficiency scenario.

In the BAU scenario, taking one star rating up to 2019, the future projection is made based on the historic 3% per annum increment in efficiency. In the accelerated efficiency-improvement scenario, the room AC minimum energy performance extrapolated at 6% per annum, two times the historical rate (efficiency 7.1). (Abhyankar, Shah, Park, & Phadke, April 2017) In the Scenarios taken in this study, the BAU of Abhyankar et. al.'s study case is assumed to be corresponding to the RCP 8.5 scenario and the accelerated efficiency scenario is taken for the RCP 4.5 scenario.

Carbon emission rates

Central Electricity Authority - New Delhi (CEA) published the historic and projected CO_2 emission rate in Kg CO_2/Kwh on 30.06.2018. These rates were calculated by considering the future plans of ministry of power and increasing participation of the renewable energy sources. As the present study focuses on the year 2030, the future CO_2 emission rate were extrapolated from the available CEA projections as shown in Fig. 2 and Fig. 3. The rate of change of emission rate between 2016 (2015-16) and 2022 (2021-22) was

0.0195 Kg CO_2/Kwh per year, this rate further reduced to 0.0160 Kg CO_2/Kwh per year, which is 0.82 times the earlier. In this study, the rate of change of CO_2 emission rate per year is assumed to continue in the similar proportion (0.82 times the earlier). Using this extrapolation method, the CO_2 emissions rate for the year 2030 was calculated. Similarly for the emission rate for the year 2011, the available data points of the year 2015 and 2014 were linearly extrapolated backwards. Here per year change of 0.005 units were observed and the emission rate for the year 2011 were calculated.

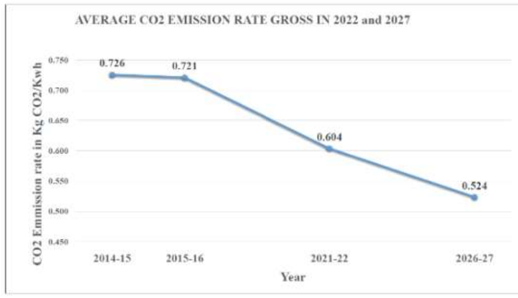

Figure 2: Average CO_2 Emission rate Gross in 2022 and 2027
Source: Central electricity authority, India.

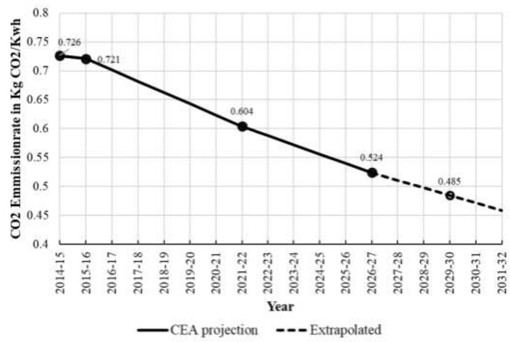

Figure 3: CO_2 Emission rate extrapolation for the year 2029-30
Source: Author

RESULTS

Cooling energy and carbon emission calculation:

The processed base data as explained in methodology section is given in Table 2. This data was used in Eq. 2 to calculate the final energy demand of the space cooling sector for residential buildings for 2011 and 2030 (RCP 8.5, RCP 4.5). The energy demand and the corresponding CO_2 is then calculated. The table 3 gives the total CO_2 emissions for the Space cooling demands of the residential energy sector of Mumbai.

Table 2: Summary of Fixed data considered.
Source: Author

Fixed Data	2011	2030 (4.5 RCP)	2030 (8.5 RCP)
No of Households	2,779,943 (Census 2011)	35,90,843 (Calculated)	
Penetration of AC %	5.4 (NITI Ayog)	36.8 (Calculated)	
GDP	$ 48,646,697,072 (Calculated)	$ 268,041,881,412 (Calculated)	
Monthly Household Inc $	$ 1458.26 (Calculated)	$ 6220.50 (Calculated)	

Efficiency of AC	2.7 (Bureau of energy efficiency, 2015)	7.1 (Abhyankar, Shah, Park, & Phadke, April 2017)	4.2 (Abhyankar, Shah, Park, & Phadke, April 2017)
CO_2 emission factor of electricity (Kg CO_2/kWh).	0.741 (calculated) CEA, 2018	0.485 (calculated) CEA, 2018	

Table 3: Summary of results
Source: Author

Year	Adaptive thermal comfort model used to calculate CDD	Set point (Tn)	CDD	Final Energy due to cooling (GwH)	CO_2 due to cooling (KiloTonnes)
2011	**ATC Mumbai (TnET*)**	**28.00**	**402.9**	**14**	**11**
	IMAC (TnTOP)	24.75	1185.9	77	57
	ASHRAE 55 2010 (TnTOP)	24.6	1230.5	81	60
2030 (RCP 4.5)	**ATC Mumbai (TnET*)**	**28.00**	**511.5**	**383**	**186**
	IMAC (TnTOP)	24.75	1370.1	613	298
	ASHRAE 55 2010 (TnTOP)	24.6	1416.4	626	304
2030 (RCP 8.5)	**ATC Mumbai (TnET*)**	**28.00**	**542.3**	**662**	**321**
	IMAC (TnTOP)	24.75	1416.7	1058	513
	ASHRAE 55 2010 (TnTOP)	24.6	1463.3	1079	523

Impact on carbon emissions:

It can be evidently seen that the change in set-point from 24.6°C as per the ASHRAE international standards to 28°C as per the present adaptive thermal comfort study makes a huge difference to the usage of AC and thus the energy consumption as seen in Fig. 4. The energy requirement is 70 % higher in the 18°C case. A higher set- point so long as thermally comfortable, leads to a considerable reduction in energy.

As seen in Fig. 4 the cooling energy in future increases considerably because of the rising outdoor temperature. In each case of setpoint, the proportion of rise in cooling energy appears similar. The difference in the IMAC and the ASHRAE cases are not too high due to a similar set-point. Comparatively lesser cooling energy is required in present and future climate scenario if the set point is changed to 28°C as suggested by present study. The rise in cooling demand ultimately increases the utilisation of air conditioners and CO_2 emissions. Fig. 5 shows the rise in CO_2 emission due to cooling energy consumption in Mumbai. The use of set point suggested in present study immediately will drop the CO_2 emissions to less than half as compared to the international standards.

The use of set point of 28°C as suggested in present study immediately will drop the CO_2 emissions to about 1/6th, and the future CO_2 emission will drop to 3/5th. Almost 696 GWh annual energy consumption can be reduced if LATC is used. This saving is enough to power residences of about 2008 average Indian villages (assumption of 1826 kWh/day/village and 52% used for residential) (Smart power India, 2019). The reduction of 337 Kilotons annual of CO_2 emission is possible if LATC and aggressive mitigation strategies implemented; which is equivalent to that absorbed by 19 forests of the size of Sanjay Gandhi National Park (SGNP) in Mumbai (CPCB, 2021).

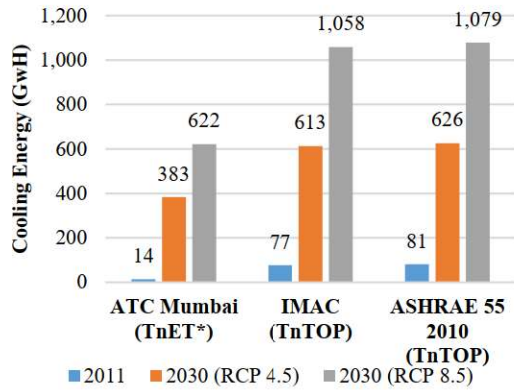

Figure 4: Cooling energy due to change in set-point in future weather scenarios,
Source: Author

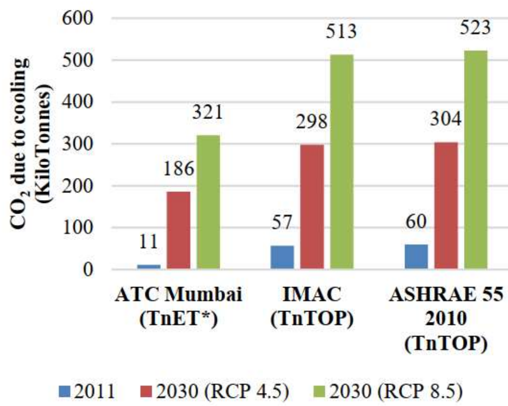

Figure 5: CO_2 emissions due to change in set-point in future weather scenarios
Source: Author

CONCLUSION

The cooling energy demand requirement is expected to reduce if the set point of the air conditioners were set to higher temperatures. Through this study it is evident that 28°C is the neutral temperature up to which the occupants need not switch on the air conditioners as they are comfortable in naturally ventilated condition.

The cooling energy is calculated in this study for when the air conditioners are switched on at and above 28°C indoor temperature. The study also included cooling energy due to set points suggested by other relevant studies and standards such as IMAC and ASHRAE. The rising global temperature might increase the need for cooling in future hence future climate scenarios were also studied. The CO_2 emission is directly related to the cooling energy consumption, hence the CO_2 released in all the above conditions due to cooling energy consumption. The resulting cooling energy consumption and related CO_2 emission in this analysis show that the use of suggested set point temperature (28°C) in this study (as against IMAC or ASHRAE 55 2010 standards) can help in reducing the Cooling energy and related CO_2 emission.

This study presented a method of estimating energy consumption and corresponding CO_2 emissions as a tool to measure impact of thermal comfort model. This estimate of achieving energy savings and thereby carbon emission (CO_2) reduction at the residential building sector, shall assist the local, state and country level like Ministry of Environment and Forest and Climate Change (MOEFCC) for policy making.

By simply increasing the set point temperatures, developers and municipal bodies can claim CO_2 emission reduction at national or international platforms.

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SMART BUILDINGS AND RADIATION: EVALUATION OF THE DIFFERENCE IN THE NATURAL AND ARTIFICIAL RADIATION PATTERN IN HUMAN HEAD MODEL

Reshna Raveendran[1], Kheira Anissa Tabet Aoul[2]

[1] Post doc Research Associate, United Arab Emirates University, Al Ain, reshnaraveendran@gmail.com
[2] Professor, United Arab Emirates University, Al Ain, kheira.anissa@uaeu.ac.ae

ABSTRACT

Since the industrial revolution, humans have been exposed to artificial radiation more than their predecessors. This overexposure became more predominant with the usage of smartphones and smart devices. The exposure problem can also intensify with the deployment of 5G Internet of Things (IoT) and smart gadgets such as smartwatches and health monitor devices worn by the user constantly. Scientific evidence has pointed out that exposure to artificial radiation can create health issues ranging from simple health issues like dizziness, nausea, and lethargy to major illnesses like cancer, tumors, and immunity problems. However, most of these studies have not considered the fact that we humans also use natural frequency with an operating window of 0 - 30 Hz known as bio-electromagnetism. Further, the value of bio-electromagnetic frequency is used by the brain for tasks including sleep and cognitive performance and variations in these are proven to cause physical and mental health problems. This study aims to evaluate the change in the radiation pattern based on natural bio-electromagnetism and artificial radiation along with consequent absorption of electromagnetic radiation (EMR) on the head of a male model with normal weight using smart glass. The study is performed in Computer Simulation Technology (CST) and uses a smartphone to induce artificial radiation under varying frequencies (6 GHz and 10 GHz). The results from the simulation reveal that there is a considerable difference in the radiation pattern from artificial sources and natural. Further, absorption of E-field and H-field increases with an increase in frequency, though Specific Absorption Rate (SAR) is below the safety limits.

Keywords: Smart Buildings, Radiation, Bio-electromagnetism, Computer Simulation Technology (CST), Specific Absorption Rate (SAR).

INTRODUCTION

Smart buildings are predicted to provide energy savings, reduce CO2 emission and satisfy various occupants' needs (Buckman, Mayfield and Beck, 2014). However, there are concerns related to cyber-security, health problems due to high wireless radiation and e-waste accumulation from IoT devices (Raveendran and Tabet Aoul, 2021). Radiation from smart and IoT devices can be quite high, sending 24 to 90 billion microwaves per second (Russell, 2018). Although the sustainability and wellness rating system emphasize the health of occupants, they promote smart gadgets from smart health monitors to smart meters (LEED, International WELL Building Institute). Medical health reports state that radiation from these devices can cause milder problems such as dizziness, vision problem, insomnia to major health effects like cancer, immunity issues, tumors (Levitt and Lai, 2010;Ojuh and Isabona, 2015). Current policies and regulation do not cover the complete heath complication from long-term exposure to wireless radiation (Hardell, 2017). World Health Organization (WHO) follows Federal Communications Commission (FCC), whose regulations were based on studies conducted two decades ago (Hardell, 2017) and, recently, in August 2021, lost its landmark case in a US court that demanded to update their policies and regulations ('United States Court of Appeals for the district of Columbia circuit', 2021). Moreover, 5G appeal signed by scientists from several countries like the Netherlands and Switzerland have claimed to implement 5G only after conclusive evidences based on its safety (Scientist Appeal for 5G Moratorium, 2017).

Though the majority of studies correlate only radiation and direct health consequences, the real problems can be more convoluted. The reason is that humans also use bio-electromagnetism from frequencies ranging from 0-30 Hz which causes a pronounced effect on cell and tissue healing, nerve regeneration, sleep patterns, and cognitive development (Ş, Gheorghe and Curie, 2012). Research have shown that brain frequency functionality can be intercepted by radiation from mobile phone (Anderson, 2011). Supercomputing Quantum Interference Device (SQUID) has shown that human has a bio-energetic field that can extend up to 15 feet in space, figure 1 (Meyers, 2013).Any alteration to this natural radiation pattern in the long term will cause health issues (Zhang *et al.*, 2019). However, very few studies are done in this research area, especially in radiation patterns. Generally, far-field gain of all wireless devices is mainly evaluated to understand the signal distribution, not from a health perspective. This study aims to determine the difference in the radiation pattern between natural radiation and radiation from an artificial wireless source (smart glass) using Computer Simulation Technology (CST) besides calculating E-field absorption and Specific Absorption Rate (SAR).

Figure 1. Bio-energetic field of human (Meyers, 2013)

METHOD

The research followed a simulation approach to estimate the difference in the radiation pattern for natural and artificial radiation. CST was selected as the suitable software based on the reliability of results as proved by academicians and industry (Qi *et al.*, 2008). Natural radiation pattern was evaluated for a frequency of 8 Hz (also known as the alpha wave frequency or waking brain frequency) (Huang and Charyton, 2008) whereas artificial radiation pattern was estimated for 6 GHz and 10 GHz (frequencies that will be commonly used for IoT applications). For the artificial wireless source excitation, an antenna operating under 6 GHz and 10 GHz were designed in Antenna Magus and later exported to CST (figure 2). A plane wave excitation was irradiated to determine the natural radiation pattern.

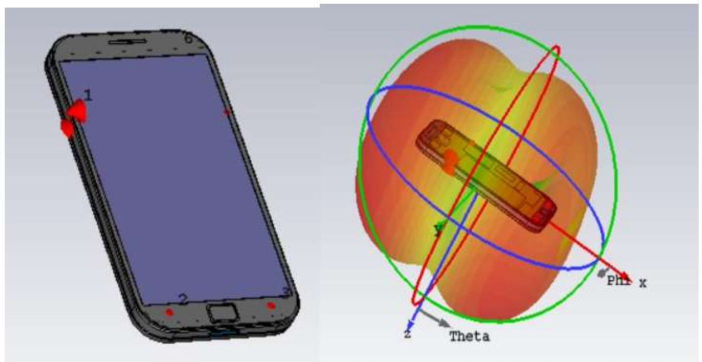

Figure 2. Smart phone and radiation pattern simulated in CST

A male model with normal weight of 25 years was chosen as the phantom model for the simulation that was available with the bio-model library in CST (figure 3 and 4). The age correction factor was done in macros to correct for the aging required for the model. Smart glass was selected to simulate the radiation pattern of smart devices as the occupant can wear smart glasses for augmented reality and use them for both work and entertainment purposes. The radiation pattern is shown by far-field gain, measured in dBi. Besides, E-field, H-field, SAR and far-field gain were also calculated for the simulation runs with 6 and 10 GHz.

Figure 3. Male model with smart glass

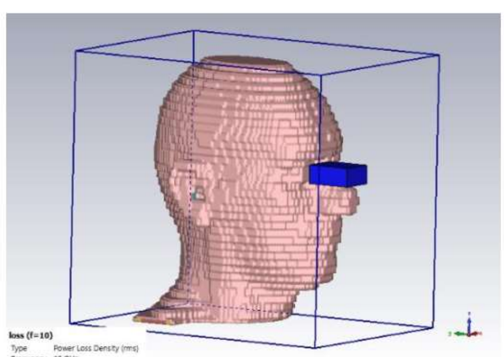

Figure 4. Model exported to CST with antenna source

Validation

The accuracy of the simulation results was checked using a real hand placed in front of the mobile phone and measuring the absorption value, which was 3 V/m. Similarly, a scenario was designed in CST design suite with age correction provided for the female hand model and the electric field value was found to be 3.122 V/m at a coordinate value of -28.803, 2.15, -5.068 cm and 4.68 V/m at a coordinate value of -29.308,2.15 and -4.898 cm (figure 5). It must be noted that an EMF measuring device provides only two values, either the highest or average, however, CST result visualization allows the researcher to determine EMF at any point in any of the axis. Result validation for both phase 1 and phase 2 shows that actual and simulation values were in good agreement.

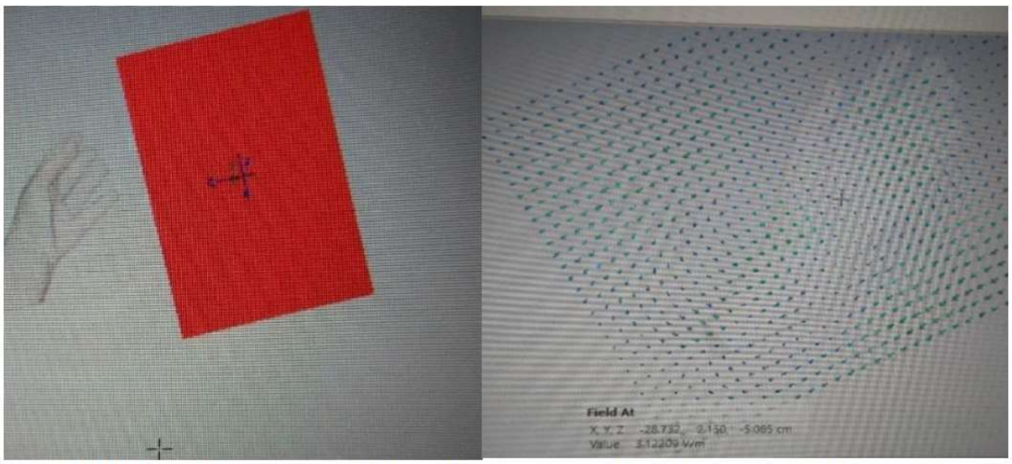

Figure 5. EM distribution conducted for hand simulated in CST for 2.45 GHz mobile phone

RESULTS AND ANALYSIS

The radiation pattern due to wireless exposure from a smart glass was simulated in CST (figure 6), and results were compared to radiation pattern or far-field gain with natural bio-frequency (figure 7). Figure 8 shows the E-field distribution inside the human head phantom model for 10 GHz.

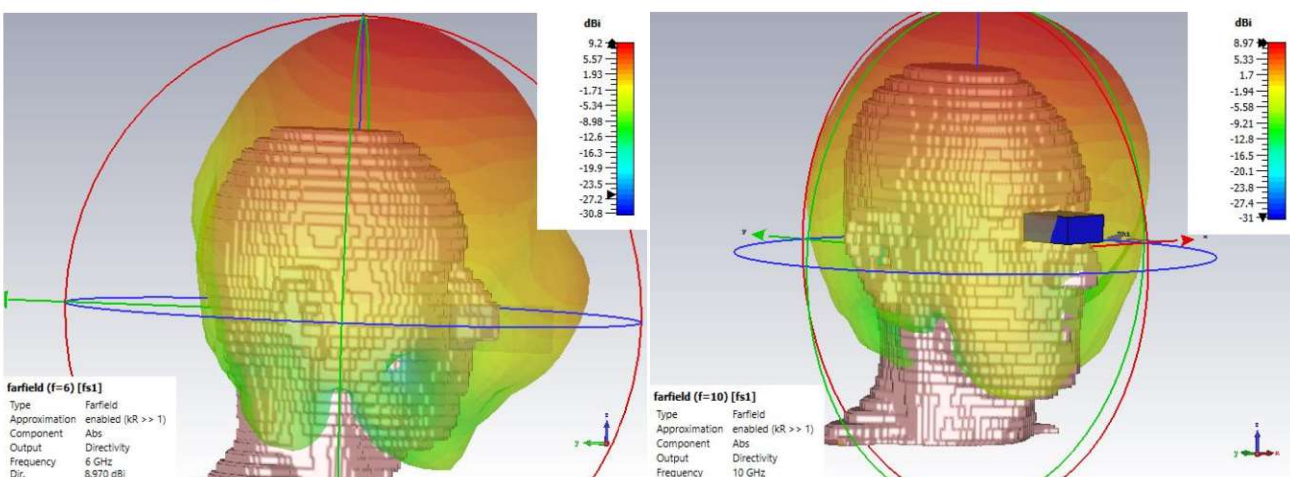

Figure 6. Radiation pattern of human model under 6 and 10 GHz

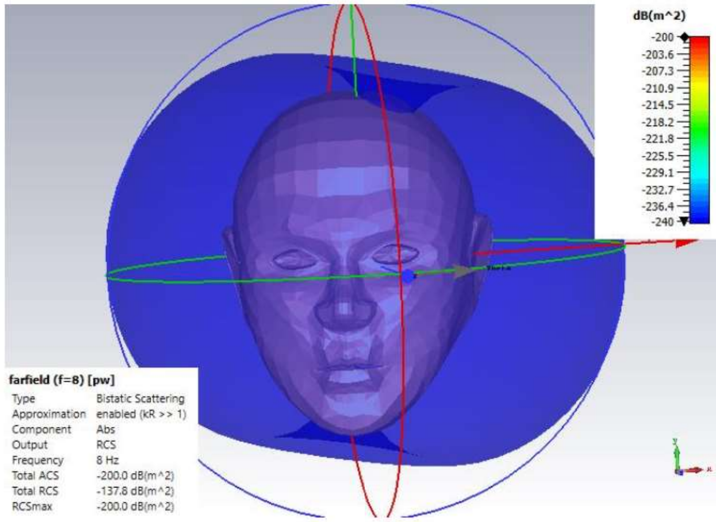

Figure 7. Natural radiation pattern of 8Hz

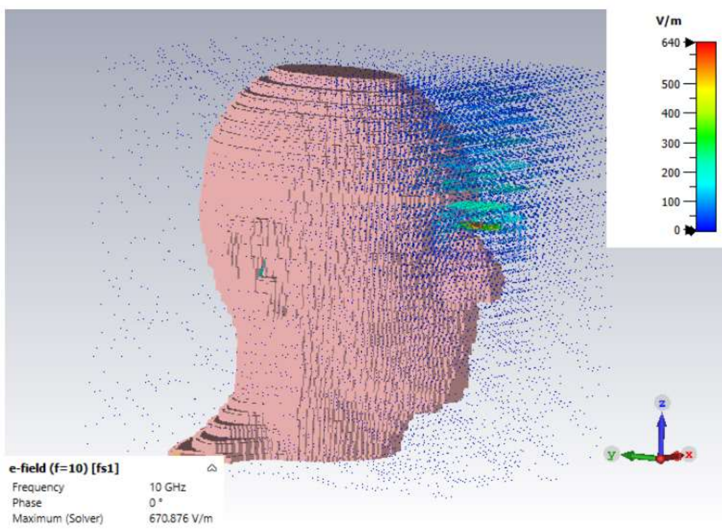

Figure 8. E-field distribution for the human model at 10 GHz

The simulation also tabulated the E-field, H-field, Specific Absorption Rate (SAR) and far-field gain for the two tested frequencies for the male model (Table 1).

Table 1. Tabulations of estimated parameters: E-field, H-field, Far-Field Gain and SAR

Frequency (GHz)	E-field (V/m) taken in plane in front of face	E-field (V/m) taken in plane back of head	H-field (A/m) taken in plane in front of face	H-field (A/m) taken in plane back of head	Far-field gain (dBi)	SAR (W/Kg)
6	135.458	7.845	0.528	0.01	8.97	0.236
10	164.478	3.427	0.615	0.007	9.202	0.628

The E-field before absorption by the head for 6 GHz and 10 GHz are 135.458 V/m and 164.478V/m, respectively. However, more absorption occurs at 10 GHz than at 6 GHz; as frequency increases, scattering also increases. H-field variation between two frequencies and absorption is less compared to E-field variation. Comparing the far-field pattern of natural (doughnut shaped that is similar to the one produced by SQUID) and artificial radiation sources, there is a significant difference in the shape. As humans use bio-electromagnetism with natural frequencies from 0- 30 Hz for several tasks ranging from cognitive processing, sleep, and nerve regeneration, a long-term change from natural radiation patterns may cause unseen health risks (Meyers, 2013). Table 1 also shows the SAR for 10 g (considering thermal effect) generally considered for radiation safety regulations, which is below the safety limit of 2 W/Kg for the general public. However, US court has asked organizations to update the regulations and consider effects beyond thermal (figure 9) (Commission, 2006); as regulations do not consider long-term exposure or the implications on different types of people, for example, on children and pregnant women ('United States Court of Appeals for the district of Columbia circuit', 2021).

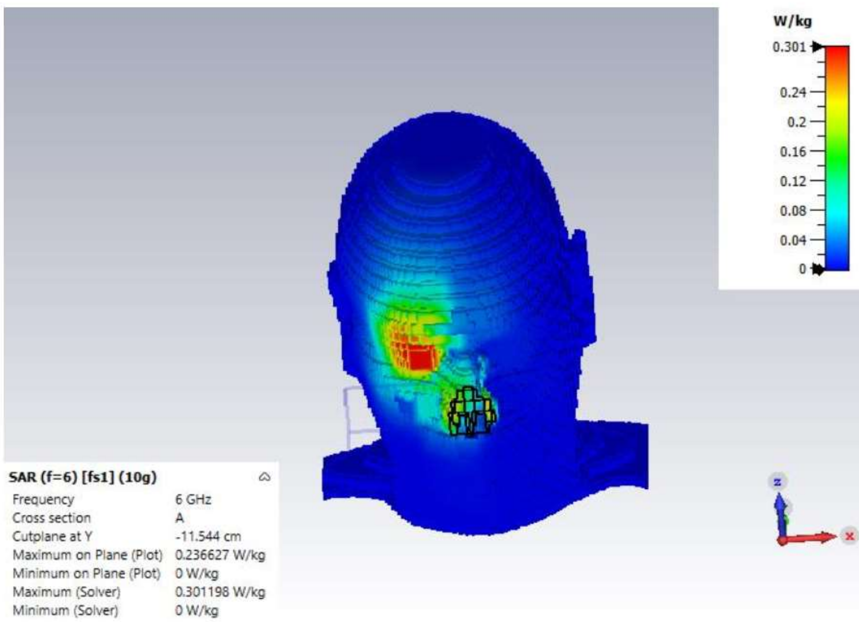

Figure 9. SAR for the model for 10g at 6 GHz

CONCLUSION

The research study focused on evaluating the radiation pattern from an artificial wireless source using high frequency for smart glass. This was then compared with a bio-energetic field naturally used by the human body for several functions, including resonance of cells, tissue repair and nerve regeneration. Radiation pattern changes drastically for artificial sourced radiation (6 GHz and 10 GHz) compared to the natural frequency of 8 Hz. Moreover, E-field absorption is higher for 10 GHz than 6 GHz. SAR evaluated for both 6 and 10 GHz are lower than the current tolerance limit by IEEE, which considers however only the thermal effect. The study demonstrated that natural radiation is altered due to exposure from artificial sources and requires further investigation to fully evaluate the health impacts this may cause on humans.

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ENVIRONMENTAL EXPERIENCE DESIGN AND NATURAL LIGHT IN HOTEL ARCHITECTURE; CASE OF FERNAND POUILLON EL MOUNTAZAH HOTEL IN SERAÏDI (ANNABA, ALGERIA).

Sara Zineddine[1]*, Azeddine Belakehal[1], Kheira Anissa Tabet Aoul[2]

[1] LACOMOFA Laboratory, Department of Architecture; University of Biskra, Algeria; sara.zineddine@univ-biskra.dz, a.belakehal@univ-biskra.dz,

[2] Architectural Engineering Department, United Arab Emirates University, Al-Ain, UAE; kheira.anissaAuaeu.ac.ae

ABSTRACT

In architecture, natural light plays a prominent and multidimensional role. It can structure the route one takes within a building as well as prioritize its different sequences and guide the user to follow a specific and ultimately welcoming route. The main objective of this research is to explore the variability of the luminous ambiences found within the routes of the hotel El Mountazah located in the coastal village of Seraïdi the outskirts of Annaba, a large city in the (extreme northeast of Algeria,) and designed by the French architect Fernand Pouillon. The choice was made for hotel architecture as it is generally considered to be a unique experience for users who discover and live in various successive places. Each of these places is designed to create different ambiances and trigger diverse sensations. Moreover, Pouillon built several prominent hospitality projects throughout Algeria between 1966 and 1986, all of which were marked by an intricate play of light and building massing. Accordingly, this study explores: i) the luminous physical character (the types, the effects, and the forms of distribution of light in the space under study), as well as ii) its morphological character (openings, shape, depth, etc.). To this end, the approach relied on the qualitative methods based on field observations associated with the description of different sequences of routes identified beforehand by means of a survey carried out among hotel's users. Finally, the outcomes revealed that: i) the architectural conformation and openings design create the type and quality of light within the sequences of routes, ii) a gradient is visually perceptible from the light going from the opening to the depth of the space, and iii) the architectural space is subdivided in a sequential way through a sequential contrast of shadow and light.

Keywords:: natural light, hotel, route, sequence, environmental experience design

INTRODUCTION

Currently, there is a widespread interest in environmental design create places that meet concurrently a number of high quality functional and energy-conservation requirements (Bekkouche, 2005, Eldien, 2008). Ambient quality is also another requirement for designing an architectural space. It can meet the psychological and sensory needs of the space users as well as, at any given moment, the multiple perceptions that the same space suggests to them (Adolphe, 1998).

The physical environment is considered as a sign that replaces speech; it transmits material and/or immaterial information in the architectural space (Guillemette and Cossette, 2006). Therefore, the mastery of physical and sensitive phenomena (light, temperature, sound, etc.) has become an intent that stirs architects and designers alike to ensure the perceptible architectural and urban quality of their design (Augoyard, 1998). In this context, our research work focuses on the luminous atmospheres of the various routes, within the El Mountazah Hotel through the study of the luminous physical and morphological characteristics of this building complex and by emphasizing the variations in natural light. Because of its fluctuations and variations when moving from one space to another, natural light is not limited to solving energy or aesthetic problems in a building (Saraoui, 2012) Rather, it makes the space sensitive, practical and reveals it by taking it to another limits, in this case those the immaterial, and by increasing the sensory experience and the well-being of the occupants (Coulombe, 2016). On the other hand, and by its nature, the hotel architectural space is a very sensitive space. It is considered as a second home, in such a way that we expect to find our home qualities there: privacy, security and comfort; all in a place that is completely foreign to us (Zineddine, 2019). In this sense, the hotel architecture of Fernand Pouillon constituted an edifying example for the study of the role of natural light in the sensitive characterization of indoor pedestrian routes within the building complex. For instance, he took into consideration the notion of route by involving a "body in motion" in these spaces created by inducing a close relationship with spatial orientation (Saraoui and Belakehal, 2011).

Second, the architect created a promenade effect with routes including multiple sequences (Zineddine and al , 2018).Regarding this point, he stated: “I considered architecture as an immense decor where the tourist must be immersed like inside a theater play that lasts fifteen days and where he walks around the changing scenery” (Pouillon, and Marrey, p74). On the other hand, he succeeded by fully considering the environmental aspect in these buildings and also thought of creating spaces by placing man and his spatial and social environment at the heart of his concerns, highlighting the immateriality of these relationships and the materiality of the environment (Manola, and Geisler, 2012). For example, the architect used known natural factors from the Mediterranean environment, including natural light, the subject of this study (Boulbene- Mouadji, 2017). Hence, this research will an attempt to qualify the architectural route, within Fernand Pouillon’s hotel, by means of the identification of the effects of light and their relationship to the components of the architectural space.

EL MOUNTAZAH HOTEL (ANNABA, ALGERIA) AS A CASE STUDY:

The choice of the El Mountazah hotel as a case study is motivated by many consideration. First, the building perfectly illustrates presents the architecture of Fernand Pouillon (Figure 1). Then and compared to Fernand Pouillon's other hotels, El Mountazah still retains its original features, particularly in terms of form and spatiality (Zineddine, 2019). The hotel (Figure 1) was built in 1969 on the ruins of an old hotel (The Rock Hotel) (Figure 1). The site is located north of Seraïdi, a mountain village, 17 km from the city of Annaba, a major coastal city located in eastern part of Algeria. At an altitude of over 800 meters, the hotel is well exposed to wind and sun. The building is oriented to the north and makes the most of the panoramic views that overlook the Mediterranean sea and the surrounding dense forests. Placed on a cliff, the hotel is accessible from a single vehicular and pedestrian route. It is made up of several levels: i) two in the basement, where the bedrooms are located, ii) the ground floor where the reception hall, the guest rooms, the hotel living room, and a café terrace are located, and iii) the first floor for the restaurants, the kitchen, and an annex for the studios. The guest rooms are noticeably larger when compared to the standard rooms of other hotels. They all enjoy the northern views towards the sea and the mountains.

Figure 1. View of the El Mountazah Seraïdi-Annaba hotel
Source: Author

METHODOLOGY

Naturally- lit architectural spaces provide a diverse visual environment that changes with natural cycles and affects the occupants' perception (Fontoynont 1999, Hégron, and Torgue, 2010 , Loftness and Snyder, 2008, Parpairi, 2004). Within the hotel, the natural light varies along the route taken. The latter illustrates a conceptual strategy that enriches the luminous quality of spaces and articulates its different sequences by associating nature and architecture (Lemonde-Cornellier, 2022). Indeed, the route is not just a simple ritual of mobility (Grosjean, and Thibaud, 2001). It is also the superposition of several statements that refer to the components of the space travelled. In architecture, the route is often considered as a conceptual strategist allowing to properly explore and enhance architecture.

Thus, the concept of 'Route' is retained because it connects several notions that correspond to the conceptual intentions sought in the design of the hotel El Mountazah. In addition, it plays a very important role in the discovery of the ambient environment (Zineddine, 2019). Moreover, the route concept allows undertaking a study based mainly on the notion of visual sequences of architectural events (Saraoui and Belakehal, 2011). In this sense, the method developed for this research essentially uses the observation and characterization of the different sequences of the course.

The adopted approach aims to reveal how the morphology of these daylight places (sequences of the route) interacts with natural light by means of an identification of: i) the luminous physical qualitative character of the route (types, effects, and forms of distribution of light within the space of the sequence studied), and ii) its morphological character mainly based on the natural lighting of the various sequences constituting it (spatial orientation of spaces, geometry of openings, color, and texture of surfaces as well as shape and depth of spaces) (Lacombe, 2006, Steane and Steemers, 2004).

In order to select the course to be studied, an in situ survey was undertaken with 30 people (men and women) among the users of the El Mountazah hotel. The outcomes reveal that there are two main routes widely used in the hotel: i) a direct route to the room, and ii) an indirect route through the use of stairs to the lower ground levels. Statistical analysis helped us to extract the routes most frequented by users and identify the sequences constituting them. About three quarters of users (73.33%) use the route number "1" (garden, reception, corridor, and bedroom), while an average percentage of 26.67% go through the route number "2". In addition, the sequential division was based on the textual analysis of the users' discourses during the survey as well as according to the daylighting devices marking these places.

The investigated route is located at the ground floor. It encloses different spatial sequences, each distinguished by a specific light atmosphere derived from natural light (Figure 2). A number of seven (07) daylit spatial sequences were detected within this route: i) sequence 1: garden and outdoor space of the hotel, ii) sequence 2: intermediate space between the outdoor space and the reception hall
, iii) sequence 3: reception hall, iv) sequence 4: connecting space between the reception hall and the bedroom corridor, v) sequence 5: the curvilinear corridor, vi) sequence 6: guest room, and vii) sequence 7: bedroom terrace facing northeast (Figure 3). A set of image was taken by the authors for each of these sequences.

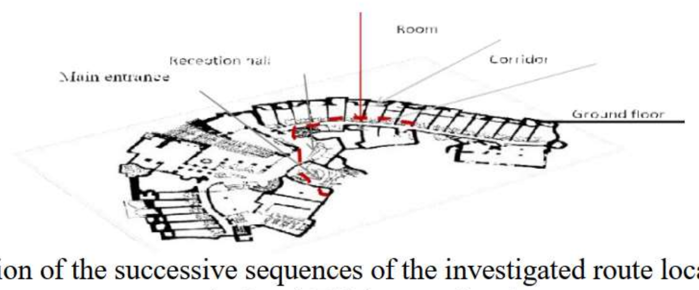

Figure 2. The location of the successive sequences of the investigated route located in the ground floor of the hotel El Mountazah – Anna

Figure 3. Views of the different sequences of the investigated route in the El Mountazah hotel

RESULTS AND DISCUSSION

The application of this double qualitative approach for the analysis of the different and successive sequences of the route has made it possible to bring about the various specificities and distinguishing them from each other.

Sequence 1
Starting from the main entrance of the hotel and ending at the entrance staircase of the reception hall (Figure 4), this sequence includes open spaces, in this case the exterior gardens of the hotel. These places are flooded with natural light. Direct solar radiation, received from the top of the hotel, amplifies its volume, and enhances its specific shape by highlighting its curvilinear contours. In addition, there are shaded areas created by the trees in this garden.

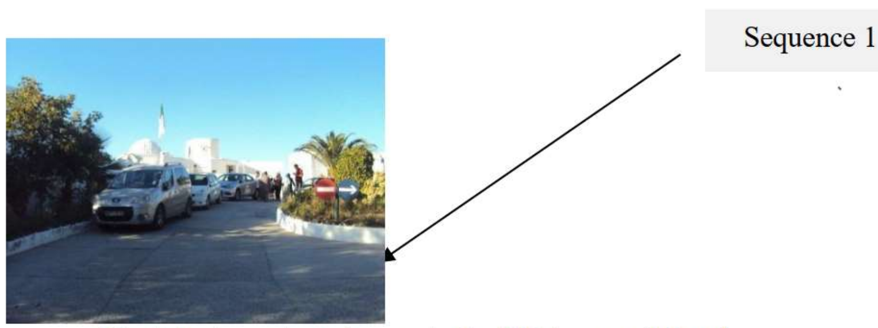

Figure. 4. View the sequence (1) of the investigated route in the El Mountazah hotel

Sequence 2
The second sequence of the route is considered as a connecting space between the exterior and the interior of the hotel. It is a semi-open passage, dug into the ground with a low ceiling height. While providing shade, this place is curvilinear and painted in white colour. However, it is above all remarkable for the subtle gradation of light intensity resulting from the transition from a very bright outdoor space (garden) to an indoor space with subdued light. At the end of the sequence, we face a large, glazed access door that occupies the entire wall surface. This transparent rectangular bay ensures the admission of natural light in the next sequence of the route (Figure 5).

Figure 5. The shading effects within the semi-open space of the sequence (2) of the studied route

Sequences 3 and 4

The space of the hotel reception hall was subdivided by the architect using light and shadow (light space, dark space). He chose to play with the intensity of the global and punctual glare and the control of the densest shadow. The sequence dynamic, and this type of light can play the role of an indicator to facilitate the use of space by users. Through a subtle play on the variations in the intensity of the light installed, the architect offers a different perception in of the same place space (from burst light to soft light).

In sequence (3), the light subdivides the place into two opposites, but complementary sub- spaces. The first is located under an intense light provided by bilateral lighting due to the presence of two glazed walls facing north and south. Allowing the direct admission of a large quantity of solar rays (figure 6); these two light sources attract the attention of the observer because of their high luminosity. They introduce glare and give rhythm to the spaces. Under certain conditions, this abundant direct light constitutes an unavoidable solicitation of the user's gaze and can make the reception hall uncomfortable. The second subspace plunges into shadow (Figure 7); which makes it easy to perceive and distinguish the shapes, contours and relief that characterize the space. Between these two contradictory sub-spaces, a succession of multiple spaces is distinguished by the gradations of shadows (Astrid martin. 2011).

Unlike sequence (3), the space of sequence (4) is characterized by the presence of a single opening. In addition, this bay is zenithal, circular in shape and occupies the total surface of the dome located above the staircase (Figure 8.9). By means of this opening, the architect created a luminous scenography that draws attention to a specific point in the sequence (Reiter and De Herde, 2004). It highlights the staircase within the space where dark space, thus creating a 'space of light' (Von Meiss, 1993). Indeed, the contrast between the intense falling flux of vertical light and the dark and fluid horizontal interior light environment marks quite strongly the borders of this 'space of light'. Moreover, the difference in luminosity between the openings and the general darkness of the place makes the exact shape of the opening fluctuate (Reiter and De Herde, 2004).

Figure 6. View of the naturally lit sequence (3).

Figure 7. View of the dark space within the sequence (3).

Figure 8. View of the zenithal daylighting within the sequence (4).

Figure. 9. The zenithal daylighting aperture of the sequence (4).

Sequence 5

The depth of the space, the rounded shape of the corridor, the dark color of the walls, the changes of direction, the narrow passages, and the limited number of openings operate, together, to create a closure of the space crossed at the beginning of the sequence. This contributes to the reduction of the quantity and the propagation of natural light. From an architectural point of view, the low height of the corridor ceiling creates a crushing of scale accentuated by the low intensity of light (Zineddine, 2019) (figure 10).

For the other parts of the sequence, a variation in brightness and contrast is observed. It is due to the existence of lateral windows juxtaposed at the level of the wall to the right of the sequence. The arched shape of the openings recalls the organic shape of the hotel. However, the size, shape and arrangement of these openings alter the quality of the lighting atmosphere compared to the beginning of the sequence. They create a uniform lighting thereby avoiding any space hierarchy (Figure 11)

Figure.10. View of the dark space at the beginning of the sequence (5).

Figure. 11. The lateral openings of sequence (5).

Sequence 6

This sequence is characterized by the presence of a large opening that occupies almost the entire surface of the guest room wall. This bay promotes the direct admission of a large amount of light into the room. Thus, it offers a luminous atmosphere varied in quantity and quality which contributes to the enrichment of the sensory experience of users (Rockcastle and Andersen, 2013) (Figure 12). In addition, the use of clear glazing facilitated the direct view of the outside. Furthermore, light coloured surfaces reflect natural light in all directions.

Figure12. The clear character of the luminous environment within the sequence

Sequence 7

Sequence (7) is that of a terrace overlooking the natural landscape (sea and forest) (figure 13). It presents a semi-open, semi-covered space, in direct visual contact with the outside and flooded with direct and reflected sunlight (Fontoynont, 2002, Fratini, and Pittaluga, 2019).).This space helps control the admission of direct sunlight. Indeed, it reduces glare in the room while allowing light from the sky to penetrate (Reiter and De Herde, 2004).

Figure.13. The daylight quality of the sequence 7 (the terrace)

SYNTHESIS

The study results show that the investigated route in the El Mountazah hotel is definitely marked sequentially by means of shadow and light (figure 14). Following the first place flooded with natural light, the user is received in a dark hall. The latter is followed by a place where the light is subdued, illustrated by the passage of a stream of light through a staircase. Next, semi-darkness prevails, this time in the corridor; to find themselves then in a bright room and finally under an intense light while reaching the terrace. This hierarchy was carried out by means of: i) openings located on the periphery and/or covering the sequences crossed, and ii) the use of curvilinear shapes accentuating the labyrinth effect. Such a sequential scenography using direct and indirect natural sunlight is indeed reminiscent of the luminous ambient character of the urban routes of traditional human settlements in Arab-Muslim countries that are very much reported in academic literature (Petruccioli, 1990, P 38). It would appears that the architect Fernand Pouillon wanted to make it an attraction for tourists as an identity atmosphere encouraging the user to live within an environmental experience that is indeed local and original.

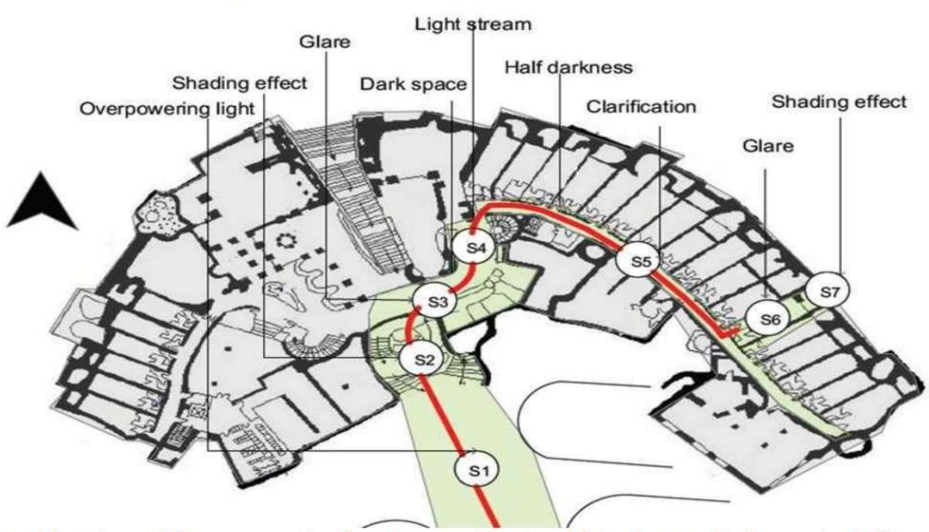

Figure.14. Identification of the successive luminous effects within the studied route's different sequences of the El Mountazah hotel.

CONCLUSION

This study allowed the characterization of the luminous atmosphere specific to the various sequences of the routes of the El Mountazah hotel in Seraïdi, Annaba. Presentations and interpretations of data related to the luminous environment of the studied space revealed the character of various places as defined by natural light in this hotel. Also, the different spatial components used by Fernand Pouillon to generate the luminous ambiences in the hotel have been identified (morphology of space, shape, depth, and construction elements such as openings, etc.). This was also the case for variations in light intensity specific to the different sequences of the same route (contrasts, areas of high luminosity, and traces of light on surfaces).
This set of material components used to create such immaterial luminous based effects highlight the creative design of Fernand POUILLON in terms of ambiences as well as of local context adaptability. The variety of architectural features used for this purpose is well coherent with the overall design idea of the hotel El Mountazah including natural landscape, view outside, climatic control, regional identity as well as spatial and formal innovation.

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UNDERSTANDING THE ROLE OF USER-SPATIAL RELATIONSHIP IN AN ASSISTED LIVING CENTRE: A CASE OF DURGAPUR, INDIA

Saurabh Ojha[1], Richa Raje[2]

[1]PhD Scholar, Department of Architecture, Indian Institute of Technology, Roorkee, India (skishoreojha@ar.iitr.ac.in)
[2]Assistant Professor, Department of Landscape architecture, School of Planning and Architecture, Bhopal, India (richa.raje@spabhopal.ac.in)

ABSTRACT

An assisted living centre is a residential facility for old-aged people who cannot choose to live independently. A typical resident would usually be a senior citizen who prefers companionship and need assistance in day-to-day living. The ailment considered for research are memory impairment and patients with terminal illness requiring end-of-life care treatment. Hence there is a need for customized spaces for patients depending on their physical and psychological conditions. Such customization can be achieved by developing a patient-space-cure relationship matrix. A connection between patients and spaces, can either be of passive or active order. It has been widely studied that natural garden passively cures by simulating sensory organs to experience spiritual value. Social corridors and common areas cure actively and encourage physical participation and interactions between patients, which not only engage the mind but has a significant impact on health. Both these active and passive approaches strengthen the mind, body, spirit of an individual to create physical and mental balance. This paper proposes a framework for designing an assisted living center by understanding user-spatial relationships along with site analysis followed by built form evolution. The aim of the master plan hence generated shall be to provide a set of design guidelines based on parameters identified for developing an old age home in the future.

INTRODUCTION

A significant proportion of the population in India has been driving in direction of the rapid modernization at an increasing pace. Along with the uncountable benefits of modernization, the self-centric aspect has been consuming our culture which has transforming the entire family values that were shared earlier. With the transient definition of success, a higher number of people are willing to migrate in search of wealthier future, completely ignoring the elderly in the family system. This perception generally proves brutal for the elderly who are unable to cope up with the lifestyle and demands of the successive generations. An increasing number of senior citizens are either left behind deliberately or genuinely by their children who have been working. Cases have also been seen where independent elders prefer residing in separate residential setup because of the incomprehension caused by their children. Estimating a large number of senior citizens living alone in neglected condition. Witnessing the rise in abandoned elders, states like Haryana (India) have announced the state aided development of old age home in each district. Thus, special old age care centres have been devised to cater to their needs of physical and mental care through integrated clinical facilities with passive healing gardens (Cooper Marcus et al., 1995).

The western nations as America have already acknowledged this as an important issue of elderly people being settled in old age residential facility in later stages of life. An assisted living centre is a residential facility for old aged people who cannot choose to live independently. A typical resident would usually be a senior citizen who prefers companionship and need assistance in day-to-day living Figure 1.

The condition considered for current study of developing an assisted living centre with passive healing design approach are memory impairment and patients with terminal illness requiring end of life care treatment. However, there is a need for developing customized architectural spaces for patients depending on their physical and psychological conditions. Such customization can be achieved by developing an architectural program based on patient-space-cure relationship matrix (Cohen Mansfield J, 1998) (KullerR, 1996).

A connection between patients and spaces, can either be of passive or active order. It has been widely studied that open garden spaces passively cures by simulating sensory organs to experience spiritual value. While architectural elements like social corridor and common gathering spaces cure by encouraging physical participation and interactions between patients. Passive approaches strengthen mind, body, spirit of an individual to create physical and mental balance staff (Ulrich R.S., 1991) (Van Den Berg A.E., 2011).

This paper proposes a framework for designing an assisted living centre with passive healing outdoors by understanding user-spatial relationship along with site analysis. The aim of the site plan hence generated shall be to provide a set of recommendations based on identified parameters like high-quality customized spaces taking into account the patients 'physical and mental health. It is known that professional treatment cures illness, but it is equally necessary to make patients feel well. Passive healing can be seen as a process that promotes wellbeing (Stigsdotter U.A., 2002).

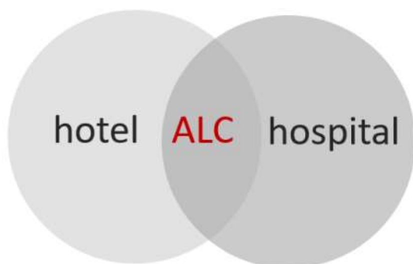

Figure 1: What is Assisted living Centre (Hospital to Hospitality); Source Author

Clare Cooper Marcus (Cooper Marcus C., 1995) (C., 2005) (Cooper, 2005) (C., 2007) describes therapeutic outdoor settings as areas where people can improve their physical, mental, and spiritual wellbeing. The benefits of a passive healing from garden can be multiple (Cohen Mansfield J, 1998) stress reduction for patients, family and staff (Ulrich R.S., 1991) (Van Den Berg A.E., 2011), reductions in care costs (Chantal Erbino, 2015), increased autonomy for patients (Namazi K.H., 1992) (Seifert P., 2005), improved mood (Rodiek, 2002) and quality of life (Stigsdotter U.A., 2003) (Sherman S.A., 2005). The main advantages of the healing garden include (I). Humans and nature are in active and passive touch. (II). taking part in horticultural treatment activities such as maintaining. According to Cristina Borghi (Borghi, 2007), The two methods are interdependent because they cooperate to bring about balance and harmony in the body and mind, particularly in individuals with memory impairment.

MATERIALS AND METHODS

The proposed framework contains two early analyses: one of the qualities of the site and the other of possible users. Site analysis reveals the boundaries and potentials of the region and zones best suited for specific activities, while user analysis pinpoints the activities of patients, employees, and family members and specifies user needs.

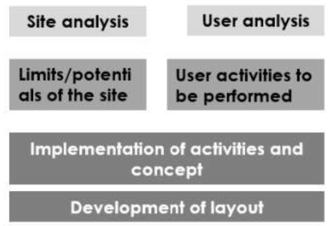

Figure 2: Methodology flowchart
Source : Author

Study area characteristics
The site is located in Durgapur Figure 3. The residents are mainly aged adults whose children are located in nearby cities. The layout of the city is providing a community space in every residential zones. Current study area comes under seismic zone 4. Climate condition is warm and humid as per ECBC 2017 guidelines Figure 4. Major wind pattern in summer from south west and west side, in winter it changes to north-east direction. Temperature ranges in summer from 30 - 38 ºC during the day and 20 - 30 ºC at night. Hottest month are April, May, June while temperature ranges in winter varies from 15 - 25 ºC during the day and 5 -10ºC at night. Coldest month are November, December, January, February. Global solar radiation varies from 1100 kwh/m2 per year. Average rain falls ranges from <1200 mm annually. Soil conditions are mostly basic with red alluvial soil. Proposed Site area is 20200 sqm. Approach road width is 18 meter and nature of the traffic is city traffic.

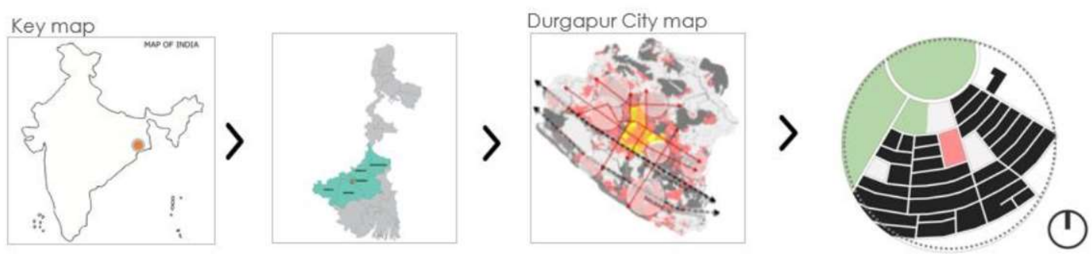

Figure 3: Location and Site Selection
Source: Municipal Corporations, edited by author

WARM AND HUMID CLIMATE ZONE	
Thermal Requirements	**Physical Manifestation**
Reduce Heat Gain	
Decrease exposed surface area	Orientation and shape of building
Increase thermal resistance	Roof insulation and wall insulation
	Reflective surface of roof
Increase buffer spaces	Balconies and verandas
Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale color, glazed china mosaic tiles, etc.
Reduce solar heat gain	Use glazing with lower SHGC and provide shading for windows. Minimize glazing in East and West
Promote Heat Loss	
Increase air exchange rate (Ventilation throughout the day)	Ventilated roof construction. Courtyards, wind towers and arrangement of openings
Decrease humidity levels	Dehumidifiers/desiccant cooling

within 200 m
nearest bus stop
water tank
society play ground
temple
society association head office
kids welfare association
within 500 m
hospital (super specialty)
bank - IOB & UBI
post office
meals delivery shops
main road to city center
within 1 km
NH 45 directly connected to airport
directly to kolkata - 165 km
within 5 km
railway station
within 9 km
city centre and bus terminal

Figure 4: Climate zones details (Adopted from ECBC 2017 manual) and proximity analysis

The chosen location provides basic amenities including playgrounds, hospitals, banks, post offices, and children's parks within a 1-kilometer radius. The well-known Mission Super Specialty Hospital is a significant landmark close by. It provides hospital services and responds to emergencies. The neighbourhood's parks and lawns give the locals a place to socialize. The park serves as a gathering place for locals to perform daily Aarti rites and celebrate holidays.

Site zoning and User analysis

Site zoning is done in accordance with the traditional healthcare spaces model, which divides the site into public and patient spaces along with supporting services. (Figure 5). The proposed design program accommodates single storey-built form for elderly wards with ground coverage of 5200 sqm. Total area of different spaces are as follows; residences (65% of gross floor area). health care (25% of gross floor area). others (10% of gross floor area). Estimated occupancy for 45 staff, general store 20 visitors/day pharmacy 30 visitors/day. However, Parking area accommodate 30% of total built up area.

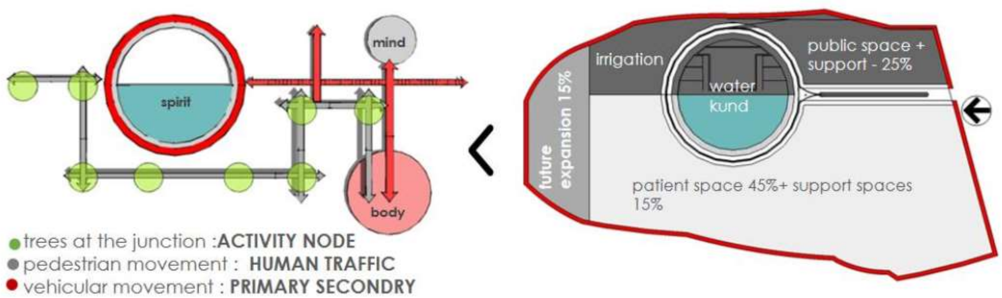

Figure 5: layout showing public and patients zoning
Source: Author

Public space: There is a waiting area for guests, a library, a prayer room, a grocery store, a sitting area. Healing gardens are outdoor spaces to encourage health and wellbeing for people suffering from illness. The concept of healing garden can be understood as process that promotes wellbeing (Chantal Erbino, 2015). The primary area for interaction between residents and guests and neighbours is here. It is the most adaptable area, offering several opportunities for staff. Following are the list of trees and plants used for planting design in the garden spaces Table 1 Figure 6.

Table 1: List of Plants and tress used for passive healing planting

Sl.no.	List of Plants / trees	Scintific name	Remarks
1	Wild betal	Piper sarmentosum	Roots are used in traditional medicine as a diuretic and to treat cough and asthma.
2	Betel Nut	Areca catechu	Leaf paste is used to relieve fever while roots decotion is used to treat stomach ailments
3	Black cuurant tree	Antidesma ghaesembilla	Leaves are used to treat headache and as a purgative.
4	Texas frogfruit	Phyla nodiflora	Infusions of the plant use to treat constipation, knee pains, indigestion. A poultice of the plant is use to stop bleeding.
5	Red date , jujube	Ziziphus jujubae	Fruits are used for medicinal prepatations to treat conditions like insomnia and anxiety.
6	Butterfly pea	Clltoria ternatea	İt can reduce body pain, migraine, swelling. Lowers blood pressure. It is rich in antioxidants.

Figure 6: List of Plants and tress used for passive healing planting
Source: Author

Patient space: Caretaker rooms and quarters for elderly inmates are included. When compared to public space, this lot is larger. A caretaker room, private patio, and guest house for family and friends are all included in the cluster of elderly inmate units. A separate structure for support facility near to inmates' units will cater space for Administration, pharmacy, doctors from 9am to 6pm, ICU and therapist for consultation support facilities, storage with wet and dry disposal, cleaning and washing departments.

Integrating the both zones: The design incorporates zones that symbolize the mind, body, and soul. Mind represents the public space where they keep themselves occupied and involved by conversing with neighbours and tending to a garden that can enhance both their physical and mental welfare (Stigsdotter U.A., 2002). Body symbolizes support structure for taking care of the clinical treatment facility. Spirit is the plaza consists of water body present in between the Public and patients' space. The site's primary focal point is this plaza. Water is a calming element that promotes a sense of security and stability. The site's ability to harvest water is also improved by this body of water. Harmony between the mind, body, and spirit unites the location (Figure 7).

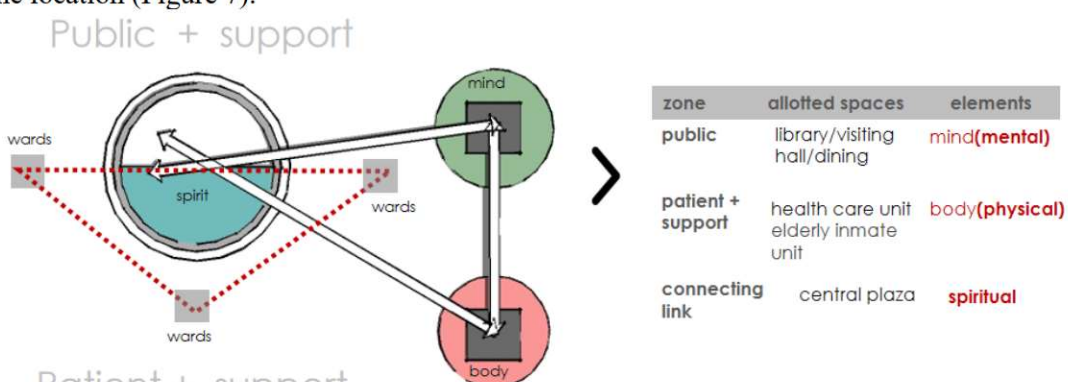

Figure 7: Integration of site element
Source: Author

The primary goals of providing optimum circulation were to limit public cars at the entry and decrease road coverage within the site. The administrative staff, a support group, and a public area with a garden are all located close to the site's entrance. As a result, there is less traffic overall and it is largely stopped at the entry, which makes the job of the security guard easier. The plaza around the water feature is where pedestrian traffic (elderly inmate units) travels further inside the facility. In order to create environments that are hospitable to pedestrians, there are no automotive obstructions. The private prison units are only accessible to medical personnel, employees, immediate family members of the residents, and maintenance personnel.

Analysis of User: Every building on campus will have a different focus group format. Long-term care is currently undergoing a transition. Nursing homes are becoming a destination for people who require substantial care or are undergoing rehabilitation following a hospital stay, while assisted living facilities are accepting higher levels of care. Many assisted living facilities now accept those who require help with all daily activities. The "Overview of Assisted Living Report" (U.S. Department of Health and Human Services, March 2016) from 2010 in the US stated that 54 percent of assisted living residents are 85 years or older; 27 percent are 75–84 years old; 9 percent of residents are between 65 and 74 years; and 11 percent are younger than 65 years old.74% of assisted living residents are female; 26 percent are male. The planned facility was designed to help two different sorts of residents. The first was a person with memory impairment who required daily assistance for a longer period of time in order to complete duties like keeping to a schedule Figure 8. The other type is end-of-life care support, which necessitates constant monitoring by assistants and doctors.

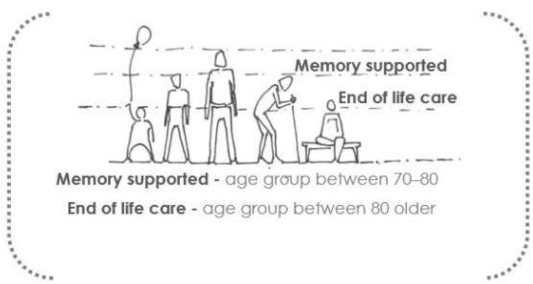

Figure 8: Typology of patients for the proposed facility
Source :Author

RESULTS AND DISCUSSION

Identification of the activities to be carried out and types of users involved in different time of the day and a conceptual plan (Table 2). The following activities were identified: relaxing, physical activity, rehabilitation work, eating outdoors, meeting relatives, cigarettes breaks.

Table 2: Activities, types of users involved, time of the day

Activities	**Users involved**	**Hours (time of the day)**	**Area (m2/person)**	**Facilities**
Physical activity	Patients-staff	Morning after breakfast	4	Outdoor gym equipment
Rehabilitation activities	Patients-staff	Evening after snacks	2	Tables; benches; chairs; awning; waste bins
Dinning indoor / outdoor	Patients-staff	Afternoon and Night	2	Tables; chairs; awning
Horticultural therapy	Patients-staff	Morning after breakfast	8	Storeroom with tools and supplies

Physical activity	Patients	Morning before breakfast	12	Outdoor gym equipment
Meeting relatives	Patients	Afternoon	2	Benches; pergola; waste bins
Relaxing	Patients	Morning - Evening	2	Benches; pergola; waste bins
Relaxing	Staff	Morning - Evening	2	Benches; pergola; waste bins
Cigarette break	Staff	Morning - Evening	2	Awning; benches; ashtray; waste bins
Dinning indoor / outdoor	Staff	Afternoon and Night	2	Tables; chairs; awning

Analysis of area required: Most residents of assisted living facilities have their own private unit that is tailored to their needs. In a nursing home, there is typically no specialized medical monitoring equipment, and the nursing staff may not always be on duty. To provide other required services, however, skilled personnel is typically present on-site round-the-clock. Private apartments are typically self-contained when available; they have a separate bedroom with bathroom, as well as a possible separate living space or small kitchen. To ensure prompt care when needed, registered nurses and licensed nurse aides are on call 24 hours a day. As an alternative, private or semi-private sleeping quarters might be combined with a communal restroom to mimic a dorm or hotel room. Typically, communal spaces for socializing exist, (Adevi A.A., 2012).

Concept of area segregation and built form evolution:

According to user types, the first phase resulted in the identification of two main zones. The senior inmate quarters and communal facility make up the zone designated for patients. The first category of shared space offers a ground-floor room with a nurse station for hosting guests and family members. For those who wish to remain for a couple of days, a bedroom with a bathroom is situated on the first floor. The second sort of common area includes outdoor spaces, building courtyards, and exterior walkways that connect all senior inmate quarters. The following step was selecting various locations for the upcoming activities (concept of area segregation) Figure 9, Table 2.

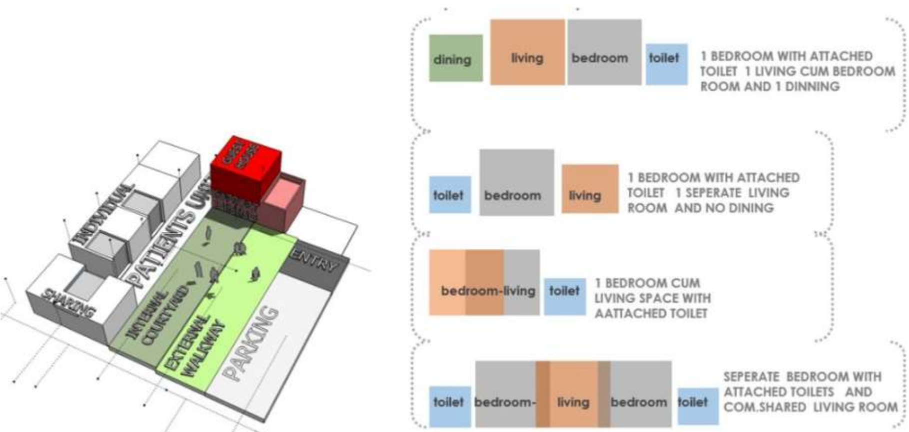

Figure 9: Left: Concept of area segregation and Right: Typology of patient's units
Source: Author

For the development of the aim of the detailed plan was to define the function to be performed and designing of the inmate's wards, care taker units, connected walkway and courtyards. According to the concept development as illustrated in figure 9, the works planned are as follows:

(i). Inmates Units: Planning is carried out effectively using a hierarchy of space, facility, and user requirements. The accommodation for the facility is constructed with four different ward pattern types. The first consists of a one BHK (Bedroom Hall Kitchen) home with a bedroom and private bathroom, dining area, living room, and kitchen. This is intended for users who require life-care assistance, especially physically challenged individuals. All year long, these residents require daily support. The patient can stay with a guest for a shorter period of time in the second arrangement, which contains a bedroom and a living area. The third design is a single-occupancy bedroom solely with no further living space. The fourth design features two bedrooms and a combined living area for double occupancy. Here, a couple or two pals can stay together in private guestrooms.

(ii). Passive healing outdoor as Social Corridor: The built form was created with a vision to propose new ways of imagining and experiencing healthcare spaces. Shaded corridors (social corridor) are best as it, creates a comfortable environment throughout the day (Figure 10a and 10b). Shaded corridors give the pedestrian a walkway to access other wards at any time of day or season. The trees punctured in between walkways gives ease of the way finding as a repetitive element in regular intervals.

(iii). Passive healing garden as central courtyards: Planning is done with the hot, humid weather in mind. Courtyards are provided as an activity hub connected to shady social corridors for residents to mingle (Figure 10a).

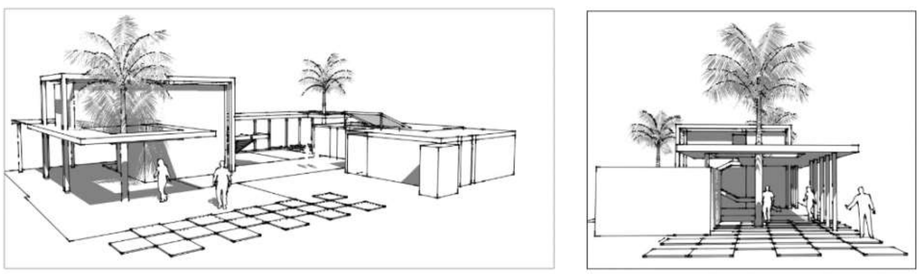

Figure 10a: Social corridor and courtyard
Source: Author

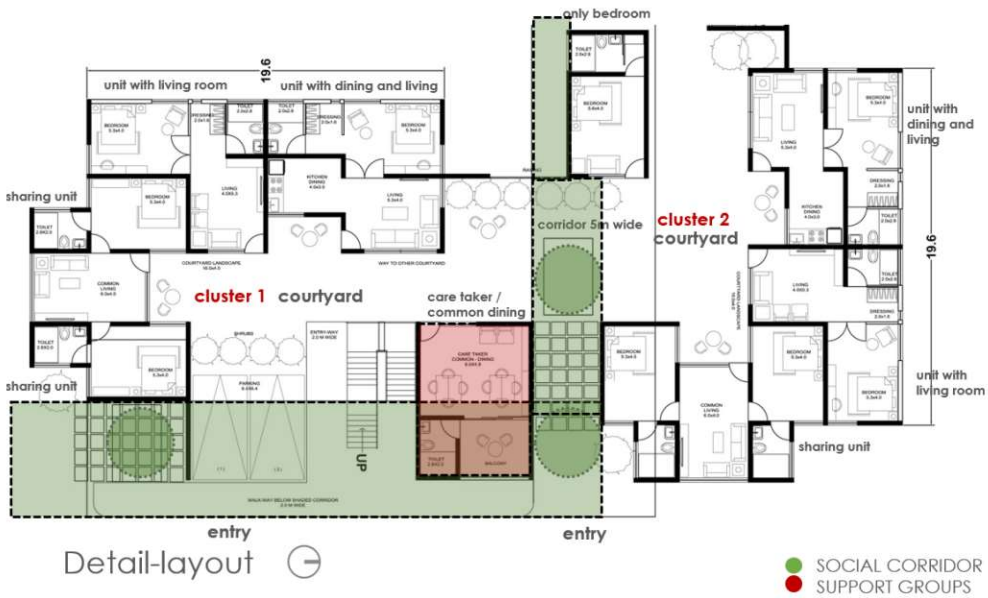

Figure 10 b: Detailed layout of inmate units and support facility
Source : Author

CONSIDERATIONS AND CONCLUSION

The designing of an Assisted Living Centre requires considerations of some key issues such as: Connectivity to open spaces and gardens, patient autonomy and ease of orientation, freedom of selecting customized spaces and functions.

Connectivity to open spaces and gardens

A connection between patients and adjoining open spaces, can either be of passive or active order. It has been widely studied that natural garden passively cures (Cooper Marcus C., 1995) (C., 2007) by simulating sensory organs to experience spiritual value. Social corridor and common meeting areas cure actively and encourages physical participation and interactions between patients, which not only engage mind but has significant impact on health (Chantal Erbino, 2015). Following are the list of zones/areas for performing group interaction and individual activities Table 3.

Table 3: List of space and their impact on patients

List of Activity	List of spaces	Impact on pateints - Active	Impact on pateints - Passive
Physical activity	Common courtyard / Social corridor	Yes ,	No ,
Rehabilitation activities	Garden / Inmates units	Yes ,	Yes
Common dinning indoor / outdoor	Support facility / Common courtyard	Yes,	No,
Relaxing	Common courtyard / inmates units / Public space	Yes,	Yes,
Cigarette break	Support facility / Gardens	Yes,	No,

Patient independency and ease of walkability

One of the main sources of stress for patients and visitors in care facilities is the need for independence (Beer, 2000). The capacity to navigate the garden on one's own can be encouraged in a number of ways, including: strategic placement of signs, integration of the site's natural and architectural features, clearly visible routes, signs, and landmarks, and visibility of the building's entrance.

Freedom of selecting customized spaces and functions.

Dedicated Facilities with discrete area program motivate patients to perform activities efficiently. From a psychological standpoint, having a choice is crucial for a patient along with their physical progress. The patient should be given the option to select between active and passive, quiet and bustling, or direct and indirect involvement in the assisted living facility by having access to spaces with diverse roles where different activities are carried out (Cohen Mansfield J, 1998).

In an assisted living facility, passive healing areas should ideally be created using evidence-based design and scientific knowledge from environmental psychology and neuroscience. Regarding the examples, the proposed project calls for actively utilizing the garden through the practice of horticulture in addition to using it as a place for relaxation (J., 1992). Comparable situations can be employed using the provided methodology, but different patient types may require different design choices based on their needs as identified by both experts (focus groups) and the users themselves. Patients' safety, comfort, independence, and freedom of choice are taken into consideration while choosing design elements including building materials, furniture, and landscape.

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COMMUNITY DESIGN CHARRETTE: A PARTICIPATORY TECHNIQUE FOR IMPROVING THE PERCEPTION OF SAFETY OF URBAN RECREATIONAL PARKS

Karthik Mohan [1], P.S.Chani [2]

[1] Research Scholar, Built Environment Laboratory, Department of Architecture & Planning, IIT Roorkee, Roorkee – 247667, India (k_mohan@ar.iitr.ac.in)
[2] Professor, Built Environment Laboratory, Department of Architecture & Planning, IIT Roorkee, Roorkee

ABSTRACT

Perception of Safety is a vital factor that affects the usage and activity of urban public space. This study explores community participation techniques to identify the perception of safety and usage of a park within the context of Bengaluru, India. Condition mapping, Survey questionnaires on-site (n=66) and online (n=72) were used for the analysis of the perception of safety within Cubbon Park, Bengaluru. The community participation was further attained with the help of a community design charrette within Cubbon Park for various stakeholders (n=61) of the park. Park users, Park officials, security personnel, vendors, and shopkeepers participated in the design charrette. The design charrette enabled the involvement of various stakeholders within the park for the analysis, inference, and suggestions for improving the perception of safety within the park. The stakeholders opted for their actual requirements and that enabled the researchers to come up with proper design strategies. This study contributes valuable knowledge to the domain of participatory design techniques for implementing Crime prevention in an Urban Park and helps ways to strengthen the perception of safety associated with the urban public spaces.

Keywords- Community Design Charrette, Participatory technique, Perception of safety

INTRODUCTION

Perception of safety

A person's subjective assessment of how secure they believe a location is in terms of criminal danger or personal victimization is known as the perception of safety. Risk graduation is a highly individualized process that is largely influenced by the psychology of the individuals and, to a lesser extent, by word of mouth. Physiological safety can be achieved only if people feel safe from wild animals, criminal assaults & various types of accidents: household, vehicular, and so on. To attain psychological safety, there should be a possibility to avoid the unexpected, be in control, know where one is in one’s social and physical surroundings, and not be afraid of other people and social situations. The environment's quality has an impact on people's perception of safety. Environmental factors such as environmental legibility, visual annoyance, light pollution, cleanliness, and noise pollution all help people feel more secure. (Nozari et al., 2016).

Urban Parks and Perception of safety

Perception of safety is considered an important urban stressor. Multiple studies had already found that urban environments can either increase or decrease the chances of crime happening (Hedayati Marzbali et al., 2012). The major factors that can reduce the perception of safety in an urban park include landscape design, the density of the vegetation, park maintenance, physical incivilities, the amount of light present in, wayfinding and legibility, and visibility. (Mahrous et al., 2018)

While parks present more frequent issues than stadiums, they do so on a smaller scale. Even if authorities take efforts to erect gates and limit the area at a specific hour, parks are by their very nature open green spaces in urban areas that may typically be accessible 24/7. (Karthik Mohan, 2017) They serve as an essential urban respite. However, these elements also draw criminals to parks. Parks can host criminal activities like assaults and the sale of illegal drugs because of lax enforcement, ineffective patrols, and passive monitoring. Foliage serves as crucial cover for criminals. In addition, parks can become unsafe for visitors when recreational activities grow out of control.Urban safety problems could be categorized into traditional safety problems (Traffic accidents, floods, earthquakes & crime) and Non-traditional safety problems (Terrorist attacks, pandemic disease disasters) (Cai & Wang, 2009).

The study conducted by Bonnie & Jim 2018, examined three groups of fear-evoking factors in urban parks in Hong Kong – Inherent park characteristics, Park design and management issues, and visitor-related concerns(Mak & Jim, 2018). As with stadiums and other types of spaces, addressing park challenges requires assessing the specific problems encountered in the park and understanding how to work with local stakeholders to solve them. I have. Community members include park rangers and custodians, residents and neighborhood associations around the park, local trade associations, local schools and nursing homes with regular park customers. The paper by Ilknur & Zengel (Türkseven Doğrusoy & Zengel, 2017)analyses how people perceive safety and how it affects how they use parks. The purpose of the paper is to investigate the significance of safety perception as a facilitator or deterrent of park use. The perception of safety in parks is improved by effective green design, according to a study. Formally planned, manicured parks have been determined to be safer than ones with a more natural appearance. The main perceptual components of perceived safety are user satisfaction, familiarity, wayfinding anxiety, and congestion.

STUDY AREA AND METHODS

Study Area – Cubbon Park Bengaluru

Bengaluru is a capital city with a rich history dating back to the colonial era and the years after independence. The city later experienced fast expansion as a result of the massive infusion of telecommunication and information technologies. Early in the 19th century, the British constructed a military road in Bangalore's center, known as M.G. Road, which ultimately developed into the city's main thoroughfare. Later, this location developed into the center of commercial and recreational activity. This avenue has churches, a parade ground, stores, bars, parks, etc., just like other colonial areas. At the end of M.G. Road, Cubbon Park was quickly constructed as an urban park. As it is logically situated in the center of Bengaluru, in the major administrative region, Cubbon Park is a 197-acre "green lung" location (fig.1). Commercial areas like UB City and St. Mark's Road are nearby. Aside from those looking for a quiet place to relax and unwind in the middle of the busy city, it is a popular destination for tourists and exercise and fitness aficionados. Central government agencies including the Reserve Bank of India and Vidhana Soudha, as well as Highcourt, are located in the region.

The increased number of residential home entrances to the streets and the presence of pedestrians on the streets both have the potential to reduce urban crime. Less crime results from more people, more activities, and eyes on the street.(Matijošaitienė et al., 2013) Cubbon Park is in the heart of the city, but the nearby land uses were mostly commercial and institutional buildings and not many residential buildings in and around the park premises. This also leads in low perception of safety for the users of the park.

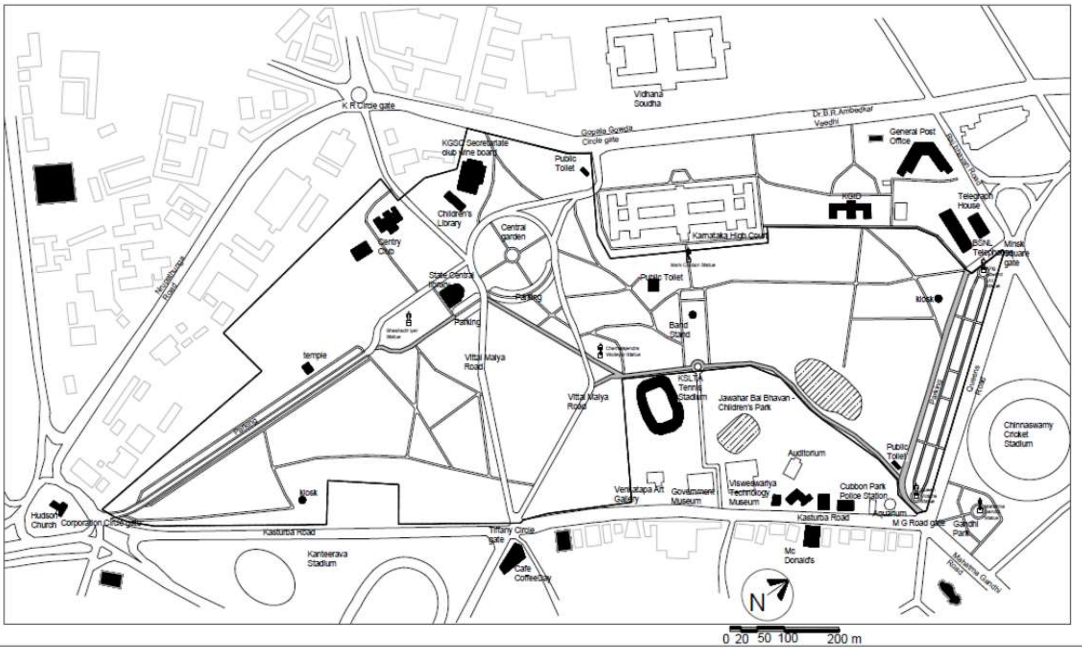


Figure 1- Cubbon Park Layout
Source – Author

Study Methods
The site study of Cubbon Park was conducted using multiple methods, which include:

Condition Mapping
The analysis of the site required an in-depth study. Site concerns and opportunities are studied first to identify the possibilities and required corrections. Condition mapping for the park is done to identify the situation of infrastructure within the park. This is done to identify community safety factors that enhance users' actual and perceived sense of safety.

A site assessment records the location of vulnerable areas. This includes public facilities, parking lots, bus stops, open spaces, sidewalks, restrooms, open spaces, etc. It also examines the potential presence of vulnerable groups, who they are, how they use the area, whether they are potential or actual targets, and why. The purpose of site evaluation is to determine the factors that influence the actual and perceived safety of the site for potential users (Figure 4). A site evaluation may involve multiple site visits to evaluate and investigate various design aspects of an area. The whole site has different kinds of fencing and compound walls. However, their areas where the fence is broken and is not repaired. Instances of using bamboo and other local materials for covering these broken fences places are seen in some areas, especially in the space near Kanteerava Stadium. The whole park becomes dark after sunset and feels vulnerable to use. (Fig. 2)
Bamboo plantations are seen in ten different locations within the park premises. The base of the bamboo itself grows thick making a minimum circumference of 2.5m. It is very evident from the looks of bamboo that no sufficient pruning measures or management strategies had been followed in dealing with the overgrown flora. The presence of such huge overgrown bamboo creates entrapment locations for possible offenders. Public urination and gambling by antisocial elements happen even in the daytime in this area of the park. However, couples find these spaces as ambient hide-out spaces. Few of the users who come as a group prefer this area for exploring their photographic skills may be due to the beautiful background it provides The entire Cubbon Park has six authorized areas designated for parking; however, it is not sufficient for the current influx of people visiting the park. The road from Corporation Circle gate to state central library y has two-wheeler and four-wheeler parking parallel to the road, which gives the major parking lot within Cubbon Park compound. Apart from this, the area near Queen's Park also has two-

wheeler and four-wheeler parking. (fig.3) However, this parking spots become insufficient during busy weekends and other days, especially when there is a cricket match happening in Chinnaswamy stadium. As the Park is surrounded by buildings with sports and game activities; like Kanteerava Stadium, Chinnaswamy stadium and KSLA Tennis stadium, the premises demands more parking. As a result, there are unauthorized parking in most of the park areas and encroachment by bikers and car users on park area is seen during busy weekends and cricket matches.

Figure 2 - Badly lit areas & broken fencing at different areas of the park
Source- Author

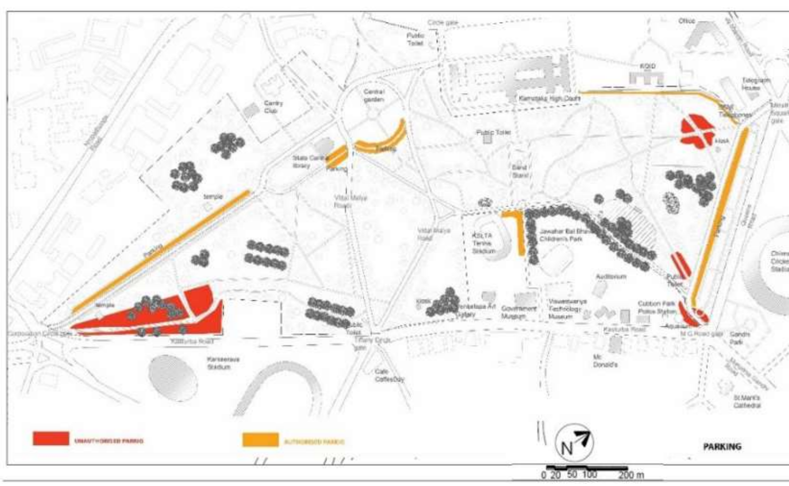


Figure 3 - Parking layout showing Authorized and Unauthorized Parking
Source – Author

The park lacks a sufficient number of dustbins, also badly positioned which results in garbage dumping in many of the areas, especially near the Kanteerava stadium area. Plastic waste and paper waste were adding chaos to the park premises. The dustbins that are not well designed ergonomically add up to spreading garbage through the landscape of the park. Once when you observe 4ft by 4ft frames, there will be garbage in the frame. It is not only the lack of proper dustbins but there were a few other reasons like dogs, birds, and passers-by making the space dirty. Water drain provided on the site at 2 locations are not covered and remains vulnerable spaces for the park users. The drain is sometimes filled with sewage water and drainage provides a very bad odor. This makes it a reason for most park users to avoid that space.

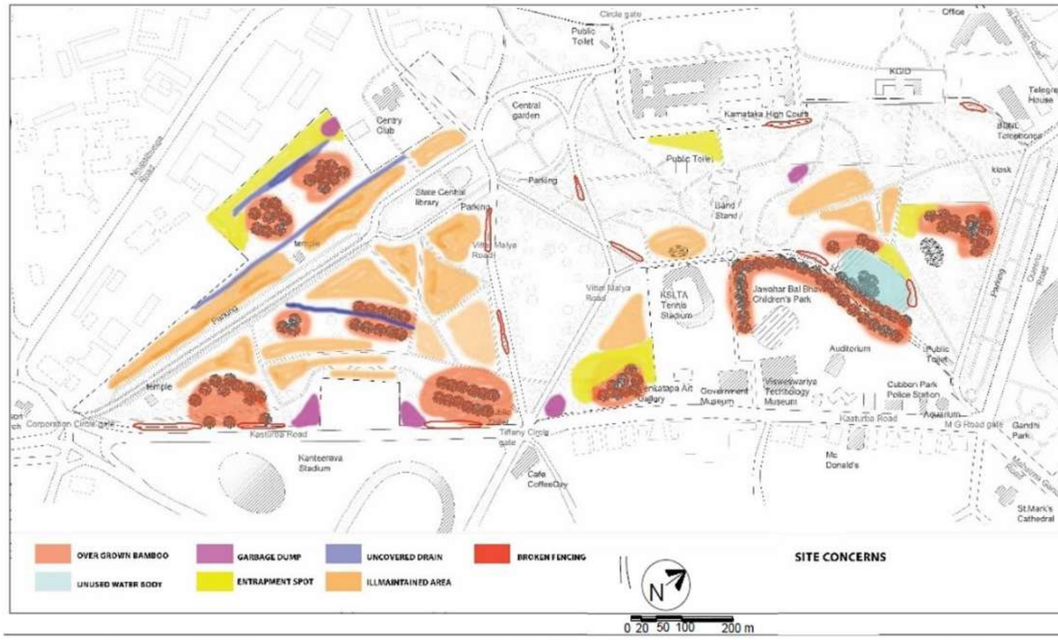


Figure 4 - Site concerns mapped - Cubbon Park Bengaluru (Source – Author)

Questionnaire Survey

The face-to-face survey has been conducted on-site at different locations and also with the help of an online questionnaire survey. A total of 66 respondents answered the survey at Cubbon Park and 72 respondents answered in the online survey. The online survey was conducted via google docs and the questionnaire survey was sent to residents of Bangalore who had been to Cubbon Park at least once. The onsite survey was conducted by asking the park users each question one by one. One-on-one interaction enabled better communication, without distribution and retrieval. This helped in reducing errors.

The questionnaire was prepared in such a way that it allows an easier way to respond to the park users. The majority of the questions were having three options – Yes/ No/ Not Sure. This way of multiple-choice questions enabled easy responses and a fast survey. It helped in getting ample time to guide through questions and observe reactions. The highlight of the face-to-face survey was the variance in the sample set. The questionnaire ended with a self-determined column to allow free expression by the respondent in giving comments/ suggestions for making the park safe and secure. People from different age groups, gender, occupation, and economic background were interviewed and primarily all were stakeholders of Cubbon Park.

Community Design Charrette

The methods of involving the community in the planning and design process were developed in 1960 and it is characterized by various degrees of involvement or participation. It is also important on how and when the stakeholders get involved in the process of design development. The methodology of helping communities visualize the project and helping designers in planning and decision-making is the key role of a community design charrette. Charrettes provide an array of views, possibilities, and visions for creating the urban project. The involvement of multiple stakeholders helps in better discussion and better design development. The participation envisaged here is modest involvement, which only caters to advisory decision-making. The expression "community planning" recommends physical planning at the group scale e. g., neighborhood, urban scale community developments, and/or suburban communities, through process entangling community and other respective agents. As per the study conducted by Kimihiro Hino (Hino,

2018) community-based crime prevention approaches are showing good results in Japan. This study sought to determine whether two initiatives run by "Plus Bouhan" could broaden the pool of crime prevention volunteers as well as what impact they might have on volunteer behavior and attitude. In the first practice, daily gardening was given a crime prevention component, and in the second, walking and jogging received a crime prevention component. Including new bottom-up community collaboration mechanisms in the planning process can improve the participation of different space user groups and promote their active role in neighborhood crime prevention.(Piroozfar et al., 2019)

Tools and techniques used for Design Charette: Flashcards
Flashcards were used as a tool for communicating with the Workshop participants. A5 size colored flash cards were printed and taken to site to show it to the participants of Design Charrette workshop. (Fig.5) The benefits of flashcards:

- to give more clearer idea about the general conditions of recreational spaces in and around the world
- To emphasize the situation of the parks in terms of sense of security
- to make the stakeholders aware of other well utilized parks
- more handy and easier to discuss

Visual communication - Participants became more aware of the other well-designed parks.

The flashcards were designed with English and Kannada script on the topic “Workshop – park design for crime prevention”. Kannada being the local language in Karnataka would help communicating with all kind of stakeholders.

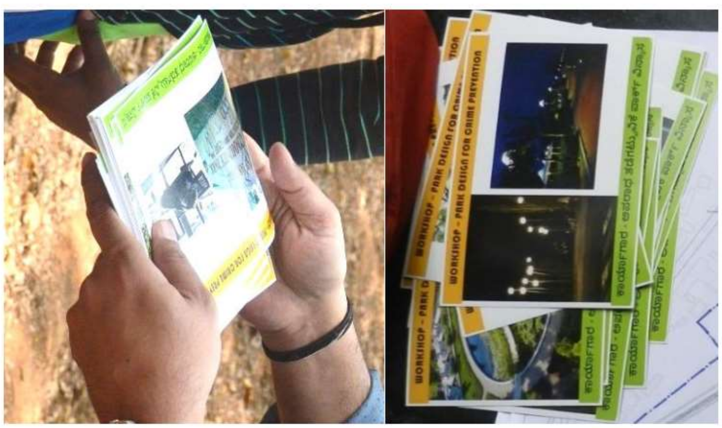


Figure 5 - Flash cards for Community Design Charette

Design Charette Workshop
The workshop was preceded by detailed questionnaire survey at multiple locations within, but not limited to Cubbon Park, Chinnaswamy stadium, MG road, Indian Express etc at Bangalore. The design charrette workshop was conducted at 12 locations (fig.6) within the Cubbon Park site on 4th and 18th of March 2017 and the suggestions, comments from the stakeholders were taken into consideration. The main aim of the workshop was to understand the needs of multiple stakeholders in and around the chosen study area, giving possible design suggestions and thereby streamline the list of possible interventions for making the Cubbon Park more safe and secure for the users.
A total of 61 stakeholders participated in the design charrette workshop which was conducted in 2 days. 12 groups were formed out of the participants and minimum 4 members were present in each group. Attendees participated in a design game (fig.7) for making the park more safe and secure. Aerial view of site was printed in A2 size and was taken as a design board. After the questionnaire survey, author came up with a custom collection of hand drawn design elements which the participants of the survey suggested as required interventions for the park. These design element chits were given to the workshop groups and they had to select the required elements together. Prior to design game the flashcards were given to the participants of

the workshop and that enhanced a clearer idea related to habitat improvement, secure and safe urban parks. While doing the design game, the group members were asked to keep in mind the major goal – to create a safe and secure urban park, to reduce likelihood of illicit or anti-social activities and also to make the park more active.

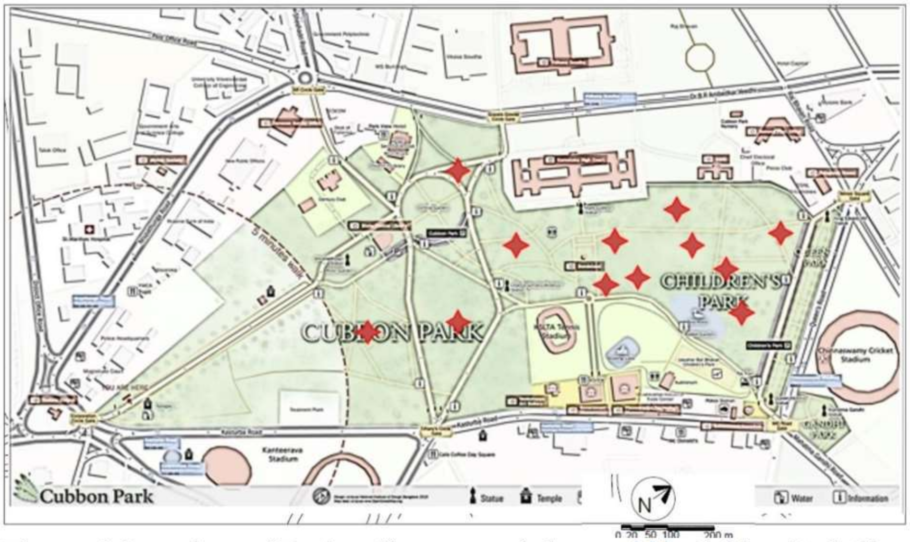


Figure 6- Locations of Design Charette workshops within Cubbon Park Site
Source – Author

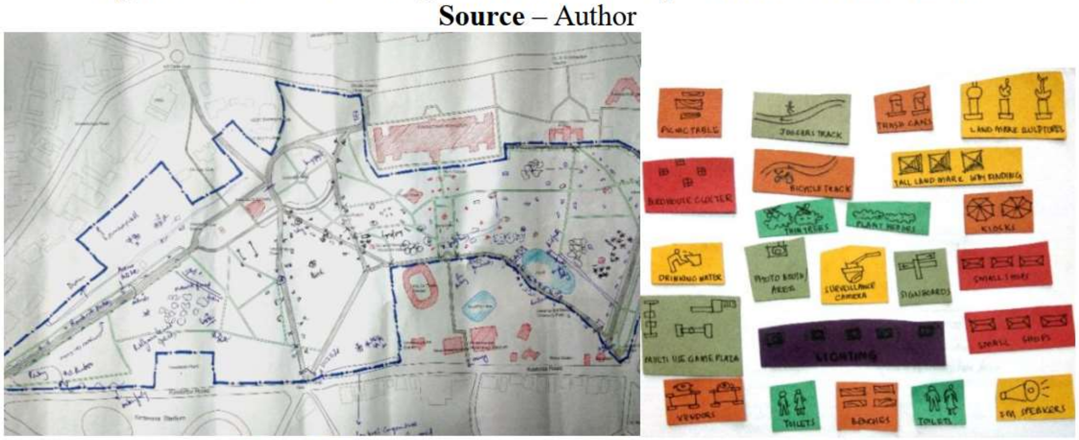


Figure 7- Design Game board & design element chits

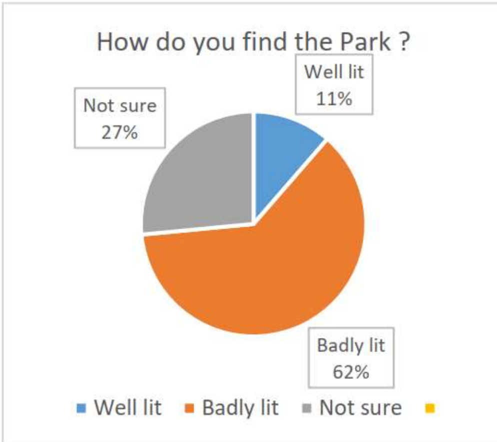
The major rules of the design game were to respect every one's input and think about what others would like to experience in the Cubbon Park. Apart from the provided design game elements, participants of the workshop were given freedom to express any comments or suggestions pertaining to the redevelopment of the site. The list of design elements provided for the game were, picnic table, benches, bird house cluster, tall landmark wayfinding sign, landmark sculptures, signboards, joggers track, bicycle track, lighting, trashcans, toilets, Amphitheatre, vendors, small shops, drinking water, kiosks, photo booth, FM/ Radio speakers, surveillance cameras, plant hedges, thin trees and multi-use game plaza. (Fig.8)

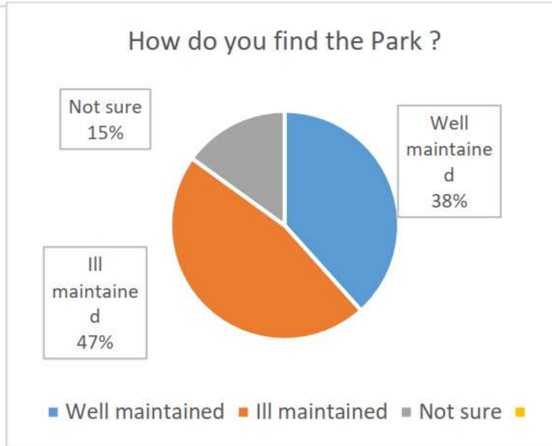
Figure 8 – Design Charette groups within park and Completed Design game Sample (Source-Author)

ANALYSIS

As per the results from the questionnaire survey, the majority of visitors come to the park to socialize, jog or walk, and to relax. The majority of joggers go to the park every day with their family or friends. Weekend visits to the park were made by 32% of respondents, and 95% of them said they liked to go with friends or family. 47 percent of visitors believed that the park needed more upkeep. 62 percent of those surveyed concur that the park needs more lighting. Despite the fact that 38% of respondents thought the park was unsafe, 53% still believed it was in use. This may be due to the fact that people prefer visiting Cubbon Park, especially on weekends, despite Bengaluru being a busy metropolis with few green areas.

Poorly maintained urban space can attract criminals and it can support graffiti, vandalism and rubbish. Vacant spots can act as entrapment locations, where as well managed, well-maintained spaces make the people feel safer. There arouses an opinion by almost 55% of the users that the park has drunken people around who had created nuisance. 43% of the users felt that there are empty buildings/ spaces within the park. The area near the waterbody opposite Jawahar Bal Bhavan had unused empty spaces, which were vulnerable. Almost 61% people responded that the park lacks sufficient benches/ sitting spaces. Some of the users were of the opinion that there were benches within the park, but it is all either poorly maintained or placed in an improper manner. Lack of sufficient number of dustbins were also highlighted by 69% of the users. There were evidence of vandalism, graffiti and presence of rubbish reported by 55% of the survey respondents. Even after all these image management issues, 66% of the respondents were agreeing to the fact that the aesthetics of the park still attracts users. This again has many other reasons of being an urban green lung space, which is in the heart of a city which is over crowded with traffic congestion and pollution. The presence of greenery and nature always brings positive vibes to the users of Cubbon Park.





RESULTS

The participants of the design charrette were hesitant initially, but with the introduction of the problem and provision of flashcards made the users more active and enthusiastic. Almost all groups were actively discussing and debating before going into selection of design elements. The design charrette comprised of 12 groups, with different age group and gender involved. Groups involved degree students, physical education trainer and students, IT professionals, Tourist people, Bank professionals, vendors, architects, interior designers, slack lining enthusiasts, and family members.

Total of 11 groups out of 12 had opted for signboards, trashcans and toilets, 10 of 12 had suggested the requirement of landmark sculptures, bicycle track, lighting and drinking water for enhancing sense of security. (table-1) The other major design elements chosen by the groups were joggers track, Amphitheatre, surveillance cameras, and planting hedges in required areas, small shops, tall landmark wayfinding sign and picnic tables.

The design strategies for crime prevention in Cubbon Park are formulated after careful examination and analysis of the site using various methods. Activity mapping helped to provide the kind of activities happening in each zone of the park and its associated effects in giving sense of security to the users. Safety audit helped in getting people's perception of fear and its vulnerability pertaining to the site. Safety audit made sure the fact that there should be sufficient interventions required in the site for attaining sense of security. Detailed questionnaire survey of onsite and online stakeholders of the park gave feedback and suggestions on improving the conditions of the park. Site areas which were a concern to most of the users were with less sightlines, surveillance, lighting and activities. This was a common inference in all the above-mentioned analysis. All these analyses, helped in generating design suggestions, but it was also required to incorporate the user/ stakeholder feedback. Community design charrette was introduced to interact with the users of the park and thereby getting one to one feedback of how to go ahead with design solutions. Twelve groups of varying age, gender, race, economic and occupation had participated in the design charrette and the results were tabulated to generate a list of design suggestions by the users.

Table 1 – Design Charette Results compilation Chart

CUBBON PARK - DESIGN CHARETTE														
	Design Elements	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	TOTALS
		4 members	5 members	4 members	4 members	4 members	4 members	9 members	5 members	5 members	6 members	6 members	5 members	= 61 members
1	Picnic Table	x		x	x	x		x		x			x	7
2	Benches	x							x	x			x	4
3	Bird house cluster		x	x	x	x			x	x				6
4	Tall Landmark Wayfinding sign		x			x		x	x	x	x		x	7
5	Landmark Sculptures	x	x	x	x	x		x	x	x	x	x		10
6	Signboards	x		x	x	x	x	x	x	x	x	x	x	11
7	Joggers Track	x			x	x			x	x	x	x	x	8
8	Bicycle Track			x	x	x	x	x	x	x	x	x	x	10
9	Lighting	x		x	x	x		x	x	x	x	x	x	10
10	Trash Cans	x		x	x	x	x	x	x	x	x	x	x	11
11	Toilets	x		x	x	x	x	x	x	x	x		x	11
12	Amphitheatre	x	x		x				x	x	x	x		7
13	Vendors					x								1
14	Small Shopping Areas	x	x	x	x			x	x	x	x	x		9
15	Drinking Water	x		x	x	x	x	x	x	x	x	x		10
16	Kiosks		x						x	x				3
17	Photobooth		x		x	x								3
18	FM/ Radio Speakers									x				1
19	Surveillance Cameras	x		x			x	x	x		x	x	x	8
20	Plant Hedges		x	x	x	x			x	x	x	x		8
21	Thin trees			x	x		x		x					4
22	Multiuse Game Plaza									x	x		x	3

CONCLUSION

The study came to the conclusion that the, feeling of being safe is a very important factor in attracting people to use the built environment. Mixed land use promotes local activity, thereby increasing the security of the site. Therefore, locating commercial facilities opposite public spaces improves vitality. Activity generators attracts more people, more people mean more surveillance and more security. Natural surveillance has to be provided on all the streets, roads, public areas like parks etc. there should be maximum sight lines from, to and within the different spaces to enhance a crime free environment. Trap routes to avoid and predictable escape routes when planning an area. However, if there is still the possibility of a predictable path, increase lighting and line of sight in the area to ensure safety. All theories in security design indicate that you can improve or increase the sense of security of a place by improving or increasing visibility of entering and exiting an area.

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ROLE OF INDOOR AIR QUALITY ON THE OVERALL HEALTH OF OCCUPANTS IN EDUCATIONAL SPACE

Anita K Kavathekar[1], Shaila Bantanur[2]

[1] Anita K. Kavathekar, Asso. Prof., Marathwada Mitra Mandal's College of Architecture, Pune Maharashtra, India. kavathekar.anita@gmail.com
[2] Dr. Shaila Bantanur, Director & Professor, BMS School of Architecture, Bangalore, Karnataka, India shailabunty@gmail.com

ABSTRACT

Air pollution is one of the major environmental threats in India. World Health Organization (WHO) considers Indoor Air Quality (IAQ) as the 8th most important risk factor for the burden of disease. In the contemporary era, occupants' physiological and even psychological health is affected by indoor air quality whereas the majority of people spend time indoors. Furniture, carpets, paints, room fresheners, and cleaning products are the main sources of indoor pollutants. The death rate, because of air pollution, rose by 4% worldwide and by 12% in India from 2005 to 2010. The study aims to examine the effect of indoor air quality on the overall health of occupants of educational buildings. Initially study will be focused on the present scenario of air quality and its implication. The pollutants considered were $PM_{2.5}$, PM_{10}, TVOC, and comfort parameters are CO_2, temperature, the humidity was examined. The research will be delved into the impact of IAQ on physical, and psychological health as well as academic performance aspects. Research is based on a rigorous review of the literature of recent research papers. The parameters studied were the types of instruments used, and experimental design (experiment, field experiment, or survey). It also includes sampling frequency, the position of the instrument, the mode of measurements (periodical or continuous), and, the type of analysis such as statistical. The findings of this study mentioned the importance of indoor air quality as the study showed that every pollutant affects students' performance either physiologically or academically. Further study can be proposed for searching sustainable ways to enhance the quality of indoor air.

Keywords: Indoor air quality, Classroom, Students' performance, Indoor pollutants, Indian context

INTRODUCTION

India is a developing country; urbanisation is taking place at a very fast pace. It is deteriorating environmental quality in the form of air, water, and soil pollution. In India significant population is at risk of high levels of air pollutants. Indoor air is a function of outdoor air so it is also getting contaminated. However, the situation is getting worsen because of the emission of many indoor pollutants like cleaning agents, room fresheners, adessives, cooking, dusting, etc. As per the World Health Organization (WHO), 'Clean air is the basic requirement for human health and well-being' and the organization also considers, IAQ as the 8th most important risk factor for the burden of disease (WHO, 2006). According to Central Pollution Control Board's (CPCB) Indoor Air Pollution 2014 Report, indoor air quality is the quality of air inside the building which is exemplified by the concentrations of the pollutants and thermal conditions (temperature and relative humidity). IAQ has a great impact on the health and performance of the occupants. Smoking and cooking are the sources of particulate matter (PM) pollution. Though these sources are not present in classrooms and laboratories like commercial and residential buildings, PM pollution is high. The biological bases of occupant health, well-being, and comfort are a function of suitable indoor environmental qualities of temperature, sound, air, light, visibility, personal control, and physical space. It was seen that indoor air quality is affected by many reasons like the existence of contaminant sources (e.g. furnishings, building materials, and equipment), outdoor pollution, season, indoor temperature, humidity, and ventilation rates (N.Sireesha, 2015). Chances of increased long- and short-term health problems in the occupants of school may rise due to indoor air pollution. One of the studies found a correlation between air pollution, building dampness, and ventilation system with absentee due to daily illness (Yang *et al.*, 2015). These findings underline the importance of the in-depth study of the impact of indoor air quality on the health of occupants of educational buildings.

LITERATURE REVIEW

Air is consisting of 78% nitrogen, 21% oxygen (O_2), and 1% other gases and water vapor. When this composition changes then it is called contamination of air. Particulate matter ($PM_{10,2.5}$) and gaseous contaminants like CO, and TVOC along with other prime indoor pollutants have a significant impact on human health and cause mortality (Jan *et al.*, 2017). Hence in the literature study, these pollutants were focused more. In India, occupancy of the student is high ranging from 40 to 60 per class irrespective of primary or higher education classes. The greater part of the students spends in the classroom where they are involved in varied activities. For such activities, students need to be focused and dedicated. It indicates the relevance of the study of the effect of indoor air quality on students.

Total Volatile Organic Compound (TVOC)

A set of compounds having low water solubility and high vapor pressure is VOC. It denotes a collection of substances that possess chemical properties alike. There is a number of VOCs so it is difficult to supervise all of them. Hence, TVOC was adopted to determine the overall VOCs in a given space. These are among the most common indoor pollutants. While studying VOCs is the most relevant as their concentrations tend to be higher than outdoors and few of them have been classified as carcinogenic (Aydogan and Cerone, 2020). Commonly found are listed below

- Formaldehyde - discovered in furniture upholstery, disinfectants, plywood, carpets
- Benzene - is found in paint thinner, tobacco smoke, deodorizers, furniture polish, air fresheners,
- Toluene - used for paint, metal cleaners, adhesives
- Xylene- vehicle emission, solvents, thinners

SBS is highly influenced by TVOC and Formaldehyde levels. It was observed that severe and long-lasting diseases of the eyes, central nervous system, and respiratory organs occur in contact with these pollutants.

Carbon monoxide (CO)

Another vehicular pollutant of worry is carbon monoxide (CO) in urban areas.

Particulate Matter (PM_{10}, $PM_{2.5}$)

It is the term used for a mixture of solid particles and droplets of liquids obtained in the air. PM_{10} are inhalable particles having a diameter of 10 micrometres and $PM_{2.5}$ are having a diameter of 2.5 micrometres. The primary source of these particles is automobile emissions, dust, cooking, or burning smoke. Complex reactions of chemicals like sulphur dioxide and nitrogen oxide particles in the air mixed up and pollute, and it could be a secondary source. Indoor activities contribute to the coarse particles (>PM2.5 μm) concentration and outdoor activities to the finer particles (<PM1.0 μm) concentration levels. Outdoor concentrations, indoor-outdoor air exchange rates, and indoor sources and sinks dictate the indoor PM concentration as defined by the IAQ model (Goyal and Khare, 2011).

Carbon Dioxide (CO_2)

Air consists of 0.038% of CO_2 concentrations. In the human respiration process, this 0.038% of CO_2 concentrations gets converted into 4%. Hence, CO_2 concentrations are greater in high occupancy areas and less ventilated spaces. Numerous studies noted that inside a classroom, air quality is often poor. A high density of students and inadequate ventilation increases CO_2 concentrations and frequently it exceeds the threshold values recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

METHODOLOGY

To know the role of air quality in learning spaces different research papers were studied comprehensively. Then based on the study, different parameters were listed for the systematic review. Identified parameters were the type of experiment, environmental condition, types of instruments used, frequency of sampling, study duration, location of the instrument, mode of readings, and type of data analysis.

Decisive factors for the selection of research papers

Selection of research papers were done on some factors such as 1) recent publications were considered, 2) to understand the present local scenario, Indian context-based papers were preferred, 3) papers based on all pollutants and focusing on any one parameter were studied, 4) papers based on field study were only considered, 5) student's age group was not limited to any, so from primary to higher institute learning spaces were selected, 6) As a learning space, the study was not limited to only classrooms but library and labs were also reviewed.

RESULTS

Research papers were searched based on the keywords on Google scholar and ScienceDirect. Around 30 papers were identified and after screening and considering the parameters, 9 papers were retained and analyzed systematically. Table 1 summarizes the results of complied study.

DISCUSSION

After studying the literature, the effect of each pollutant on the students was noted. Along with the pollutants, comfort parameters were also mentioned. While going through the literature it was noticed that the study of indoor air quality is complex and dynamic as it depends on occupancy, time, location, season (climate), and immediate context. Moderation in one of the pollutants can affect the other elements of the air. To have some parity the papers from the Indian context were mostly studied.

TVOC

It was found that Sick Building Syndrome (SBS), asthma, and respiratory problems are highly correlated to different VOCs (N.Sireesha, 2015). In schools and colleges teaching tools are either blackboard, whiteboard, or projector screens. Whereas markers used for whiteboards increase the VOC and CO concentrations.

CO

CO gets mixed with the haemoglobin of human blood and creates carboxyhemoglobin. It interrupts the transmission of oxygen to human tissues. Thus, CO intoxication may be caused by a surplus intake of CO concentration. Various symptoms of neuropsychological damage have been associated with acute low-level exposure to CO concentration (Chithra and Shiva Nagendra, 2012)

PM

PM mass concentrations as per WHO standards are 50 μgm_{-3} for PM_{10} and 25 μgm_{-3} for $PM_{2.5}$. (*WHO, 2006*). It was found that chalk blackboards lead to increased levels of PM even though the ventilation rates were greater, a High PM count was responsible for elevated carcinogenic risk, and 7-9% of health problems were correlated to PM count (Jan *et al.*, 2017). The finer PM fractions and CO indoors were found to be influenced by concentrations of ambient particles, emitted by traffic (Chithra and Shiva Nagendra, 2012). In the classroom, the probable sources of PM affecting IAQ could be suspended dust particles from different activities of the students (Yang *et al.*, 2015), high occupancy levels, chalk, and outdoor sources like dust from playgrounds, and vehicular traffic around the classrooms if any. The behaviour of PM pollutants changes with respect to temperature. Removal of PM pollutants can be possible with higher indoor temperature whereas quiet and low indoor temperature is linked with increased accumulation of PM in an indoor environment. But wind velocity plays also an important role (Chithra and Shiva Nagendra, 2012).

CO_2

CO_2 concentrations increase with the occupancy of the class because of the exhalation by the students. ASHRAE 62.1-2007 has recommended default value for CO_2 is '35 person/100 m^2 per classroom for ages 9 plus'. SBS symptoms decreased with decreasing CO_2 (N.Sireesha, 2015). Increased CO_2 concentrations lower the concentration performance score in the students of the class (Singh, Arora, and Goyal, 2020). It was also observed that an increase of 100 ppm CO_2 affected in attendance of the students by 0.4 days /year (Gaihre *et al.*, 2014). This was also correlated with the economic loss of parents in terms of their leaves. Pengs' study has noticed that if CO_2 concentrations are reduced below 800 ppm, the risk of air-related health problems also decreased (Peng, Deng, and Tenorio, 2017). The link between classroom CO_2 levels and student absenteeism is reported by Gaihre (Gaihre *et al.*, 2014). CO_2 concentrations > 20,000 ppm cause deepened breathing; 40,000 ppm increases respiration markedly; 100,000 ppm causes visual disturbances and tremors and has been associated with loss of consciousness; and 250,000 ppm CO2 (a 25% concentration) can cause death (Satish *et al.*, 2012). The relationship between low ventilation rates (which resulted in increased CO_2 concentration), reduced attention, and vigilance of students was evident in one study. It was also negatively correlated to memory and concentration (Gaihre *et al.*, 2014). A study in the United States explains an inverse association between CO_2 concentrations and academic performance. It also states the direct linear link of ventilation rates up to 7.1 L per second per person and reading scores (Haverinen-Shaughnessy, Moschandreas, and Shaughnessy, 2011). Overcrowding of the classrooms, low ventilation rates, and outdoor pollutant air were the major reason for increased CO_2 concentration. The addition of other indoor air pollutants such as NO_2, fine particulates, molds, volatile organic compounds, and allergens happens due to high CO_2 concentrations. The higher concentration is an indication of reduced ventilation. Children's respiratory health is governed by these pollutants which impacts their attendance at school. The most common reason for nonattendance is a respiratory infection in younger children (Gaihre *et al.*, 2014).

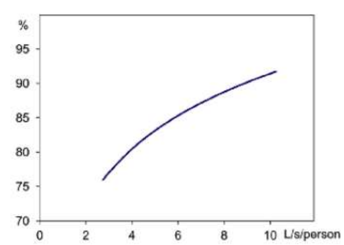

Figure 1: The experimental relationship between outdoor air supply rate per child and classroom performance of schoolwork that was found by Wargocki and Wyon(Wargocki & Wyon, 2017)

Temperature and humidity

Indoor air having low humidity is vulnerable to airborne diseases like allergy and eye irritation whereas moisture in the air can cause the common cold (Shree, Marwaha, and Awasthi, 2019). High temperature causes a reduction in the inattentiveness and learning ability of the students (Shree, Marwaha, and Awasthi, 2019). Increased temperature also correlated to higher Total Bacteria Count (TBC) and PM10. Some pollutants such as volatile organic compounds (VOCs) and formaldehyde get boosted in case of high air temperatures (Peng, Deng, and Tenorio, 2017). It was also found that there was an inverse association between academic performance and indoor classroom temperature. Enhanced academic performance was observed after a decrease in temperature from 25 to 20°C (Haverinen-Shaughnessy, Moschandreas, and Shaughnessy, 2011). It was also seen that scholars from different fields had worked on this topic indicating that this area has many dimensions that were worth studying. Fig. 2 shows the overall percentage of the author's field expertise.

Table 1: Summary of reviewed empirical studies of indoor air affecting students' overall performance

Conclusion	The score of the concentration performance of AC class increased due to raised CO_2 than naturally ventilated classroom students.	This high temperature could reduce the attentiveness and learning ability of students	The study noted time-related different activities, footfall, and correlation with the pollutants. Particulate matter concentrations were found positively correlated with TVOC, CO_2, and indoor temperature. PM1 0 and CO_2 highly correlated	Crustal elements in the air showed a high carcinogenic risk. 7-9% of daily absenteeism due to health problems was correlated to high PM levels in the class	Chemically treated walls and metal furniture cause more air contamination. Whiteboards with OHP markers
Type of analysis	Descriptive statistics Independent sample t-test	Descriptive statistics Correlation Analysis	Shapiro–Wilk test was performed for the normality checks. Kruskal – Wallis test-spatial variability Spearman's rank correlation coefficient-	Statistical analysis-Pearson correlation ANOVA	descriptive statistics t-test and ANOVA
Mode of measurements (periodical or continuous	Continuous for 6-7 hours	Continuous 6 days every school May- June 2018	24 hours-5 min resolution	8 am -4 pm consecutive three days	
Position of the instrument	Centre of the class at 1.0m ht.	Opp. to blackboard 2m towards the centre at 0.8 m above the floor	Ht. -1.2m 1.5 m away from any obstruction e.g., wall, window, air vents	At 1.0 m ht at various locations	------
Duration of study	July-Oct. 2016 Nov.-Feb. 2017	Peak occupancy period	from 31 July 2018 to 22 October 2018 six non-consecutive weeks,	Dec 2013-May 2014.	------
Sampling frequency	5 min intervals for 6-7 hours on working (12 days) , non-working days (4 days)	One time	4 days indoor 2 days outdoor	-----	------

	Instruments used	CO2- Testo-435	Forbix Semicon CO2 monitor and Mlabs HT-1000	Model 1.109, GRIMM Aerosol Technik Gmbh & Co. KG, Ainring, Germany, TG-503L, Gray Wolf Sensing Solution, Shelton, USA	MiniVol TAS, Airmetrics, USA- Aeroqual indoor air quality monitor (IQM 60)	------
	Environmental condition	AC classroom-sealed NV- Door windows open	The door and windows were open	All the windows and the doors were closed, except the main door, HVAC system was continuously working in the library during the monitoring	Door, and windows open	Door, and windows open
	Experimental design	Field study Classroom-With AC- 3 classrooms Naturally ventilated- 3 classrooms	Field experiment- 8 schools	Field experiment- Central library 9,000 sq. m.	Field study- 4 naturally ventilated classrooms of 2 elementary schools	Field study – 30 classrooms from 30
	Types of parameters studied	CO2 Concentration performance	PM2.5, CO, CO2, Temp RH, Air velocity	PM10, PM2.5, and PM1 TVOC, CO2, Temperature, Humidity	Coarse and Fine PM CO2, CO, SO2, NO2, O3	temperature, relative humidity, CO, CO_2, VOC, $PM_{2.5,4,10}$
	Paper	'Classroom Ventilation and Its Impact on Concentration and Performance of Students: Evidence from Air-Conditioned and Naturally Ventilated schools of Delhi' (Singh et al., 2020)	'Indoor air quality (IAQ) investigation in primary schools at Hamirpur (India)' (Shree et al., 2019b)	'Spatio-temporal variations of indoor air quality in a university Library'(Sahu & Gurjar, 2021)	'Exposure assessment of children to particulate matter and gaseous species in school environments of Pune, India' (Jan et al., 2017)	'A Study on Assessment of Indoor Air Quality in Secondary Schools of Hyderabad City, India' (N.Sireesha, 2015)

Conclusion	Higher temp., RH, occupancy, and related activity caused higher TBC and PM10. PM10 and TBC levels for RW schools were found to be significantly lower than SB and MT.	Overcrowded classrooms and inadequate ventilation had attributed to the higher concentration of CO_2 and cleaning and disinfecting chemicals raised the VOC lvl. CO_2 decreases exponentially for greater ventilation rates	Increase in every 100 ppm in CO_2 decreases an. annual attendance by 0.2%. Nearly 0.4 days/year. Attendance is not significantly affected by temp. and RH.	Human activities act as an important source of indoor particulate generation. Positive correlation between PM concentration and humidity during the weekend
Type of analysis	t-test, Pearson's correlation, Test, one way ANOVA, - measured indoor pollutants, Simple regression analysis-to compare indoor-outdoor concentrations	descriptive statistics	Spearman rho, Descriptive statistics	Graphical analysis
Mode of measurements (periodical or continuous	20 min interval	Continuous	Continuous measurements for one week or three consecutive days.	Continuous
Position of the instrument	centre of the rooms at 1.5 m above floor level	Centre of the classroom at 1.1m ht. from floor	Centre of the class and at 1.0m ht.	Not exactly at the centre, away from openings
Duration of study	September to November, 2013	April-May 2013 (spring)	May - June 2010	60 days In January-March - (winter) and In April-May (summer) 2011
Sampling frequency	5 hours for each school	one week at each location 5 min - 7working hours of the class	Every 6 min	Every minute hourly and daily average used for analysis
Instruments used	Temp., RH- testo 175 H1, Testo, Germany PM10- TF-450, Pall Corporation, United States CO, CO2- Model 200E, 300E and 360E, Teledyne, United States	MultiRAE IR Model PGM-54 - CO2, CO, VOCs Handheld3016, IAQ- PM10, PM5, PM2.5, PM1, and PM0.5 TGP-4500, Gemini Data	Telaire 7001Di, - CO2 HOBO HO8-003-02 IAQ-Temp, RH	GRIMM Model 1.107- PM10, PM2.5 and PM1 IAQ-CALC Model 7545- Temp. RH, CO2, and CO

		loggers- Temp, RH		
Environmental condition	Naturally ventilated class as the study was done in autumn	--------------	Sealed-windows were closed	Naturally ventilated classroom
Experimental design	Field study of 113 schools – each 2 classrooms	Field study in nine naturally ventilated primary schools	Field study-60 Classrooms studied	Field studies
Types of parameters studied	PM10, NO2, CO, CO2, total bacteria count TBC, TVOC, HCHO, temperature (RH).	CO2, CO, VOCs, PM10, PM5, PM2.5, PM1 and PM0.5 Tem(Ulrich, 1983)p, RH	CO_2, Temp, RH	PM10, M2.5, and PM1, CO, CO_2 Temp.,RH,
Paper	'Characteristics of indoor air quality at urban elementary schools in Seoul, Korea: Assessment of the effect of surrounding environments' (Yang et al., 2015)	'An integrated evaluation study of the ventilation rate, the exposure, and the indoor air quality' (Dorizas et al., 2020)	'Classroom Carbon Dioxide Concentration, School Attendance, and Educational Attainment' (Gaihre et al., 2014)	'Indoor air quality investigations in a naturally ventilated school building located close to an urban roadway in Chennai, India' (Chithra & Shiva Nagendra, 2012)

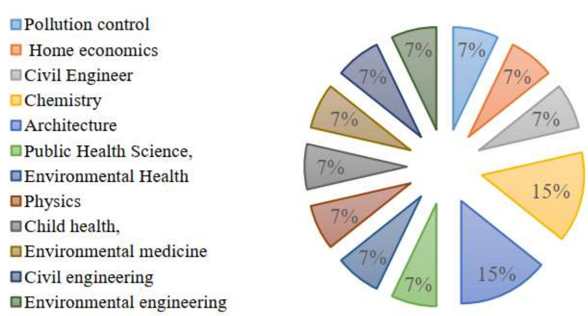

Figure 2: Information about the author's field of expertise

CONCLUSION

Indoor and outdoor clean air indicated that the students have access to clean air for their respiration, so they can be in good health while they are learning. Chronic diseases that affect the respiratory system which can impact negatively their learning and academic performance by contaminated air in the class. Maintaining indoor quality by balancing the concentration of the pollutants as a standard is very necessary as it has short-term as well as long-term effects. The exposure level and duration has also great impact on students' health and overall performance in terms of academic, cognitive, and psychological. The results of this study indicated that potential research needs to be done in this area. Further work could be finding out alternative low-energy solutions for improving indoor air quality.

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EFFECT OF VENTILATION ON AEROSOL TRANSMISSION IN AN INDOOR SEMINAR ROOM IN LINCOLN, UK

Aliyu M. Aliyu [1], Amira Elnokaly [2], Jun Peng [3], Waqar Ahmed [4], Ahmed Elseragy [5]

[1] School of Engineering, University of Lincoln, LN6 7TS, UK (AAliyu@lincoln.ac.uk)
[2] School of Architecture and the Built Environment, University of Lincoln, LN6 7TS, UK (AElnokaly@lincoln.ac.uk)
[3] School of Engineering, University of Lincoln, LN6 7TS, UK (JPeng@lincoln.ac.uk)
[4] School of Mathematics and Physics, University of Lincoln, LN6 7TS, UK (WAhmed@lincoln.ac.uk)
[5] School of Engineering, University of Lincoln, LN6 7TS, UK (AElseragy@lincoln.ac.uk)

ABSTRACT

The advent of the coronavirus pandemic has increased global awareness of indoor air quality especially, as it pertains to the design of workspaces with adequate ventilation. This study aims to quantify the effect of various ventilation configurations on aerosol dispersion in an existing seminar room using computational fluid dynamics (CFD). The aerosol transport is achieved by carrying out Eulerian-Lagrangian simulations using the Discrete Phase Model in Ansys Fluent. The seminar room studied has a closed glass observation window. The fact that the window cannot be opened may present a high risk of infection transmission, especially in cases where the air conditioning system is not switched on or is broken. To assess the impact of this on the spread of possibly infected bio-aerosol emitted from a coughing person, three cases were investigated. The baseline case consists of the room with the observation window closed and no air conditioning (AC). Minimal air change per hour (ACH) is achieved by the gaps underneath and above the door as well as the outlet air ventilation port. Two other cases were benchmarked against this base case. The first consists of having the observation window half open while the other considers the observation window closed with the AC on having the recommended 8 ACH of ventilation for seminar rooms. The simulations showed that while AC with natural ventilation help in transporting droplets out of the room by increased air circulation, aerosol propagation is also dampened at source by forcing the trapping of droplets on clothing and immediate nearby surfaces. In summary, this study contributes to the design, retrofitting and reconfiguration of new or similar existing design of university and educational facilities seminar rooms. The findings can also contribute to the design of similar spaces within other building typologies like hotels and other public indoor workplaces.

Keywords: Indoor Air-Quality; Ventilation; CFD simulations; Seminar Spaces; COVID-19

INTRODUCTION

Traditional architecture has incorporated various passive building design techniques such as natural ventilation, shading, thermal mass and passive heating and cooling techniques (Elnokaly and Elseragy, 2013), to accomplish higher comfort levels of occupants (Fathy, 1986; Mohammed, Elnokaly and Aly, 2021). The Covid-19 pandemic has brought back to the fore the adequacy of passive building design techniques, including natural ventilation built into the design of existing workspaces such as conference and seminar rooms where individuals from different backgrounds mix indoors. Most buildings housing such seminar rooms were built for functionality and thermal comfort but without consideration for ventilation to minimise the prevalence of human bioaerosols. Since the start of the SARS and MERS virus epidemics of the 2000s, there has been a increasing concerns on the health effects of air pollution and, consequently, a move towards considerations of indoor air pollution levels. Taken together with temperature and relative humidity comprise indoor air quality (IAQ). This is even more so during the current Coronavirus Pandemic of 2020 onwards, which is exacerbated by the likelihood of infectious aerosols being transported within a building due to poor ventilation (Lu *et al.*, 2020; Morawska and Milton, 2020; Stadnytskyi *et al.*, 2020). Several outbreaks in enclosed indoor congested spaces such as restaurants, offices, shopping centres, cruise ships and public transport suggest that virus transmission is especially efficient in these types of indoor environments (Leclerc *et al.*, 2020). Over 320 coronavirus outbreaks in China with more than three cases of transmission were studied by Qian et al. (Qian *et al.*, 2021). In most, they found that transmission occurred in indoors. In South Korea, an investigation was carried out into the incidence of a Covid-19 outbreak in a high-rise call centre office where 44% of the inhabitants were discovered to be infected (Park *et al.*, 2020). Nevertheless, the proportion of secondary infections to the family members of the infected patients was only around 16%. In these studies, the common thread is that increased rates of transmission occur where people are likely to be in the presence of an infected person in a crammed, poorly ventilated indoor space for fairly long periods and, thus, get exposed to contaminated airborne bioaerosols. It is therefore of immense importance to re-examine the design of buildings especially with respect to design of public spaces for adequate ventilation for aerosol control. The primary aim of building ventilation is to provide fresh air for breathing and for the removal of undesirable suspended pollutants. In this paper, the role of ventilation on the distribution of airborne bioaerosols in an existing seminar space is examined using computational fluid dynamics. The room did not have a natural ventilation source (window) and may be unsatisfactory from the point of view of possible virus transmission. Three scenarios are investigated namely base case with no window and no air conditioning (AC); case 2 with AC on, no window; and case 3 where the AC is on, a top half window is added left open. In each case, a bioaerosol source is placed at the centre of the seminar room and droplet propagation is tracked towards a second standing mannequin. As a result, this study provides quantitative evidence of the adequacy or otherwise of the room's ventilation for the minimisation of airborne infection transmission.

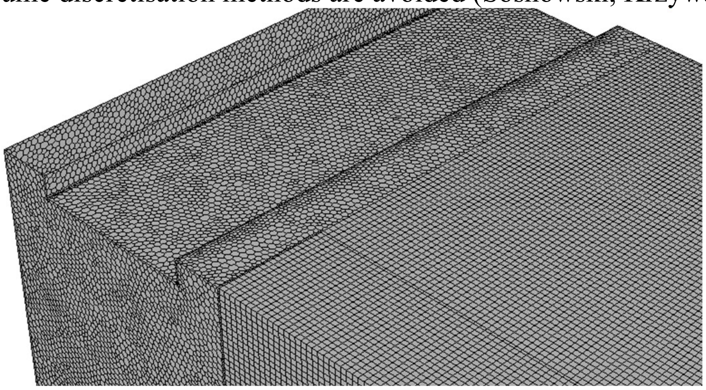
METHODOLOGY

The study adopts a numerical approach, which initially, develops geometric models of the seminar space using three different influential ventilation parameters. Secondly, meshing of the geometrical models into a hybrid tetrahedral-prismatic-hexahedral mesh is carried out in Ansys Meshing. Finally, simulation trials are performed in Ansys Fluent to obtain ventilation as well as aerosol distributions and adequacy in the seminar spaces. The results of the different geometric models are compared to identify the impact the window configuration and whether opened or closed and its location in the seminar room on the airflow quality and the aerosol disperse within the room and hence its impact on the health and well-being of the users.

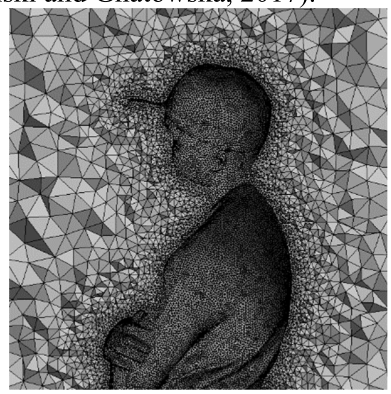
Seminar room geometry and meshing

The seminar room that was studied is within the Lincoln School of Architecture and the Built Environment and is shown in Figure 1. In the room, two mannequins were placed such that the first mannequin was sitting at the far end of a set of boardroom table and chairs. Details of the room size, boundary conditions, and meshing are given in the following subsections. The room has a size of 5 x 3.5 x 3 m with a door in which slots were created above and below for air inlet and outlet respectively. This allows velocity inlet and pressure outlet boundary conditions of air flow to be applied to mimic real-life conditions. Also, a slit was created for air conditioning (AC) and a velocity inlet boundary condition was given it. Opposite this slit and above mannequin 2 is an open vent for air egress. A zero bar (gauge) pressure outlet boundary condition was applied to this outlet vent. The two mannequins used in the modelling were obtained from the open computer aided design library (GrabCAD) and imported into the domain along with the table and chairs. These were then subtracted from the computational domain using the Boolean subtract function in the Ansys DesignModeler software. Meshing of the seminar space geometry (the computational domain) was carried out in the Ansys Meshing software. Figure 2 (a) shows the mesh and the domain was segmented so as to separate areas of complex and simple geometry. This helps to bring the mesh element count to a minimum, hence reducing computational time and resources. A mesh independency study was done (by varying the element size) and a size of 30 mm per element was found to give stable results of outlet pressure. This resulted in 31 million mesh elements that was converted to polyhedra in Ansys Fluent (Figure 1 b).

Polyhedral meshing was introduced into flow solvers such as ANSYS Fluent in order to take advantage of hexahedral mesh geometries which have low numerical diffusion hence more accurate, and tetrahedral meshing which can be rapidly and automatically generated. As such, the disadvantages of both volume discretisation methods are avoided (Sosnowski, Krzywanski and Gnatowska, 2017).



(a)



(b)

Figure 2: (a) Polyhedra in Fluent with 5 million mesh elements, translated from the original 31 million hybrid tetrahedral-prismatic-hexahedral mesh (b) detail showing refinements for standing mannequin

Solution set up

Modelling of the seminar room's airflow was carried out using the steady state incompressible Reynolds Averaged Navier-Stokes (RANS) equations. Together with the continuity equation, these are respectively given as follows:

$$u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(v \frac{\partial u_i}{\partial x_j} - \underline{u_i' u_j'}\right) \quad (1)$$

$$\frac{\partial u_i}{\partial x_i} = 0;\ where\ i, j = 1, 2, 3 \quad (2)$$

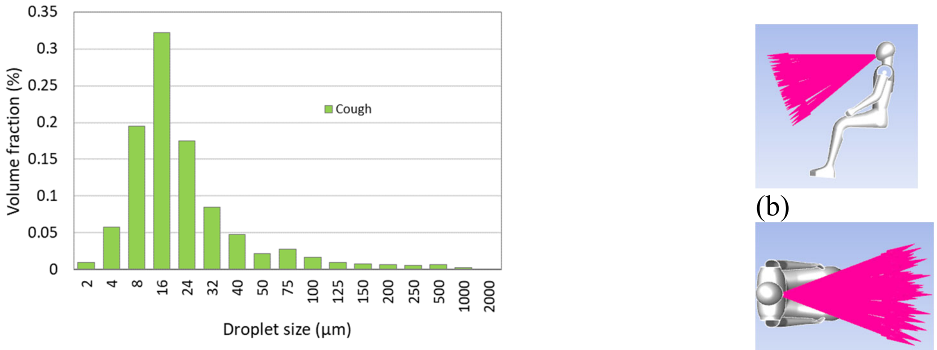
The $\underline{u_i' u_j'}$ term in Equation (1) is called the Reynolds stress and is not solved directly but modelled using a suitable turbulence model for the specific problem. Here, the two-equation k-ε RNG turbulence model was used. This is because previous studies surveyed (Hussain, Oosthuizen and Kalendar, 2012; Hang *et al.*, 2013; Heschl *et al.*, 2013) have shown that the k-ε RNG turbulence model performs better than the standard k-ε and other turbulence models. Hence, they recommended it for carrying out indoor airflow CFD simulations.

Discrete phase modelling

The discrete phase model (DPM) was developed to solve the transport equations for a dilute dispersed secondary phase co-flowing with the primary phase. The velocities and trajectories of dispersed phase liquid, solid or gas entities in a continuous gas or liquid are calculated in a Lagrangian frame of reference (Morsi and Alexander, 1972; Ansys, 2009). This method is based on Newton's second law of motion, which describes the force balance on a moving particle, relates the particle's inertia with the forces that act on the particles. Integrating it once gives the velocity of the particle and the second integration gives its location. The form of Newton's 2nd law that is formulated for a single particle that underpins the DPM method is given as:

$$\frac{du_p}{dt} = \frac{18\mu}{\rho_p d_p^2}\frac{Re}{24}\left(u_g - u_p\right)\left(\frac{K_1}{Re} + \frac{K_2}{Re} + K_3\right) + \frac{g\left(\rho_p - \rho_g\right)}{\rho_p} \quad (3)$$

where u_p and ρ_p are the particle velocity and density respectively; u_g and ρ_g are the continuous phase (gas) velocity and density respectively; g is acceleration due to gravity. The first term in Equation (3) is the drag force, the second is the gravitational force that the particles experience when moving in the continuous fluid. Here, the virtual mass force is neglected since in a dilute fluid, these are negligible. The relative Reynolds number (Re) is defined as $Re = \rho d_p |u_p - u_g| / \mu$ with μ being the droplet viscosity. The DPM method has been shown to be remarkably robust in previous by many investigators for various flow systems such as flow chemical reactors, milling devices, and drug delivery (Zahari *et al.*, 2018; Aliyu *et al.*, 2021).



(a) (b) (c)

Figure 3: (a) Cough droplet size distributions used to fit the Rosin-Rammler distribution of the cone injection in the simulations in this paper (b) side view of cone injection's geometry of ejected droplets with respect to mannequin (c) top view showing mannequin and injection

Droplet size distribution and initial velocities

The initial properties of expelled droplets by coughing which were used in the DPM simulations in this study were obtained from literature. the range of cough and sneeze droplet sizes are from 1 to 2000 µm, with a mean size of 32.6 µm for coughing. The droplet size distribution used was from the data reported by Duguid (Duguid, 1946) taken from human subjects. Duguid's data were fitted to the Rosin–Rammler distribution which is given by $X_d = e^{-(d/\underline{d})^n}$. Where $\underline{d}$ is the mean droplet size defined as that which $d = \underline{d}$, or $X_d = e^{-1} = 0.369$; Y_d is the fraction of droplets of diameter d, n is the shape or spread parameter. The number of particle size ranges used in the simulations was 200. This meant that the particle sizes were binned at intervals of 10 µm and a spread parameter of n = 3.5 was found to best fit the cough droplet size data The droplet release velocity from the mouth used is 15 m/s which was taken as a middle value from the ranges of 5–15 m/s for coughing and 15–25 m/s for sneezing (based on the reported works of refs (Kwon *et al.*, 2012; Tang *et al.*, 2013; Scharfman *et al.*, 2016)). The droplets were introduced from the sitting mannequin as the aerosol source. This was done using a cone injection with a spread angle of the cone at ±20° from its axis which itself is 20° downwards from the horizontal. These angles were based on the experimental measurements of coughs conducted by Wei and Li (Wei and Li, 2017). An initial cone radius of 15 mm was set based on again based on Wei and Li's work.

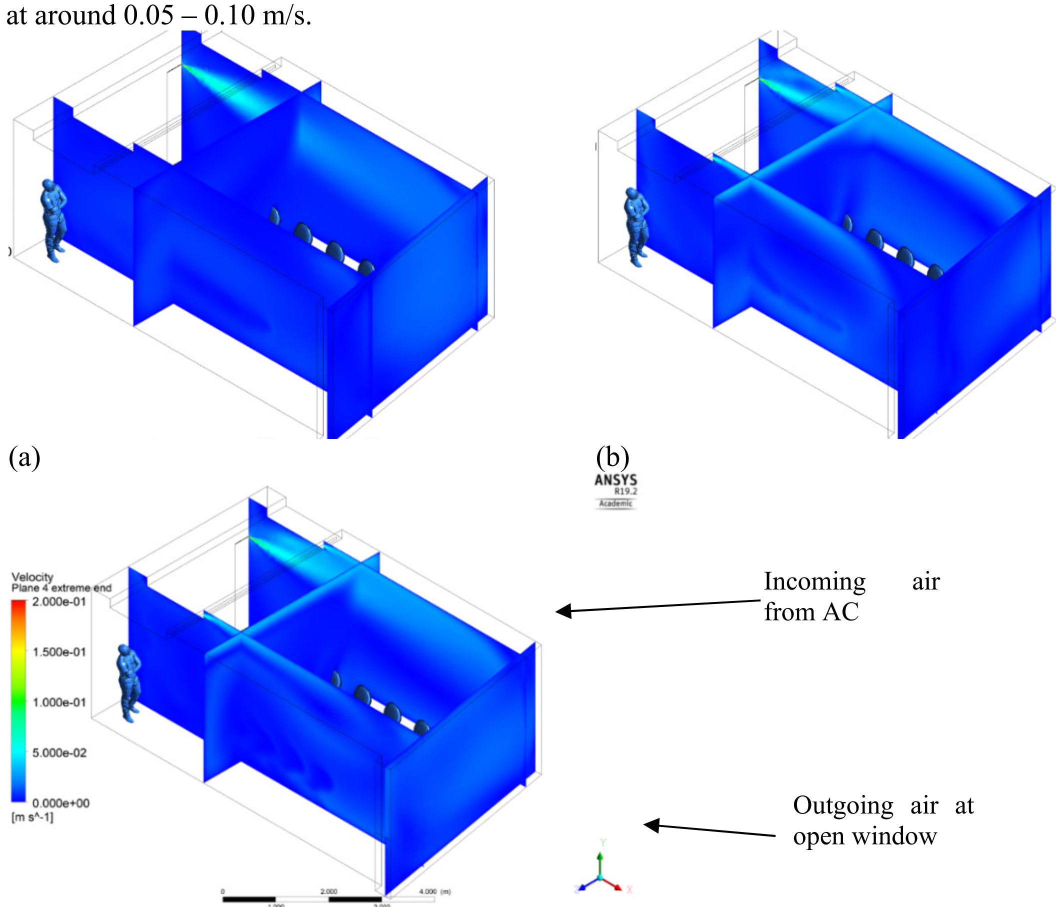
Case studies and incoming air flow rate

Three case studies were studied to determine the effect of ventilation conditions on aerosol distribution in the seminar room. These conditions are: (a) Case 1: the AC is off and no window (or window closed); (b) Case 2: AC on and window closed; and (c) Case 3: AC on and window open. Incoming air flow rates into the seminar room was kept at 8 ACH according to the level of ventilation recommended by ASHRAE (ASHRAE, 2004). The mass flow rate $\dot{m}$ corresponding to 8 ACH is 0.0241 kg/s (split between the AC–90% and door gap–10%) and is calculated using $ACH = CFM \times 60/V_{room}$. Where CFM is the air flow rate into room in cubic feet per minute (ft^3/min), and V_{room} is the volume of the room. To calculate the flow rate that corresponds to the recommended 8 ACH for seminar rooms: $CFM = ACH \times V_{room}/60 = 8 \times 3771/60 = 502.8$ ft^3/min This is equivalent to 0.2373 m^3/s. Given the density of air at atmospheric pressure is ρ = 1.225 kg/m3, the mass flow rate $\dot{m}$ at 8 ACH is 0.2907 kg/s. This was set in the simulation cases as AC inlet and above door boundary condition (on a 90-10% split respectively).

RESULTS AND DISCUSSION

Air flow patterns in seminar room

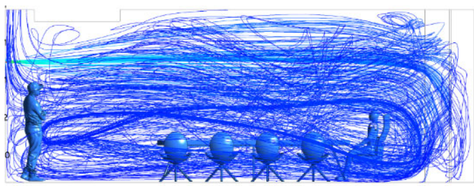
Figure 3 (a) shows velocity contours along the streamwise flow direction above the door, and spanwise at the middle and far end of the room. It is seen that the air entrance from above the door into the room is jet-like at around 0.05 – 0.10 m/s.



(c)

Figure 4: Contours of air flow velocity magnitude in seminar room (a) Case 1 – AC off, no window (b) Case 2 – AC on, no window (d) Case 3 – AC on, window open

This jet propagates streamwise along the entire length of the room and the spread can be seen on the spanwise plane far end of the room. Little aeration is seen near the standing mannequin compared with the middle of the room and to a larger extent compared with the incoming jet. Figure 3 (b) shows case 2 in which the airflow is coming from both the door and AC but with a closed window. Here more aeration is experienced near the standing mannequin than in case 1. This is because of the increased air flow into the room at 0.0241 kg/s as against only 10% of that for case 1. Figure 3 (c) shows case 3 where the incoming air above the door is complemented with air incoming from the AC port above the room. In contrast to case 1, the room is seen to be clearly more aerated especially at the middle section of the room where the mannequin 1 is positioned and at the window at the window as indicated with the arrow in the figure. It is noted that despite the window being open and the AC on, aeration near the standing mannequin does not appear to be noticeably different. This may be because of the mannequin's location being far from the cross-ventilation that the open window offers. To further investigate the air flow patterns of each case, streamlines of the air flow were created. Side views of the room shown in Figure 4 give more insight on the flow pattern in the room. They are coloured by the velocity magnitude with 40 streamlines tracked per air inlet (80 streamlines for cases 2 and 3 which have two air inlets). Figure 4 (a) shows the streamlines for case 1 where air inlet is only from the door gap. It is seen that there are pockets of poor ventilation primarily at the room corners. These are remediated in cases 2 and 3 which appear more ventilated owing to the AC being on hence facilitating more air circulation despite there seemingly the existence of vortex centres at the middle of the room. These are likely only apparent due to the limited number of streamlines tracked. Nevertheless, case 3 in Figure 4 (c) shows that the ventilation is more evenly distributed around the whole room volume, buttressing the importance of having cross ventilation in such public seminar spaces.



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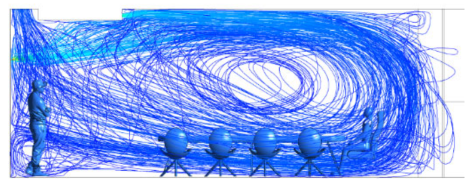

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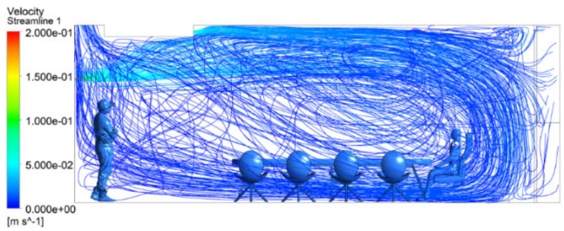
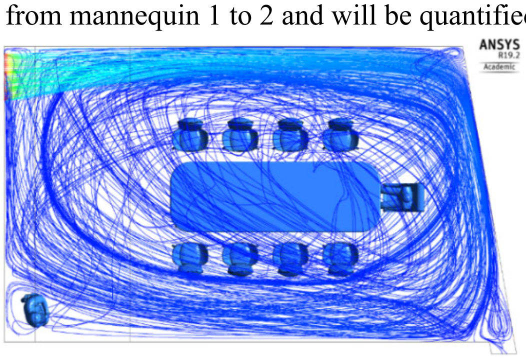


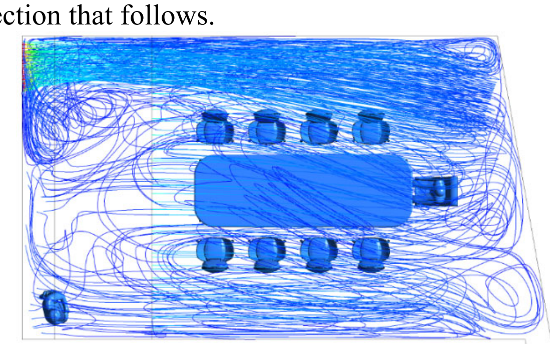
(c)

Figure 5: Side view showing streamlines of airflow in room for Case 4 (40 streamlines each from AC and above door air inlets) (a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4

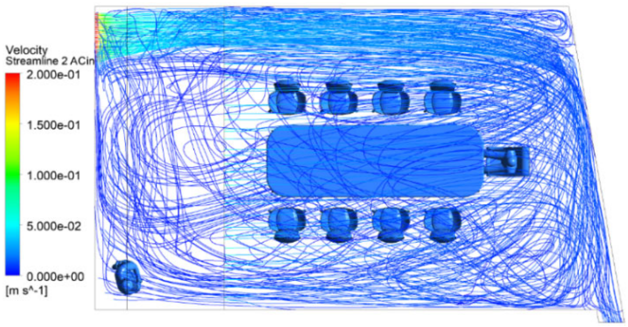
Figure 5 shows the top view of the air streamlines in the room. It is seen that for cases 1 and 2, without the window at the far end providing cross ventilation, the air flow is dense in some areas and sparse at others especially at the corners, indicating poor ventilation in these areas. Buttressing the initial side view observation, Case 3 (shown in Figure 4 c) with the window open has a more uniform air flow distribution. This includes at the location of the standing mannequin, contrasting with what was observed for the first two cases. All these air flow patterns, and ventilation conditions affect the propagation of aerosols expelled from mannequin 1 to 2 and will be quantified in the section that follows.



Case 1



Case 2

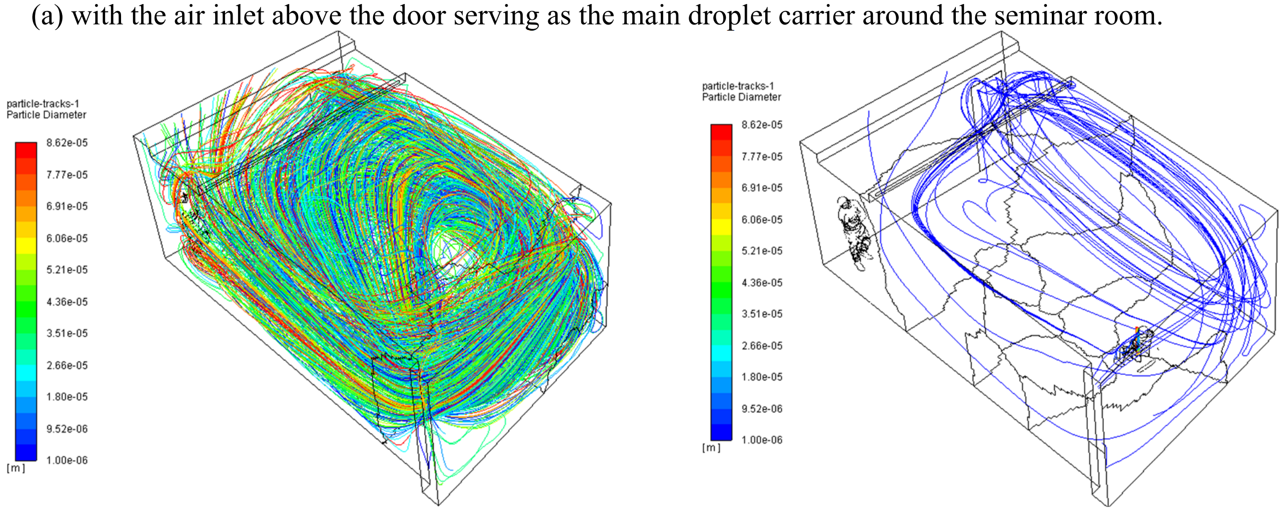


Case 3

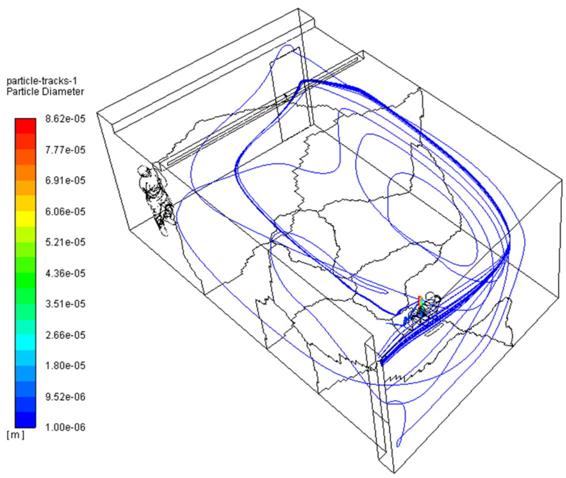
Figure 6: Top view showing streamlines of airflow in room for (a) Case 1 (b) Case 2 (c) Case 3. In each case, 40 streamlines were tracked emanating from AC or above door air inlet

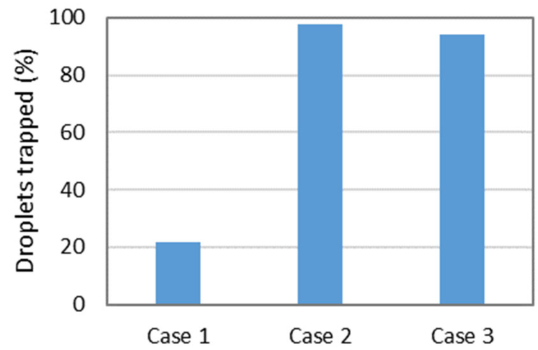
Aerosol dispersion

It has been known that ventilation affects aerosol distribution in confined spaces (Bhagat *et al.*, 2020; Aliyu *et al.*, 2021; UK Health Security Agency, 2022). To assess such an effect in the indoor seminar space under investigation in this study, particle tracks of ejected droplets from mannequin 1 were analysed from the simulation results and plotted. A total of 88 particles was tracked in each case to ease of visualisation. These particle tracks are shown in Figure 7. Figure 7 (a) shows the particle tracks in the room for case 1, the most poorly ventilated of the three cases where air inlet is only from the top gap of the door. It is seen that the residence time of the aerosol droplets is high with a lot of circulation before exiting at the top vent above mannequin 2. It is seen that the aerosol size in this case ranges from the smallest (around 1 µm to around 60 µm). It appears the pattern of the tracks are similar to those of the airflow shown in Figures 5 (a) and 6 (a) with the air inlet above the door serving as the main droplet carrier around the seminar room.



Case 1 Case 2

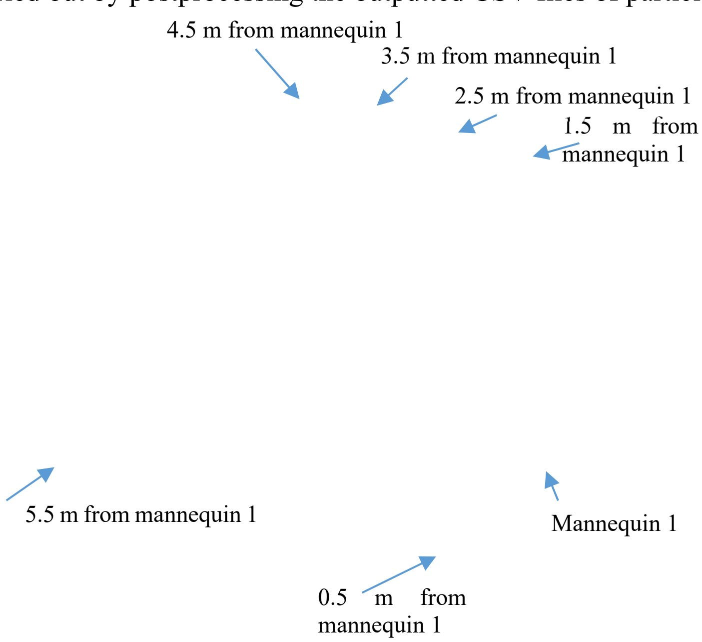


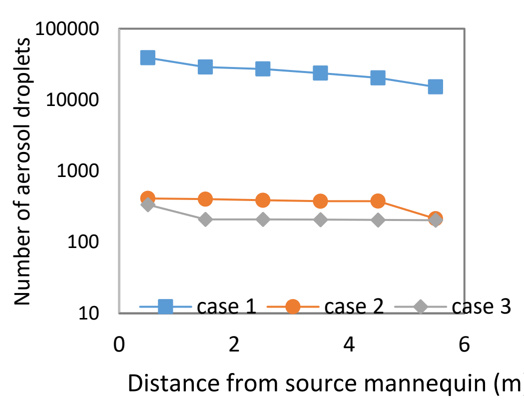


Case 3

Figure 7: particle tracks for (a) case 1 (b) case 2 (c) case 3 (d) Percentage of droplets trapped on walls (especially within mannequin vicinity) for the 3 cases investigated. In all cases, 88 particles were tracked.

Conversely for cases 2 and 3, the introduction of AC directly opposite the mannequin seems to dampen the ejected larger droplets such that they are trapped within the vicinity of the mannequin. The smaller aerosol droplets that remain are then transported around the room, with Figure 7 (c) showing the effect of the window as the aerosols exit the room through this channel more than at the overhead vent. Indeed, the number of droplets transported around the room is reduced by more than 90% in both cases as shown in Figure 7 (d), obtained by measuring the numbers of droplets trapped on the walls of the domain. For quantifying the density of aerosol propagation from source mannequin to standing mannequin, six planes were created, and droplets were sampled on each of them. The planes are shown in Figure 8 with their locations being 0.5, 1.5, 2.5, 3.5, 4.5, and 5.5 m away from the source mannequin. The sampled data from these planes give the properties of each droplet (among which are their x, y, z coordinates; u, v, w velocities; masses, ID, and time instant). Since a droplet can cross a plane more than once, cleaning of the data set was carried out by postprocessing the outputted CSV files of particle tracks.





(a) **(b)**

Figure 8: (a) Locations of planes droplets were sampled. Table and chairs have been hidden for clarity (b)

Variation of number of aerosol droplets ejected as a function of distance from sitting mannequin.
This was achieved by scripting in MATLAB so that only unique droplets are used (filtering out by droplet ID) and only those travelling forwards from mannequin 1 to 2 and not vice versa (filtering by v-velocity being only negative, i.e., in the -x direction). The results of postprocessing the droplet data obtained from each plane are plotted and presented in Figure 9. Note that the scale on the horizontal axis is logarithmic, which allows large and small quantities to be visibly shown on the same plot. As expected, it shows that droplet count reduces by more than 61% for case 1 as droplets travel from mannequin 1 to 2. For cases 2 and 3 the reduction is around 40% but their droplet counts are much less than for case 1 indicating the positive effect of increase air ventilation. Notably, case 3, which has both the AC on and the window open, produced the least number of droplets propagated through the room. In summary, AC and/or natural ventilation helps to transfer droplets out of the room by virtue of air circulation. Also, the simulations have shown that aerosol propagation is dampened at source as increased air circulation tends to force the trapping of droplets on clothing or immediate nearby surfaces. Because of the results obtained, strong quantitative evidence has been produced to reinforce the need for proper ventilation in enclosed public places, specifically in this and other seminar rooms in schools and universities. More so, it is recommended that having windows in such rooms is important given the additional ventilation and outlet they can provide for aerosol outlet. Future work is planned to experimentally validate these findings within the actual seminar room by sampling aerosols using sensors and evaluating the results using flow diagnostic methods. It is recommended that may also be carried out to quantify the effect of using typically porous face masks as well as various air conditioning and ventilation configurations. Other public building typologies such as hotels, cruise ships and shopping centres should be considered since their respective air changes per hour differ.

CONCLUSIONS

The effect of ventilation configuration on the distribution of airborne bioaerosols in an existing seminar space at the University of Lincoln is examined using computational fluid dynamics. The discrete phase model was used to simulate droplet transport within the room. As the room had an absence of a natural ventilation source (i.e., window) and the fire door is required to be kept close at time, it may provide unsatisfactory ventilation especially from the point of view of possible airborne infection transmission. To examine this, three cases were investigated. These are case 1: the base case with no window and no air conditioning (AC); case 2 with AC on and no window; and case 3 where the AC is on, a top half window is added left open. In each, a bioaerosol source is placed at the centre of the seminar room and droplet propagation was tracked towards a second standing mannequin. The droplet transmission for each case was tracked and visualised as particle tracks within the indoor domain using the discrete phase model (DPM). It was found that case 1 (no window or AC), a large fraction of the expelled aerosols (1–2000 μm in size) were transported freely around the room increasing the probability of large-scale infection. Conversely, in cases 2 and 3 (AC on), this is greatly reduced by as much as 90%. Hence, this study provided both visual qualitative and quantitative evidence of the importance of ventilation during teaching or seminars. Furthermore, we recommended that a window is added at the top half of the observation glass to further increase outlets for aerosols/minimise transmission of airborne infections e.g., Covid-19 emanating from an infected person. This study provides a foundation for the study of the ventilation in other public building typologies such as hotels, cruise ships and shopping centres.

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INVESTIGATION OF SUSTAINABLE GEO-POLYMERS FOR PASSIVE FIRE PROTECTION

D Harinadha Reddy[1]

[1] Associate Professor, BMS School of Architecture, Yalahanka, Bengaluru, Karnataka, India
Email: hari123reddy@gmail.com

ABSTRACT

For fire protection in the structures both passive and active fire protection systems were used. Active fire protection systems are automatic fire detecting and suppression systems. The passive fire protection systems are in other hand, which is used to delay the spread of the fire. In this study two sustainable geopolymers, made with Metakaolin and fly ash were investigated for high temperature resistance. Two mixes namely MF50 and MF70 were used in this study. Here in the nomenclature of the mix, the first two alphabets specify the Metakaolin and fly ash and the two numeric specifies the percentage of fly ash presence in the total powder of the mix. For example, MF70 represents Metakaolin and fly ash geopolymer and it contains 70% of fly ash and 30% of Metakaolin. The proportions were mixed till the thixotropic paste was obtained. This paste was poured in the moulds and vibrated to release the air bubbles. At an age of 24 hrs, the specimens were demolded. These specimens were placed in the humidity and temperature-controlled chambers till 28 days from the date of casting. In the controlled chamber, the RH of 70 % and the temperature of 25°C was maintained. These specimens had a hole drilled till the center point and a thermocouple inserted. After insertion of thermocouple, this hole is duly filled with the same material and dried the specimen for 3 days before testing. These specimens were kept in the electric furnace to expose the high temperature. The temperature was raised to 800°C and continuously measured the temperature at core of the specimen through the thermocouple. Initial results revealed that the Fly and Metakaolin concretes shows a better resistance when compared with normal concrete.

INTRODUCTION

Fires in infrastructure causes a severe damage to the infrastructure and hazard to the human life. In common two types of spalling occur in concrete when exposed to the high temperature, namely explosive and thermal spalling. Several factors influence the development of the conditions leading to an explosive and thermal spalling of concrete when exposed to high temperature. The parameter permeability of concrete influences significantly to cause explosive spalling under high temperature conditions. Lower permeability concrete has a higher risk to explosive spalling than the higher permeability concrete under high temperature conditions (Sertmehmetoglu, 1977). The higher moisture content presence in the concrete has high risk of explosive spalling than the lower moisture content concretes (Mindeguia et. al, 2011). Type of heating influences the occurrence of explosive spalling, the rapid heating more likely to cause spalling than the slow heating (Bazant, 1978, 1979). An increase in thermal stresses and deterioration of material properties when exposed to high temperature causes thermal spalling in concrete. Another attention to be given for the structural rebars used in the concrete. Structural steel rapidly loses its mechanical properties when exposed to even at low temperatures like 500°C to 500°C (NCMA, 1994). Hence, both the concrete and steel are sensitive against fire, which needs to be passively protected to retain its structural properties when exposed to high temperatures. The most effective and promising passive fire protection system is cladding structural elements with the fire protection material. Metakaolin and Fly ash can be used as a passive fire protection material for the structural systems.

EXPERIMENTAL DETAILS

Mix details

In this study two geopolymers made with Metakaolin and y ash were investigated for high temperature resistance. Two mixes namely MF50 and MF70 were used in this study. Here in the nomenclature of the mix, the first tow alphabets specify the Metakaolin and Fly ash and the two numeric specifies the percentage of y ash presence in the total powder of the mix. For example, in MF70 represents Metakaolin and Fly ash geopolymer and it contains 70 % of y ash. The mix details of the two mixes as a percentage of wight proportions is shown in the table 1.

Table-1: Geopolymer mix proportions given in values by mass (% weight)

	MF50	MF70
Fly Ash	30	43
Metakaolin	30	17
Sodium Silicate (Na_2SiO_3)	40	40
Liquid to Solid weight ratio	0.29	0.29

The proportions that are specified in table 5.2 was mixed till a thixotropic paste was obtained. This paste was poured in the moulds and vibrated to release the air bubbles. At an age of 24 hrs, the specimens were demoulded. These specimens were placed in the humidity and temperature-controlled chambers till 28 days from the date of casting. In the controlled chamber, the RH of 70 % and the temperature of 25°C was maintained.

Experimental procedure

Cylindrical specimens of size 75mm diameter and 150mm long were used in this study as shown in the Fig-1. The specimens were tested after 28 days from the casting. The cylindrical specimen of the geopolymer (MF70) is as shown in the Fig-1. These specimens had a hole drilled till the centre point and a thermocouple inserted. After insertion of thermocouple, this hole is duly filled with the same material and dried the specimen for 3 days before testing. These specimens were kept in the electric furnace as shown in the Fig-2.

Fig-1: Cylindrical specimen of MF70 mix

Fig-2: Furnace setup

The temperature was raised to 500° C and continuously measured the temperature at core of the specimen was obtained through the thermocouple. The time temperature curve of the furnace is as shown in the Fig-3

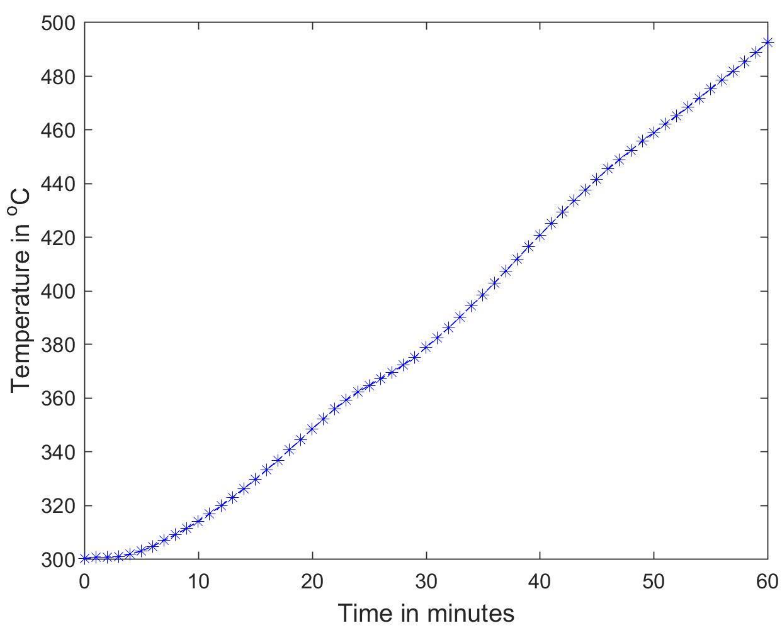

Fig-3: Time temperature curve of the experiment

Numerical modelling

In the present study the numerical model has been formulated Fourier equation as shown in the equation 1.

$$\rho C_p \frac{\partial T}{\partial t} + \nabla . (\lambda_e \nabla T) = Q \qquad (1)$$

where ρC_p is the volumetric heat capacity, T is the temperature in Kelvins, λ_e is the thermal conductivity of the material and Q is the heat source or sink.

Initial and boundary conditions:

The Initial condition of the primary variable T is specified at time t=0 on both domain Ω and boundary Γ . The boundary conditions of the problem can be described as Dirichlet or Cauchy's type boundary conditions.

The Dirichlet type boundary condition is:

$$T(t) = \overline{T}(t) \quad \text{on} \quad \Gamma$$

The Cauchy type boundary condition is:

$$\left(-\lambda_e \nabla T\right).\boldsymbol{n} = q_T + \alpha_c \left(T - T_\infty\right) \quad \text{on} \quad \Gamma$$

Where ***n*** refers the unit normal vector, $\mathbf{q_T}$ is the temperature flux, α is a heat exchange coefficient and T_∞ is the temperature immediately after the boundary.

The solution process of the above equation obtained through iteratively by the Newton Raphson method. Variable time steps starting from 1 second to 100 days were used during the computations. In Newton Raphson iteration, the Jacobian matrix updated at the beginning of every time step instead of every iteration to achieve computational cost efficiency. This model has been implemented and obtained the solution from the commercial software's MATLAB® and COMSOl®. Mesh refinement studies were conducted to assess convergence of the temperature fields based on which a suitable mesh for the domain was selected. The finite element method mesh is shown in the figure 4. The domain is discretized with a tetrahedral element for the solution process. Initial value of 293.15 K is used while solving the problem. A varied temperature according to the time temperature curve shown in the Fig-3 was specified on the boundary while solving the equations.

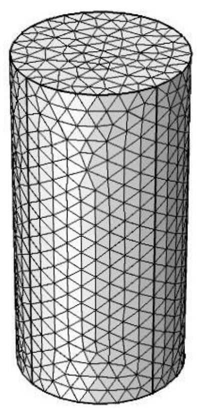

Fig-4: FEM mesh used in the numerical simulations

Results and discussion

Fig-5 shows the core temperature of MF50 and MF70 specimens with time when heated at 500oC. It is observed that mix MF70 shows a better resistance against temperature than MF50 mix. MF70 mix contains

50% more y ash than the MF70 mix, hence fly ash based geopolymer is suitable for passive fire protection material.

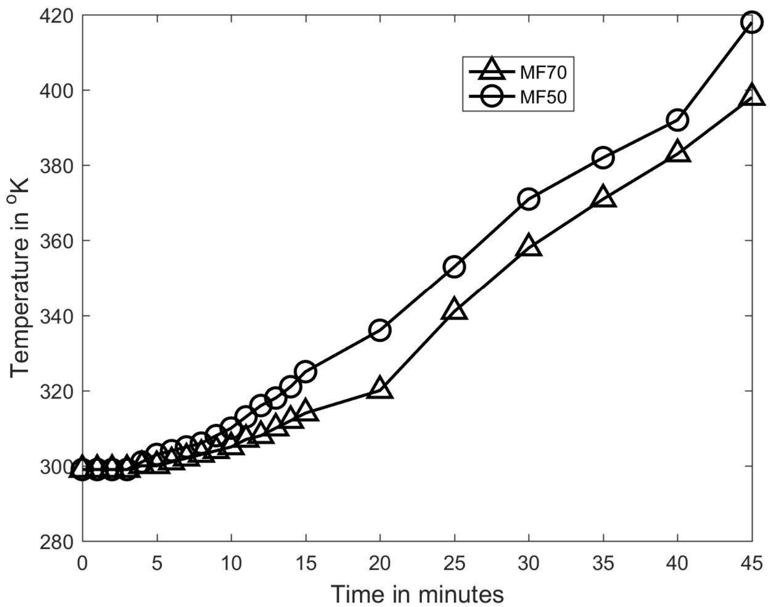

Fig-5: Measured temperature at center of the specimen for the geopolymers MF50 and MF70.

Fig-6 shows the comparison of experimental and numerical results of MF70 mix, The model predictions with the test data have been shown to be comparable to the test results.

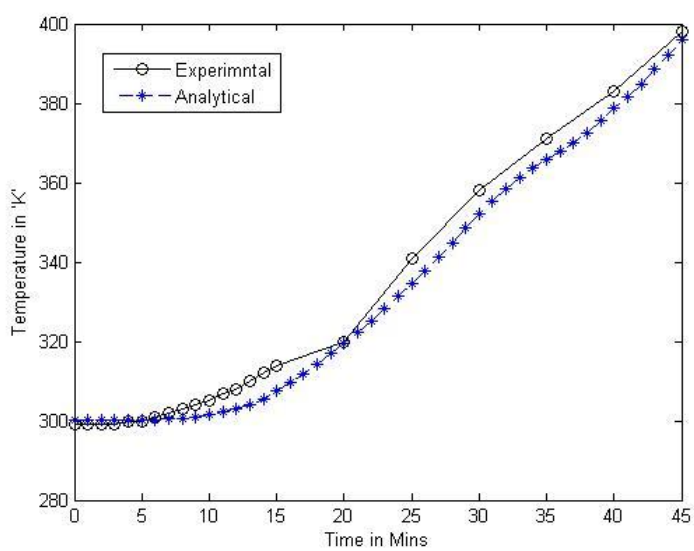

Fig-6: Comparison of experimental and numerical results of the MF70 mix.

CONCLUION

Two geopolymers made up with y ash and Metakaolin were studied for passive fire protection capability. The study shows that the MF70 mix (mix contains 70% fly ash) show a better resistance against heating than the MF50 mix (mix contains 50% fly ash). Hence fly ash geopolymer is a good option for passive fire protection.

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COIR FIBER REINFORCED SOIL BLOCKS AS A SUSTAINABLE BUILDING MATERIAL

Vidya Vijay K P[1], Gayathri S S[2]

[1] Assistant Professor, BMS School of Architecture, Bengaluru, Karnataka, India vidyavijaykp@bmssa.ac.in
[2] Associate Professor, BMS School of Architecture, Bengaluru, Karnataka, India gayathris@bmssa.ac.in

ABSTRACT

Clayey soil being available in plenty in tropical countries can be effectively used for low cost building construction. The raw materials used for rammed earth construction and stabilized mud blocks include earth, chalk, lime, gravel, laterite. Natural fibers biodegradable in nature are used for reinforcing the mud block to enhance the strength and durability characteristics. Reinforcing with coir fibers and with suitable proportion of cement stabilization increases the performance of the building blocks in the load bearing wall construction. The addition of coir fibers enhances the durability characteristics, reduction in density and linear shrinkage, along with improvement in compressive and tensile strength has been noticed. Cement stabilization along with coir fiber proves more efficient as the stabilization reduces the porosity at the microstructure level. When 3% of coir fibers by cement weight are used in the preparation of hollow blocks there is a substantial increase in the shear strength. It also shows better post-peak behavior in flexure. Moreover, the coir fiber reinforcements specimens showed improved durability for acid/alkaline attack, wet-dry and freeze-thaw weathering. Hence the study tells us that the overall performance of the coir reinforced specimens shows improved mechanical properties and ductile deformation. Fiber reinforced mud blocks will contribute to a reduction in weight of structures and have reduced cracking. In addition, the fibrous material improves the ductility of the mud blocks and can be effectively used for earthquake resistant construction.

Keywords: Coir Fiber, Rammed earth, Laterite blocks, Stabilized soil block, Durability

INTRODUCTION

Identifying and adapting towards sustainable materials in architecture is the need of the hour. When the world is facing a larger challenge of climate change and when countries across the globe is trying to reduce carbon footprint, sustainable development is a responsible and imperative decision architects have to make. In this direction architects across the world have embraced sustainable building designs and strategies. Designing a sustainable building requires various considerations including materials, energy, resources, space planning, weather etc. All these factors needs to harmonically contribute to realize a desirable sustainable architecture.

The use of natural reinforcing material in the soil/mud enhance the performance and durability of the mud blocks used as building material. Further considering the sustainable development, the addition of diverse fibrous waste because of its availability in abundance and zero cost lead to the development of reinforced mud blocks in the construction industry. Research have been conducted on different types of fibers as reinforcing material. Few among them are coir fiber, bagasse or sugarcane fibers, banana fibers, hibiscus cannabinus fibers, oil palm fibers, corn silk fibers, jute fibers and pineapple leave fibers [6]. These fibers enhance the soil properties. Soil can be stabilized by adding different binders such as cement, lime and other additives. There are many studies available in literature related to coir reinforced rammed earth construction.

The scope of this research paper is to study about a suitable sustainable building block which can be a substitute or which can prove to be a better alternate to the existing conventional blocks. Soil block reinforced with coir fibers is identified for the study. Clayed soil becomes a natural choice due to its abundance in tropical countries, especially in India. Clay soil has excellent insulating properties because of its high thermal mass and properties like plasticity, porosity and versatility qualifies it for the current study. Several studies conducted has proven that reinforcing soil with natural or synthetic fibers has shown significant improvements in mechanical properties of block. For this study, natural coir fiber is chosen due its abundance in this geography and as a cost effective solution.

The current research will be focused on the analysis of Compressive strength, split tensile strength & Stress vs Strain of the clay soil block reinforced with different percentage of coir fiber by weight of clay soil. The data for analysis will be collected methodologically from the available research materials published in various International journals. Cement is considered as the binding material and untreated coir fiber of a fixed length is considered across the analysis.

METHODOLOGY

Data collected from relevant research publications were analyzed and meaningful inferences were derived and the range of values for the parameters under study were ascertained.

Bhanupratap and Reddy (2019) [1], experimental results showed that the cylindrical samples with an inclusion of 1% and 2% coir fiber volume in the cement stabilized rammed earth (CSRE) resulted in the increase of compressive strength, ductility and failure strain both in dry and wet condition and remained intact compared to the sample with no fiber content which showed catastrophic failure pattern.

M.G.Sreekumar and Deepa G Nair (2013) [2], focused on improving the strength and durability characteristics of fiber reinforced lateritic blocks(FRLB) with coir cutting waste as reinforcing element on comparing with stabilized lateritic blocks (SLB) without fibers. In both SLB and FRLB, the lateritic soil is stabilized with 10%, 20% and 25% of sand and 8% cement. FRLB prepared for three different fiber proportion such as 0.5%, 1% and 1.5%. It is observed that with the inclusion of 0.5% fibrous material the improvement in compressive strength and tensile strength is 19% and 9% respectively and the same is found decreasing beyond 0.5% fiber inclusion. Compared to SLB the durability characteristics of FRLB improved by adding 0.5% fiber. The study shows a significant improvement in strength and durability characteristics due to inclusion of fibers making FRLB suitable for earthquake resistant construction.

Raavi and Tripura (2020) [3], evaluates the engineering properties of unstabilized and cement stabilized rammed earth for different coir percentage and length in terms of their strength, density and durability. The compressive strength and tensile strength of CSRE block increased to 54% and 85.58% for 1% fiber compared to USRE. The dry compressive strength of the blocks decreases with increase in fiber length from 25mm to 50mm.

Danso et al. (2015) [4], studied the effect of aspect ratio of three different fibers on the mechanical properties of soil blocks. There was 25% improvement in the compressive strength and tensile strength of the soil blocks for coir fiber aspect ratio of 125 and a length of 50mm.in general the study concluded thatthe strength of soil block enhanced with an increase in the fiber aspect ratio. The study was further extended on two types of soil (red soil and brown soil) and varying the fiber content from 0.25 to 1%. The experimental results revealed the addition of agricultural waste to the blocks reduced the density making it light weight, reduced the linear shrinkage hence reduced cracking. Compressive strength and tensile strength was improved in case of reinforced soil block with an optimum fiber content between 0.25% and 0.5%. The use of fibers also reduced the rate of wearing by 20 -50-% and erosion by 44-70%. Soil with high clayey content was identified as an important element in compressive strength development and durability, whereas the fiber type was important element in tensile strength development.

Conand Honore Kouakou et al. (2021) [5] in their experimental analysis on the mechanical behaviour of reinforced clay cement blocks with coconut fibers concluded 0.8%fiber in clay cement blocks has required compressive and flexural strength and can be used as filler materials and in partition walls.

Danso and Manu (2020) [6], investigated effect of coir fiber, lime and cement in soil cement mortar. The various percentages by weight of soil used in his study was coconut fibers 0.2% to 0.8%, lime content of 0 to 15% and 5% cement content. With this different variation he tested the soil cement mortar for density, water absorption apart from the compressive strength and tensile strength. The soil cement mortar achieved optimum compressive and tensile strength with the addition of 0.2% fiber and 5% lime. Adding 5% lime to soil cement mortar showed decreased water absorption and enhanced density.

Pateriya et al. (2021) [7], investigated the use of wastes (coir fiber) and nano material to enhance the strength of no fine concrete. The addition of 0.5% to 1% coir fiber increased the compressive strength and tensile strength by 39.5% and 22% to virgin no fine concrete respectively. Addition of nano material along with coir fiber increased the compressive strength by 67% and the tensile strength by 35%.

G.A.P Gampathi (2011) [8], conducted experimental study to enhance the shear strength of cement hollow block with the addition of coir fiber. This study according to the author was taken forward to get a sustainable and economic solution for earthquake resistant construction. Hence in his research he used the application of coir fiber reinforced cement hollow block as a solution for earthquake resistant construction. His main focus was to increase the shear strength of the cement hollow block without altering the compressive strength. In his study he cast-off 1%, 2% and 3% of coir fibers by weight of cement. He also tested the cement hollow block without addition of coir fiber for compressive strength and shear strength. The reduction in compressive strength was 0%, 5.6% and 12% for 1%, 2% and 3% coir fiber to cement weight respectively. The shear strength was seen to increase by 31%, 38% and 41% for 1%, 2% and 3% coir fiber to cement weight respectively. From the overall study he concluded optimum coir fiber content of 2% by weight of cement showed increase in shear strength of the cement hollow blocks.

Akinyemi et al. (2016) [9], Studied the physical and mechanical properties/characteristics of the termite mound reinforced with coir fiber and cement is very much suitable or in range when the optimum percentage of fiber used is 1 to 2 %. Above 2% the mechanical properties are seen decreasing. Due to alternate wetting and drying cycle and with the increase in fiber content cracks are developed in the blocks resulting in failure.

Thanushan et al. (2020) [10], conducted a study on the influence of coconut fibers on stabilized soil blocks. Coconut coir-reinforced blocks were tested for compression, flexure, water absorption, sorptivity and resistance against chemicals, wet-dry and freeze-thaw weathering. Mainly the influence of fibers on the post-peak behavior and durability properties of the stabilized earth block were studied. There are major issues concerned with the use of cement-stabilized soil blocks for construction including the brittle behavior of the blocks and the tensile strength. The coconut fiber showed better behavior flexural tensile strength than in compression. The addition of fibers increases the residual strength, ductility and toughness. Coconut fibers show improved resistance of the blocks against acid attacks, alkaline attacks, freeze-thaw cycles and wet-dry cycles.

Compressive Strength Analysis

Compressive strength for various percentage of coir fiber by weight of clayey soil is studied from various research papers published. Coir fiber reinforcement from 0% until 2% by weight is considered for the study. The below table details the results of the study.

Table 1: Review of compressive strength of various percentage of fiber reinforced clayed soil blocks

Fiber %	0	0.20	0.25	0.40	0.50	0.60	0.75	0.8	1.0	1.5	2.0	Source
Strength in Mpa	3.8		4.3		4.7		5.0		5.1	5.2	5.3	[1]
					4.28				3.31	3.01		[2]
									5.5		5.3	[3]
	2.2		2.8		3		2.4		1.8			[4]
	0.4	0.85		1.0		1.1		1.25	0.3			[5]
	1.2	1.4		1.65		1.7		1.6				[6]
	5.2		5.8		7.2		6.3		4.4	3.3		[7]

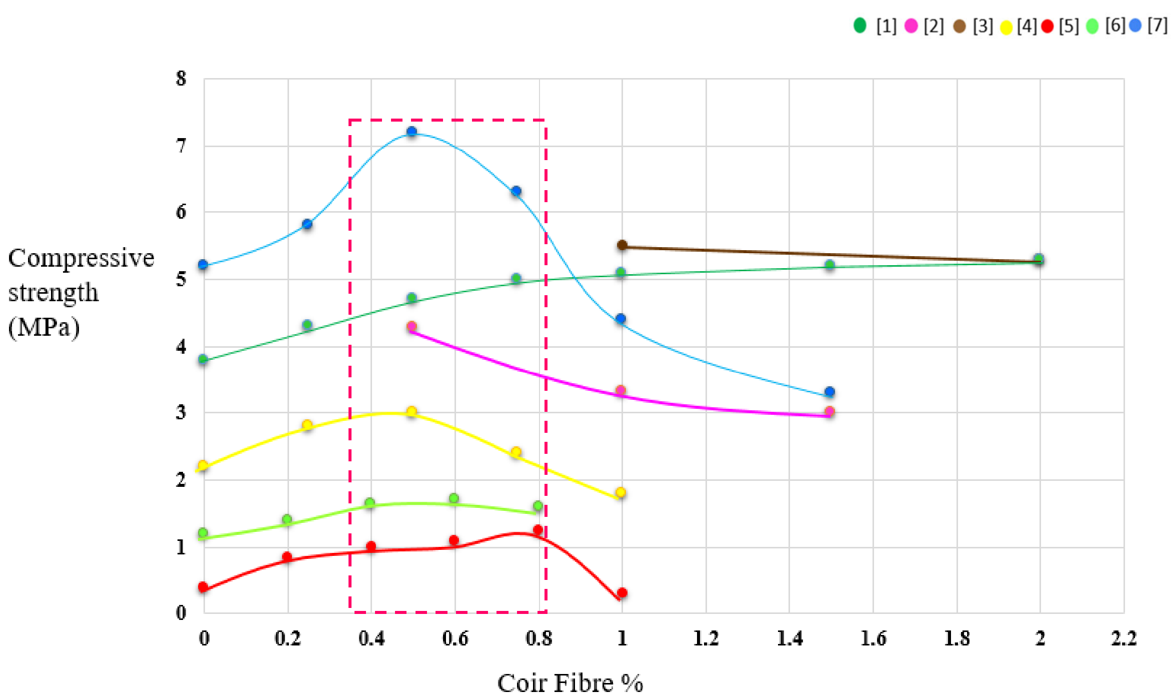

Figure 1. Plot of compressive strength of soil block for different percentage of coir fiber reinforcement

The above is the graphical representation of the data presented in the table for quick understanding and to help derive at a conclusion.

Tensile Strength Analysis

The next parameter which was studied is the behavior of tensile strength for various percentage of coir fiber reinforcement in the clayed soil block. Data is collected from multiple research papers published and is captured in the table below.

Table 2: Review of tensile strength of various percentage of coir fiber reinforcement clayed soil blocks

Fiber %	0	0.20	0.25	0.40	0.50	0.60	0.75	0.8	1.0	1.5	2.0	Source
Strength in Mpa	0.5	0.65		0.55		0.43		0.4				[6]
					0.37				0.26	0.21		[2]
	0.25		0.32		0.3		0.31		0.28			[4]
									1.10		1.2	[3]
	0.45				0.47		0.49				0.46	[7]

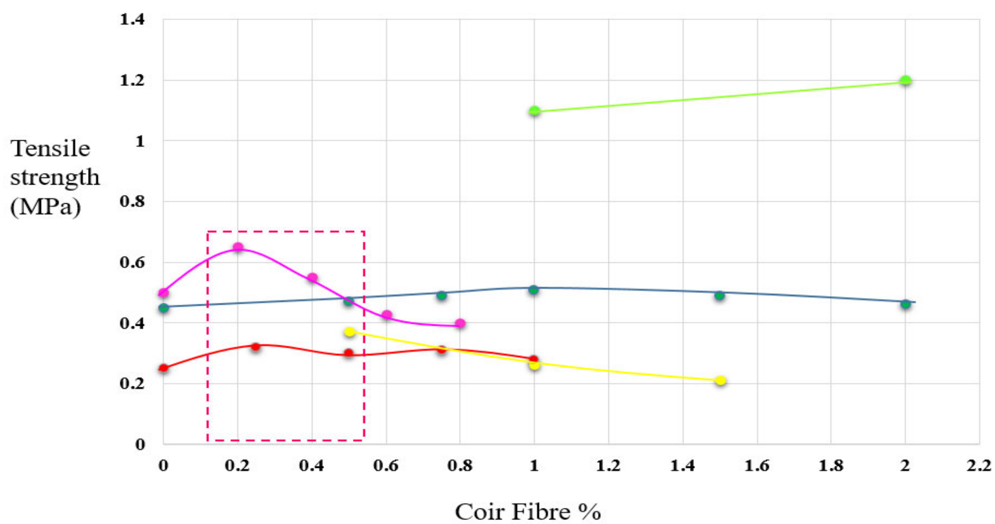

Figure 2. Plot of tensile strength of soil block for different percentages of coir fiber reinforcement

The above figure depicts the data presented in the Table 2.

Stress vs Strain Analysis

The study of this paper includes the stress vs strain relationship for various percentage of coir fiber reinforcement by weight of clayed soil. Data from couple of research material is used for the analysis which is presented below.

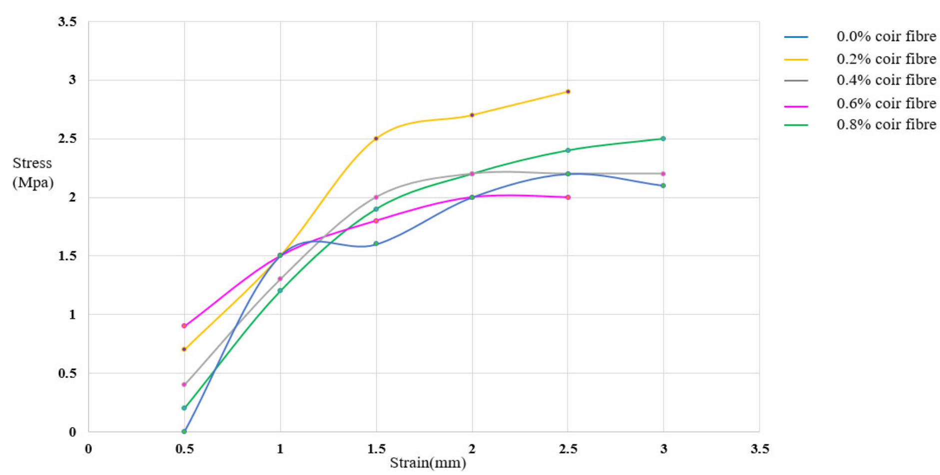

Figure 3. Plot of stress & strain for 0.0% to 0.8% of coir fiber reinforced soil blocks. **Source:** [4]

The below data shows the stress vs strain relation for coir fiber reinforcement from 0.2% to 1.0%.

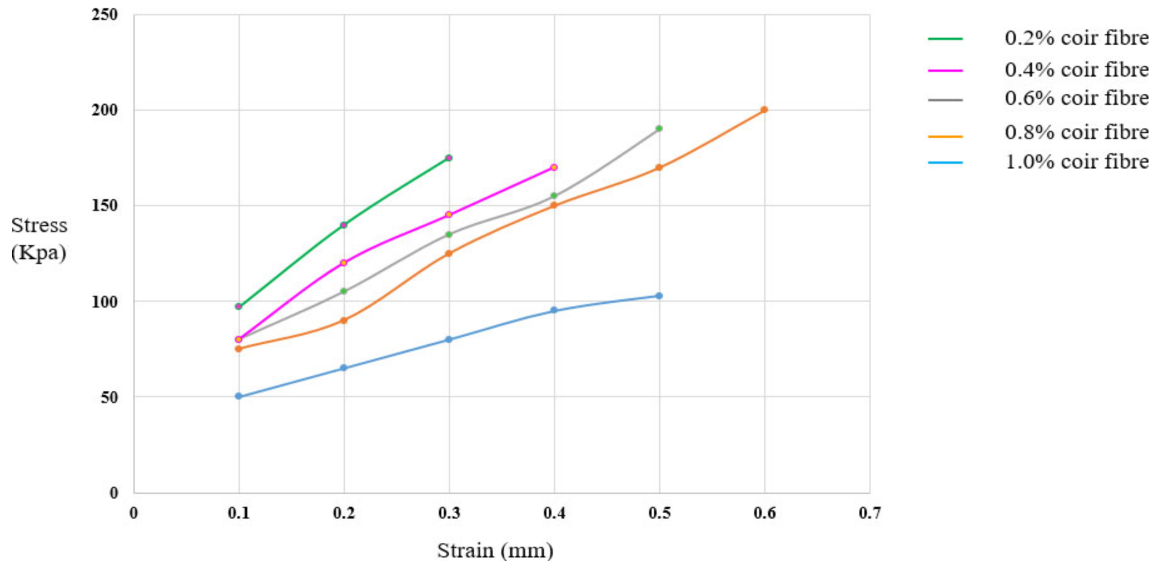

Figure 4. Plot of stress & strain for 0.2% to 1.0% of coir fiber reinforced soil blocks.
Source: [5]

INFERENCE

Figure 1. shows the compressive strength of clayed block reinforced with various percentage by weight of coir fiber. Data is studied from multiple research publications and is plotted from 0% coir fiber to 2% coir fiber by weight. From the data it can be clearly inferred that the clayed block gives maximum compressive strength when the coir fiber reinforcement is in the range 0.4% to 0.8% by weight.
The Tensile strength for various percentages of coir fiber by weight is plotted in figure 2. Each curve is obtained from individual research work and the graph is the collection of five such research findings. It can be concluded by carefully examining the figure 2 that the tensile strength value is in the maximum range, for coir fiber reinforcement between 0.2% and 0.6% by weight of clayed soil.

The scope of the study also included the behavior of stress vs strain for various percentage of coir fiber reinforcement. Data obtained from couple of research findings are plotted in figure 3 and 4. On careful examination it can be ascertained that for coir fiber reinforcements between 0.2% and 0.4% optimum stress vs strain values can be obtained.

Hence to conclude considering the findings of the 3 parameters of study it can be summarized that coir fiber reinforcement in the range 0.2% to 0.6% by weight of clayed soil gives the best results.

CONCLUSION

The aim of the study of coir fiber reinforced soil blocks as a sustainable building material is to evaluate the possibility of using them as a reliable, efficient, durable and cost effective sustainable alternate to conventional building blocks. The study was mainly focused on the vital mechanical properties of the blocks which is required to qualify it as a durable & strong building material to be used commercially.

Further study can be conducted on properties of coir reinforced blocks like linear shrinkage, density, porosity at microstructural levels and durability for acid/alkaline attacks, wet-dry and freeze-thaw weathering. Similar findings on these properties can give a comprehensive and holistic view and inference of using coir fiber reinforced soil blocks in load bearing wall construction.

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ENERGY-SAVING BY SHADING DEVICE'S SHADED AREA ON A FULLY GLAZED MULTI-STOREYED OFFICE BUILDING IN A HOT AND HUMID CLIMATE, CHENNAI, INDIA.

Chandrasekaran.C [1], Dr.Kumudhavalli Sasidhar [2] and A.Madhumathi [3]

[1] Ph.D. scholar, Dr. MGR educational and research institute, faculty of architecture, Chennai, India. chandru.motif@gmail.com

[2] Professor, Dr. MGR educational and research institute, faculty of architecture, Chennai, India. kumudhavalli.arch@drmgrdu.ac.in

[3] Professor, Vellore institute of technology, school of architecture, Vellore, India. madhumathi.a@vit.ac.in

ABSTRACT

Modern, fully-glazed office building needs to be energy efficient. External shading devices are an efficient way to improve energy-saving in fully-glazed office buildings. Increased use of dynamic shading systems in buildings due to their ability to respond to the changing sun directions is an effective way to save energy. However, dynamic shading has yet to have a clear strategy to evaluate energy-saving. The paper aims to calculate the % shaded area or the shading fraction (SF) and its influence on the energy consumption and cooling loads for a fully glazed office building in a hot and humid climate in Chennai, India**.** The scope is to determine the SF% and its space-cooling load energy saving as valuable resources to design and evaluate dynamic shading devices at the early design phase. This research is a simulation method in multiple packages. Geometry creation in Revit, Dynamo to calculate the shaded area, and E-Quest for energy simulation. As required by E-Quest window shades input with one horizontal and one vertical fin, the dynamo script calculates an hourly shaded area by varying the fin depth. Tabulating the fin depths and the SF ranges are grouped to simplify each orientation and analysis of 4 seasonal days. The 5 SF range ranges from 45% to 95%, with an interval of 10%. Hourly energy simulation with E-Quest for each hour of an SF range by assigning the tabulated fin depth to window shades of the base case model. Compare the base case without shades for each hour of an SF range with shades for energy use. For a hot and humid climate, it was observed that up to 3-15% energy saving on space cooling load for 45 to 95 % shaded area in all four orientations.

Keywords: shading fraction, exterior shading device, dynamic shading, fully glazed buildings

INTRODUCTION

The performances of building envelopes are crucial to reducing the energy consumption of buildings, which consume an estimated 40% of the overall energy used worldwide, Janssen R (2004). Today, irrespective of the climatic context, there are many fully glazed office buildings in major cities in India. These glass boxes provide good daylight and pleasant external views, with a high thermal load on façade glazing in cooling-dominated climatic zones. The high thermal loads on the glazing should be considered by using external shading devices and controlling shading patterns, Kirimtat et al. (2016) in the design stage. Use of an external shading device, a shadow is cast on the glazed façade by direct solar radiation. In a recent study by Al-Masrania et al. (2018), a fixed shading device will not generate a constant range of SF in response to hourly changing sun direction. Studies by K Johnsen et al. (2015) that dynamic shading will generate a constant range of shading throughout the year. To find the energy-saving by SF, perform the calculation of the shaded area. Previous research on SF calculation by fixed shades on windows, where the shaded area on the wall is cropped, unlike a fully glazed façade. The shadow outside the grid will fall on the following grid, creating the same sun-shading effect. The shaded and the unshaded area are only the glazed areas.

Hence the shadow on the glazing has the most significant impact on space cooling energy load for an office in hot and humid climates.

Among the various researchers investigating calculating the shaded area, Hiller et al. (2000) derived a method by calculating the sunlit fraction of a fixed shading device and suggested an algorithm for calculating the shaded area and the amount of solar radiation. An online shading tool, "Sustainable by Design" by Gronbeck, C. (2016), is a guide for a simple rectangular overhang design and annual analysis of shading percentage. Kim Y. (2013) proposed an algorithm for fixed shading devices to calculate the shaded area for a given time interval. With complex shapes and movements of dynamic shading devices, the calculation of the shaded area is a complex algorithm. The polygon method calculates the hourly shaded area drawn by a kinetic shading device's complex shape and movement. The Projection and Clipping Methods (P&C Methods) by Su-Ji Choi et al. (2020) are based on the projection of polygons in the path of a solar ray and their subsequent intersection or clipping. For calculating the hourly shaded area in this research, the P&C method proposed by Maestre et al. (2013) was validated by comparison with other methods and experimental results per European standards.

Two possible issues exist regarding the energy analysis of a building façade with dynamic shading. First, a new approach is required to trace the movement and type of dynamic shading device in response to the sun's movement and not just solar altitude angle like in a fixed shading device. Second, it Must update the impact of dynamic shading to reduce buildings' cooling loads. The latest study by Hyoungsub Kim et al. (2015) examines a new methodology, where at first, as per the sun's incidence angle, the assigned opening ratio of the complex panel, then this complex panel geometry is simplified, maintaining the same opening ratio. Based on WWR or shaded and un-shaded areas, derived energy results in E-Quest. In this research, we find the hourly shading fraction by simple shading fins and tabulate the hourly data. For energy results in E-Quest, we add the shading fin per the tabulated data, find hourly energy savings, and compare with the base case without shades. Finally, the resultant ratio could evaluate the thermal performance of any complex shading geometry for a given context.

We can find the shading calculation in buildings in the scientific literature about the influence of fixed shading on a window. Still, there needs to be more research on a fully glazed office building and the effect of exterior shading. Moreover, in hot and humid climates, the SF of the exterior shading device on fully glazed buildings is not considered an essential design criterion.

The motivation of the study is to give an insight into energy saving by the shading device's shadow for a hot and humid climate like that of Chennai (Lat. 13.0827°N Lon. 80.2707˚E). The SF range and energy saving are essential criteria for creating and evaluating any shading device in the early design phase. This research is at the first stage of the ongoing investigation, later developing and comparing the three types of shading: the fixed, kinetic, and solar screen shading devices based on their shading fraction for thermal and daylighting performances.

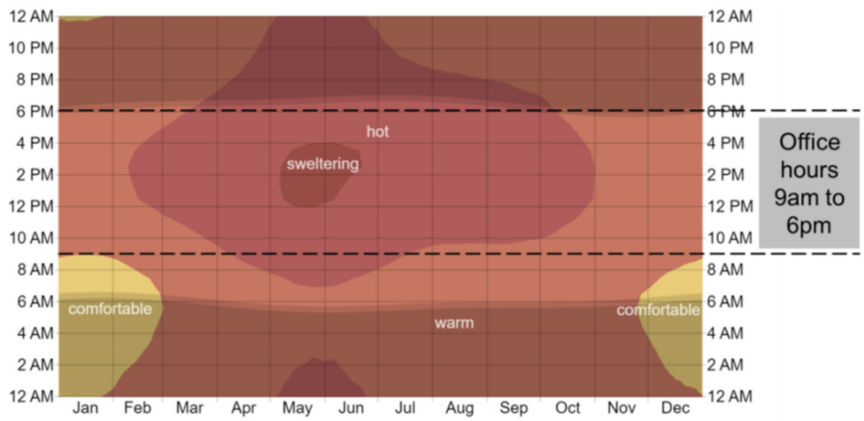
MATERIALS AND METHODS

The following stages are the method to find the energy-saving by the shading device's shaded area (fig10).
Revit to create the geometry with one Horizontal fin (HF) and Vertical fin (VF) on a 4 X 2-meter grid. SF was calculated for a given hour, orientation, and location by the P&C method in Dynamo.
To simplify the results, the five SF ranges fins depth data is tabulated for 6 hours and four seasonal days for each orientation.
In E-quest, create a base case model without window shades. (fig8)
To find the hourly space cooling energy use, the tabulated hourly fins depths are assigned to the window shades in all orientations for the base case model.
Compile the hourly energy-saving results by each SF range from 24 simulation runs (6 hours and 4 days).

For the same analysis period, compare the hourly energy use results with the base case model without shades. (Table2)

Climatic Context of Chennai, India:
Chennai locates at Lat. 13.0827°N Lon. 80.2707˚E has a hot and humid climate. The city lies on the coastal thermal equator with less variation in seasonal temperature. With a maximum temperature of around 37–41°C in summer and a minimum temperature of around 19–25 °C in winter. The daytime office use for this climate requires air-conditioning as the temperature is more than 23°C throughout the year, as in Chart 1.

Chart 1: Average hourly temperature in Chennai (source - https://weatherspark.com)



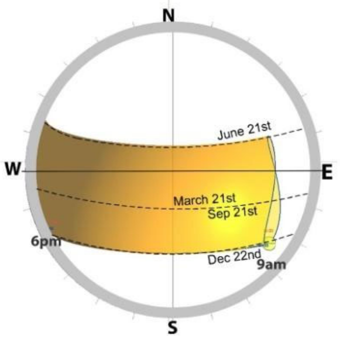
Analysis Period

The Four Seasonal Days
The analysis period is the four seasonal days of the year, as these dates are the most critical days according to previous studies in terms of the position of the sun and the length of the day. When the sun is at the median on the spring and fall equinox – March 21st and September 21st, and when the sun is at the end, the summer and winter solstice – June 21st and December 21st, as in figure 1. These four days represent the whole year for the shading device design and have been among the acceptable methods in shading device design (Bazazzadeh et al. 2021).

Shading Analysis Hours
The impact of the shading device on space cooling load is vital in the peak hours of the office working hours, from 10 am to 4 pm are the analysis hours for this research. At noon we avoid the shadow calculation as the sun would have no thermal impact on the façade plane. Hence 6 hours is the analysis period for a day.

Analysis Plane
The window or the glazed façade is the analysis plane for the shading device. The shadow cast outside the grid also has the same impact as the entire façade is a window with no walls, as in figure 2. However, the end curtain panel shadow may not fall on the plane; therefore, a small fraction of the cropped shadow area is neglected in this research.

Five Shading Ranges
To simplify the shaded area's data variations, we group the results for five SF ranges and easily relate the SF range to its equivalent energy-saving as a simple ratio. The five ranges are as in figure 3, from 45% to 95 %, with an interval of 10% between ranges. A minimum SF of 45% is required to observe the energy-saving and a maximum of 95% shaded area.



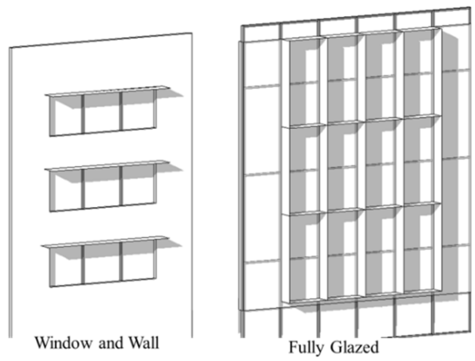


Figure 1: sun path on four seasonal days for Chennai.

Figure 2: Analysis plane for a window verses fully glazed facade.

SF50: 45 - 55 %
SF60: 55 - 65 %
SF70: 65 - 75%
SF80: 75 - 85%
SF90: 85 - 95%.

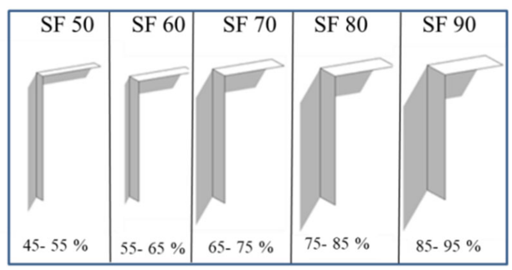


Figure 3: Shading ranges

Simulation Tool Description

In this research with multiple packages, Autodesk Revit is used to create the shading elements, Dynamo script to calculate the SF by P&C method, and hourly energy use in E-Quest.

Dynamo 2.0.2

Dynamo is a visual programming tool that extends the power of Revit by providing access to the Revit API (Darwin 2016). The "node" is a computational process that encodes the design of the workflow and creates programs that manipulate the graphic elements. Each step is a series of instructions to specific parameters that can be evaluated, revised, and improved. In this research, the Dynamo nodes calculate the SF in P&C methods for a given time and orientation.

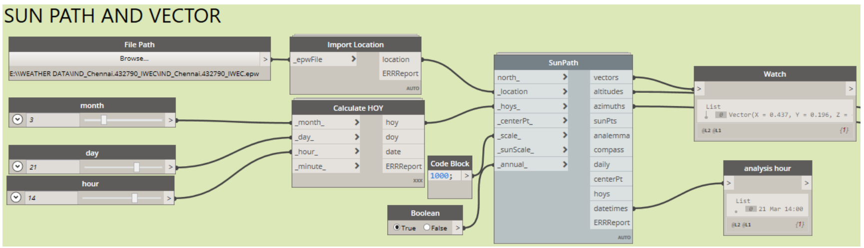
The following are the important nodes used in the research:

Sun Path: In the Ladybug package for Dynamo*,* the sun path node takes the climatic data from the energy plus weather file (epw) for the location and gives the sun vector. A sun vector is a vector in the sun's direction to the analysis plane for the given hour, location, and orientation, as in Figure 4.

Surface project input Onto For a given sun vector, this node projects the input geometry of the shading device onto the analysis surface as polygons (Figure 5).

Geometry intersects all: After creating the shadow polygon on the analysis plane, this node gets the intersected or overlaps of the shaded polygons. Detect these areas from the total shading area to get the SF (Figure 6).

Element set parameter by name: A family element created in Revit geometry with a specific parameter that can be modified during the process. A number slider assigns that element's parameter name and input values. For example, in this research, assign the different depths of the fins (Figure 7).



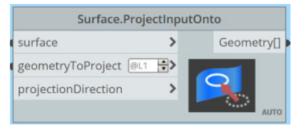
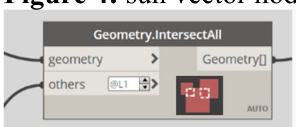


Figure 4: sun vector node

Figure 5: Surface project input onto node



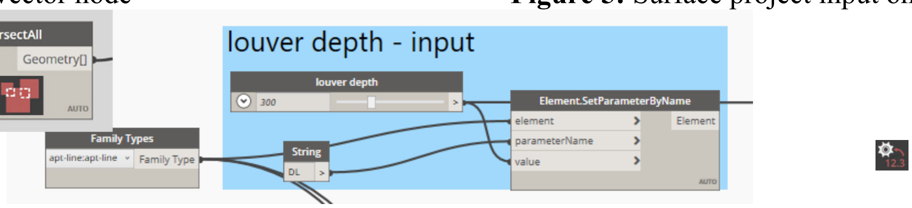


Figure 6: Node for geometry intersects all

Figure 7: Set elements by parameter node

P & C method:

A polygon and clipping method is a general intersection calculation method for two or more polygons proposed by A Murta et al. (2015), as in Figure 8. For a panel size of 4m x 2m as the analysis plane (Ap). The Dynamo nodes calculate the shaded area. The "sun vector" (Sv) node draws a line from the sun location to the analysis plane (Ap) for a given hour. The "surface projection input onto" node projects the polygon by the Sv on the Ap, which is the shaded area (Sa). The "geometry intersects all" node finds if these polygons intersect and calculate the overlapped shaded area (Oa). The calculation method subtracts the overlapped area from the total shaded area. Finally, calculate the Shading percentage as per Equation 1 below.

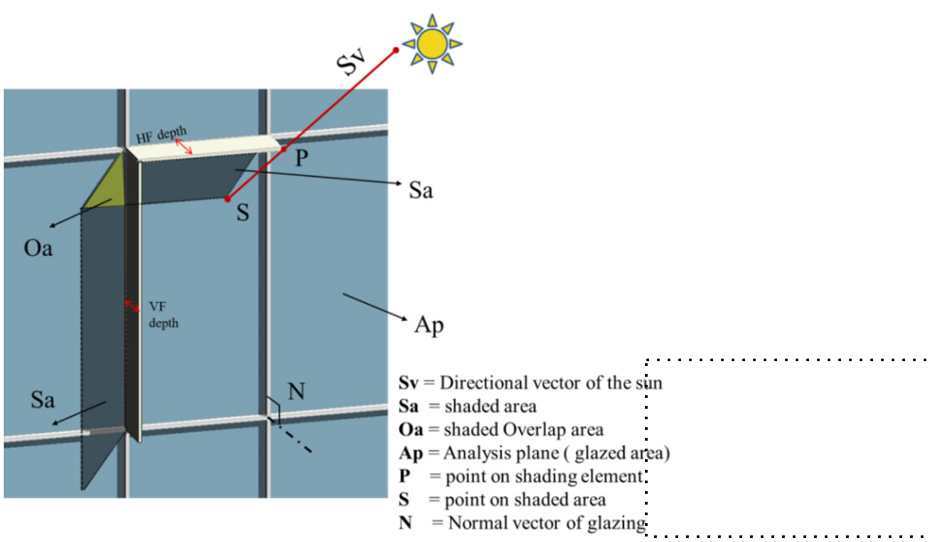


Figure 8: Shading calculation by Projection and Clipping Methods

$$SF\,\% = \frac{\text{(shaded area (Sa) – shadow overlap area(Oa)}}{\text{Area of the analysis plane (Ap)}} \times 100 \qquad (1)$$

Where SF = shading faction or percentage of shading for a given analysis hour.

E-Quest: E-quest is easy and quick energy simulation software. It gives heat characteristics for every hour, applicable for building envelope dynamic heat transfer. Derived from DOE-2, it is a graphically reporting energy model with a simulation "engine," used as both a schematic and detailed creation wizard. E-Quest is a sophisticated yet easy-to-use building energy analysis tool that provides professional-level results with minimal effort (Ying Han 2016).

EEM: Energy efficiency measures are sub-simulation runs of a base case model's elements. It is a valuable and essential tool to improve energy efficiency by changing the building envelope components, internal loads, HVAC equipment, or other mechanical systems. In this research, EEM simulation runs in building envelope components by adding window shades to the base case model.

SCL: The energy removed at the cooling coil is the space cooling load (SCL). In E-Quest, the SCL is given every hour and annually in kWh. For a fully glazed multi-storied office building in Chennai's hot and humid climate, the SCL is more than 1/3 (37%) of the total energy.
EUI: The energy use intensity is the total energy used for the building, including SCL, office lighting, office equipment energy use, mechanical ventilation, elevators, corridor lights, pumps, and other mechanic building services. The EUI is the total electricity use per year divided by the built-up area, given as kWh/m2/year.

PHGE: Peak heat gain from the building envelope allows designers to work with various materials and varying window-wall ratios. At the same time, limiting heat gain from the façade is crucial for a holistic green building design. The total sensible heat gain is divided by the façade + roof area to calculate the building envelope peak heat gain factor in W/m2 per the Griha V15 manual (2015). In this research, only the glass and glazing frame sensible heat is divided by the façade area to get the peak heat gain by glazing (PHGG).

Base Case Energy Model
From the previous research findings by Chandrasekaran (2020), the building façade needs a shading device for the Chennai location when the glazing area of more than 25% of the usable office floor area. Hence in this research, the base case model with more than 25% of the office's glazing area in E-Quest is created. The base case model of rectangular office building blocks size 30m x 45m, with a longer side oriented to east/west and 60 meters in height. Create a building with 15 floors with a floor-to-floor height of 4 meters. The total built-up area is 18,000 m2, of which the total fully air-conditioned office area is 15,000m2. Each typical floor of 1200 m2 with 1000m2 is an office area, and the model is a floor multiplier mode for the mid-floor (between the ground and top floors). Each floor with four zones in each orientation, and the core area is a non-air-conditioned space in the center, as in figure 9.

From case studies by Chandrasekaran (2020) and default data the following are the assumptions of the energy analysis in E-Quest:

Climate & location	: Chennai & as per weather data*.EPW file.
Project north	: True North
Office space planning / activity zones	: 50% Open office plan, 25 % cubicles, 10% corridors, 5% lobby and 10%utilities.
Floor to floor height	: 4 meters
Floor to false ceiling height	: 3 meters
Zoning pattern	: perimeter and core
A/C Zones	: office area 80% as air-conditioned and 20% core area as non-air-conditioned.
Occupancy rate	: 12.5 persons per m^2
Occupancy hours	: 9 am to 6 pm & 6 days a week.

Walls	: 150mm AA block with no insulation.
Glazing	: single reflective clear glass 6mm thick in an aluminium framework
Glazing no 1408 as per DOE glass library with SHGC	: 0.39
WWR %	: 95 % in all orientation.
Window size	: 2m x 4m.
Lighting load	: 1 watt / m^2
Power load	: 2 watts/m^2
Cooling set point	: 23.3 ° C
HAVC Type	: VAV with a chilled water system per floor.
Supply air temperature	: 12 ° C
Relative Humidity (RH)	: 50 %
Latent Heat gain per person	: 58 W
Sensible heat gain per person	: 73W

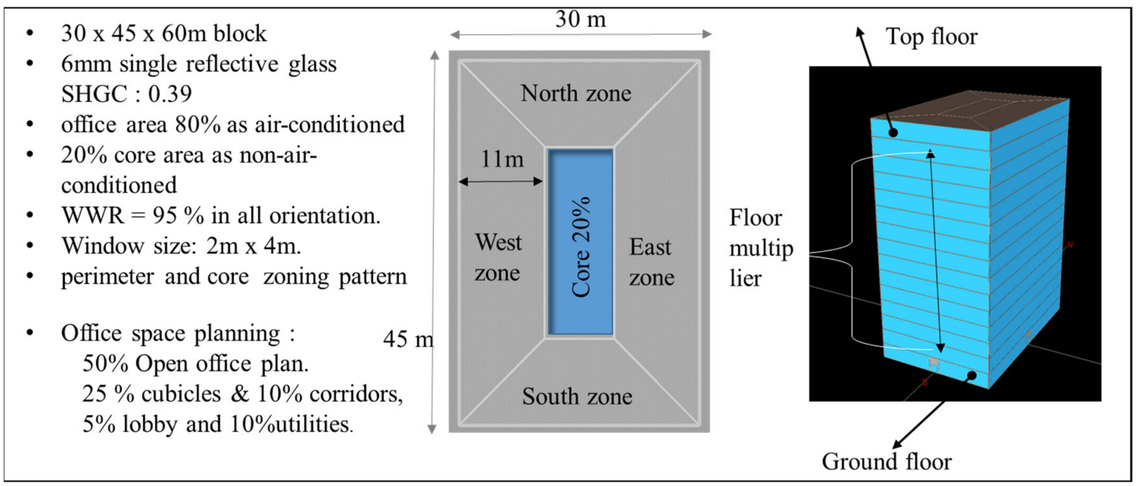


Figure 9: Base case model in E-Quest

The base case model is created as a detail design wizard to get the SCL and EUI hourly results. The simulated result for each hour of the day, a total of 8760 hours, with EUI of 196 kWh/m2 and SCL of 75kWh/ m2.

METHODOLOGY

The base case model for simulation is a typical fully glazed multi-storeyed office building in the Chennai location. To find the energy-saving by an SF range, we first create a geometry in Revit as a family with parameters that can be revised by simple inputs, like the depth of the fins and dynamo nodes, to calculate the shaded area. Then, for each analysis hour, we added similar window fins in each orientation for the base case energy model and energy simulation in the E-Quest EEM sub-runs (fig 10). The SCL and EUI results for an SF range are compiled from 24 runs (6 hours X 4 days) and then compared with the base case data without shades for the same 24 analysis hours.

Hourly Energy-Saving By Shading Device for the Five SF Ranges

With one horizontal fin (HF) and one vertical fin (VF) for six analysis hours a day for four seasonal days (Figure 10), the hourly energy saving by SF on the façade by adding different depths of fins. Create the geometry of HF and VF in Revit as a family element for a sample panel of 4m x 2m on a glazed plane (Ap) with fin type as per the window shades input in E-Quest. Dynamo Calculate the shaded area with the polygon clipping method based on the sun vector (Sv) for the given hour, day, orientation, and location for the given depth of the fins (Figure 11). The HF and VF fin depths for the given hour, day, orientation, and location are tabulated for an SF range. For east orientation at 10 am & 11 am, for the west at 1 pm to 4 pm, and all 6 hours for the south (3 analysis days except summer solstice) and north (one day at summer solstice). For example, in Table 1 for an SF 80 for the fins depth for each analysis hour, day, and orientation for the Chennai location. As in E-Quest, we can have only one fin perpendicular to the glazed plane. The solar heat transfer through the device and the thermal properties of the device are not considered in this research.

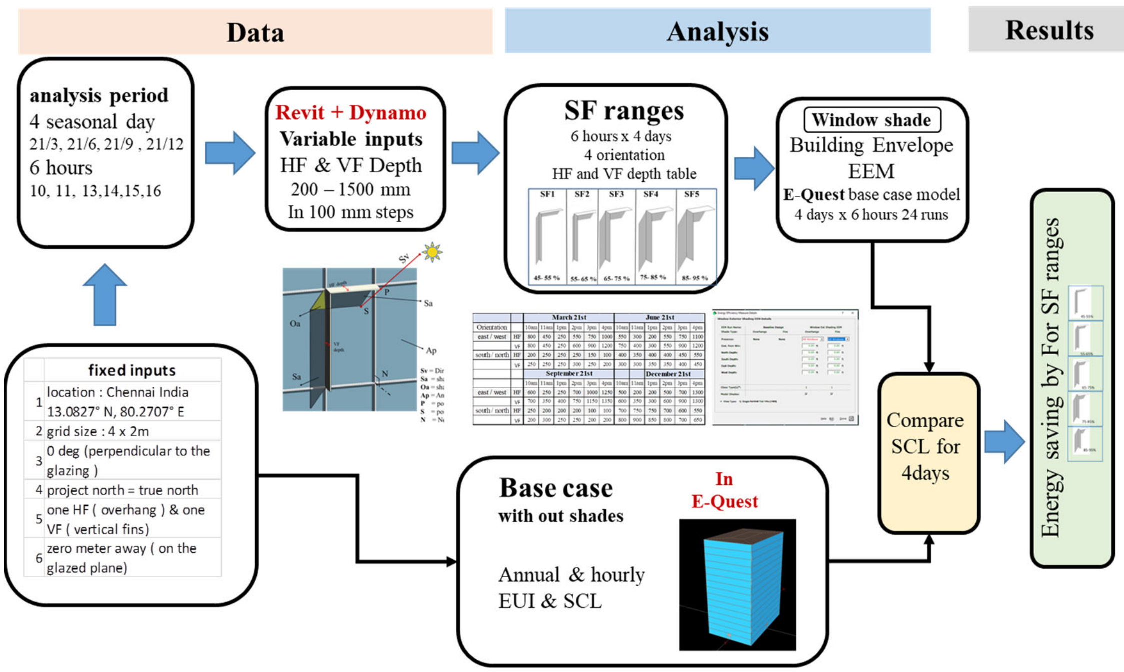


Figure 10: Methodology flow chart

Table 1: HF and VF depth for SF80 (75- 85%) shading ranges on the four seasonal days.

orientation	Fin Depth in mm	21 st March						21 st June					
		10 am	11 am	1pm	2pm	3pm	4pm	10 am	11 am	1pm	2pm	3pm	4pm
east - west	H	900	450	200	600	900	1050	600	350	200	650	900	1200
east - west	V	900	500	300	700	1050	1300	850	450	300	650	1050	1350
south /north	H	250	250	250	250	200	150	400	500	450	475	550	700
south /north	V	250	350	350	350	250	200	375	450	400	450	500	550
		21 st September						21 st December					
east - west	H	700	250	250	700	1200	100	550	250	200	550	850	1500
east - west	V	800	400	400	850	1300	100	700	350	350	700	950	1500
south	H	200	200	250	200	150	100	800	900	850	750	600	650
south	V	300	350	300	200	200	200	950	1000	1000	850	750	750

Table 2: % SCL and EUI energy saving compared to base case model for four seasonal days and total average.

Percentage of energy-saving by SF ranges										
SF RANGE	21-Mar		21-Jun		21-Sep		21-Dec		TOTAL Average	
	SCL	EUI	SCL	EUI	SCL	EUI	SCL	EUI	SCL	EUI

SF 50	4.1	1.5	4.8	1.9	2.4	0.8	2.0	0.6	3.3	1.2
SF 60	5.1	1.9	9.9	3.9	4.8	1.0	3.0	0.9	5.7	1.9
SF 70	6.9	2.6	15.5	6.0	7.8	1.7	3.9	1.2	8.5	2.9
SF 80	9.9	3.6	19.9	7.7	11.0	2.7	6.1	1.8	11.7	4.0
SF 90	12.9	4.8	24.0	9.7	15.8	4.0	8.2	2.4	15.2	5.2

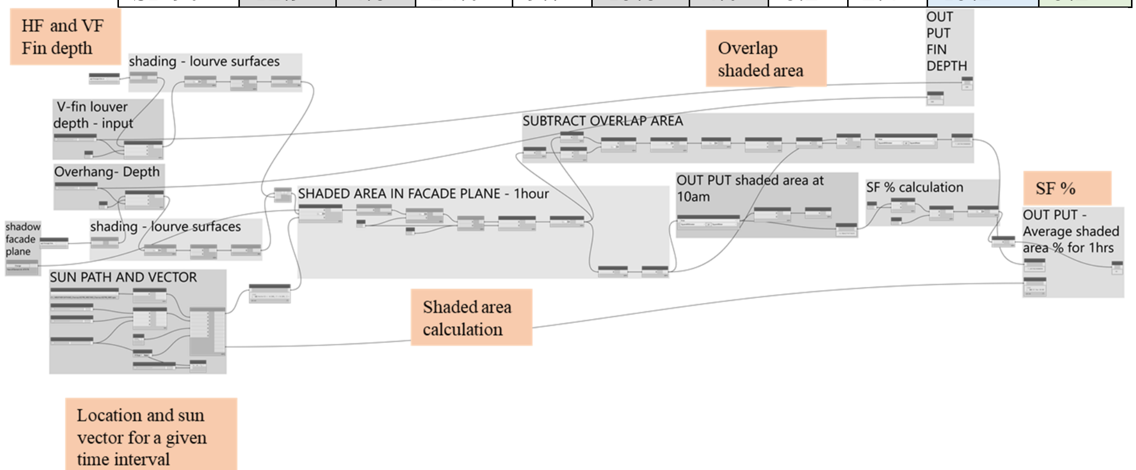


Figure 1: Dynamo script for shaded area calculation

RESULTS

The SF ranges' energy saving percentage better than the base case for the four days and total average as in Table 2 and Chart 2. The percentage saving for each of the four days compiled for all the five ranges as in Chart 3.The Chart 4 shows is the hourly SCL saving results for SF 50 , were at 10 am and 3 pm is peak saving hours for all four days. The peak hour saving results are similar for all the ranges.

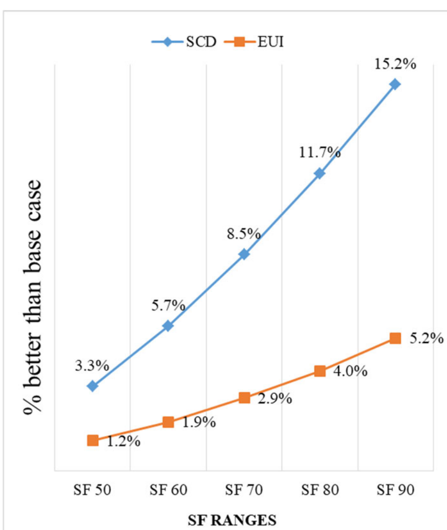


Chart 2: SF range and total average energy better than the base case.

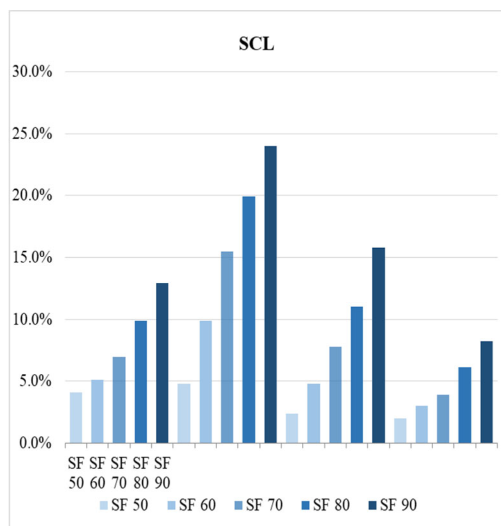
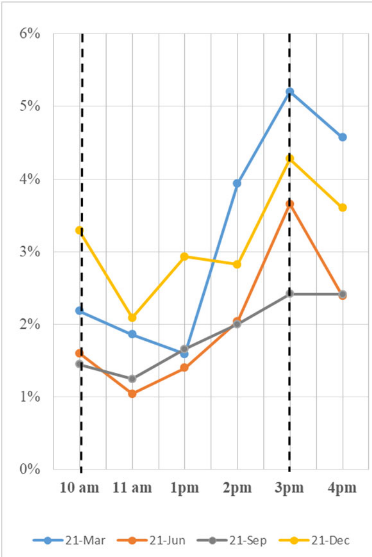


Chart 3: SF range and four days SCL energy-saving saving better than the base case for four days



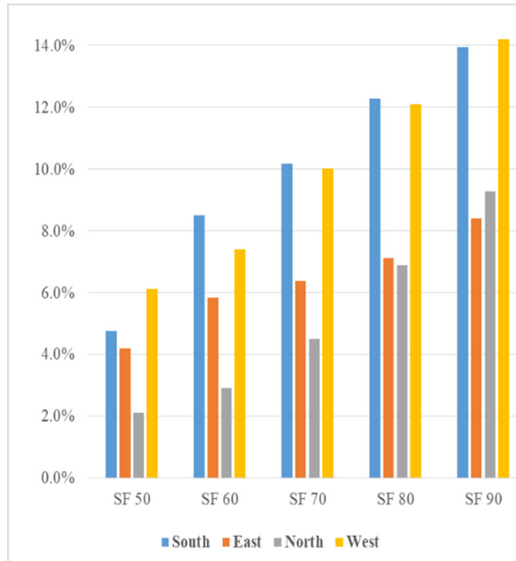


Chart 4: Hourly % SCL saving in kWh all for SF 50 on four seasonal days.

Chart 5: percentage of PFGG better than the base case for for all four orientation and SF ranges.

PEGG

The Peak heat gains factor is the sum of glazing & glazing frame sensible heat divided by the glazing area in each orientation in W/m^2. For PEGG, the data for each orientation or energy zones from E-Quest. They are used to derive the reduction in peak heat load by the shading device on each orientation of the glazed façade. Compare for each orientation the hour and day of the peat heat gain for the base case model with the closest hour and day of the simulated EEM runs as in table3. For each range, the percentage is better than the base case for each orientation, as in chart 5.

Table 3: PHGG for all orientation zones of the base case and equivalent EEM runs with shades

orientation	Base case peak cooling load - hour and day	Base case PHGG in W/m2	Equivalent EEM run	PHGG with shades in W/m2 for SF ranges				
				SF50	SF60	SF70	SF80	SF90
South	27 /01 - 2 pm	143.6	21 /12 - 2 pm	136.8	131.4	129.0	126.0	123.6
East	19/ 03 - 11 am	148.7	21 /03 - 11 am	142.5	141	139.4	138.1	136.2
North	28/05 - 5 pm	125.7	21/06 - 4 pm	121.8	122.0	120.0	117.0	114.0
West	June 1st - 5 pm	143.4	21/06 - 4 pm	134.6	132.7	129.0	126.0	123.0

Observations

From Tables 2 & 3, charts 2, 3, 4 & 5.

More shading faction gives better energy saving. SF 50 SCL saving of 3.3 % to SF90 of 15.2%
The energy-saving for EUI is lower than the SCL, from 1.2% to 5.2 % for SF 50 to SF 90, as the SCL is only 30-40% of the total energy use.
The maximum % SCL energy saving on June 21st (summer) is 24% for SF90, and the minimum on December 21st (winter) is 2% for SF50.
SCL % saving is more on the summer solstice and low on the winter solstice, and the average for the spring and fall equinox from chart 2.
As in Chart 4, the peak hour for energy-saving is at 10 am, and 3 pm for SF50 as the sun angles are shallow at these hours and with more fin depths for an SF range.
The PHGG, as per the orientation, SF range by shading in the west and south has maximum impact with 14% lower than the same orientation zones of the base case.
For the PHGG in the east and north zones, the impact is low at < 8%, as north exposure to sun direction for only three summer months and east for only two analysis hours.

DISCUSSION

Shading improves the space cooling energy efficiency for a hot and humid climate like Chennai. Calculating the shaded area is vital in reducing the direct solar rays as it influences the façade heat load for space cooling. The analysis period is only four days and not annual hence it might be imprecise. In E-Quest, the fin depth input for a window size of 4 x 2 m, with only one fin, HF spacing of 4m, and VF spacing of 2 m is not equal, and no angles are the limitation as software for shading device design. The effect of shading on daylighting, views, solar radiation through the device, or the thermal properties of the shading material is not considered in the research. The shading device only controls the direct solar radiation and not the diffused. For a hot and humid climate like Chennai, the diffused radiation is more than 45% in the peak season (Bhattacharya et al. 1996).

This method of calculating the SF range can be used as a significant criterion to evaluate the performance in the early design phase for complex fixed or kinetic shading devices. As a sustainable approach to the design of the building's form, orientation, façade plane, and glazing, the SF of the shading device is applied to achieve net-zero energy. Moreover, in the future, as the shading device interacts with direct solar rays, it will be used to generate energy.

The advancement in glazing technology, such as electro-chromic double glazing, can change the glass tint intensity as per the exterior solar intensity and would require no shading device for fully glazed buildings in the future.

CONCLUSION

Up to 15% energy-saving by the shading device SF for a fully glazed façade multi-storied office building in a hot and humid climate like that of Chennai. The developed method suggests an alternative approach to designing and evaluating a shading device by the geometry's shadow at the early design stage.

With advancements in simulation methods, it would be possible to design and evaluate very complex shading devices based on the SF in a single package. The shading device can reduce the direct solar rays; however, this climate with more hours of a cloudy sky with more % of diffused radiation requires alternative methods to reduce exterior cooling load. Besides, future experimental studies with real-time environmental conditions to determine the shading behavior when subjected to exploring new materials and techniques.

Nomenclature

API : Application Programming Interface
BIM : Building information model
DOE-2 : USA Department of energy - software for energy use.
ECBC 17 : Energy Conservation building code version 2017
EEM : Energy-efficient measures in E-Quest.
EUI : Energy use intensity in kWh/m^2
HVAC : Heating ventilation and cooling
P & C method : Polygon projection and clipping method
PAGE : Peak heat gain by envelope
PEGG : peak heat gain by façade glazing.
PV : Photo Voltaic panels.
SCL : Space cooling load in kWh/m^2
SF : Shading Fraction of the shaded area
SHGC : Solar heat gain coefficient.
WWR : window to wall ratio

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SPATIAL ORGANISATION OF COOKING PLACES IN VERNACULAR HOUSES OF KATHMANDU AND MANGALORE

Shaila Bantanur [1], Prachand Man Pradhan[2]

[1]Director, BMS School of Architecture, Yelahanka, Bengaluru, India, shailabunty@gmail.com
[2]AssociateProfessor, Department of Civil Engineering, Kathmandu University, Nepal, prachand@ku.edu.np & Dean, School of Engineering, Manmohan Technical University, Nepal, prachand.pradhan@mtu.edu.np

ABSTRACT

Vernacular houses are constructed based on local needs, construction materials and local climate. They reflect the culture and local tradition of the place. The paper is the result of analysis of cooking places in rural houses of India and Nepal. Two houses from Mudar, three houses from Mala from India and seven houses from Kushadevi and Malpi from Nepal are considered for the study. The data is collected with respect to spatial spaces of kitchen including carpet areas, opening details, cooking fuel used and day lighting illumination. Topography of land resulted into go for more vertical in case of Nepal as compared to Indian villages. Opening sizes are optimal and volume of the rooms is comparatively low to reduce heating loads in Nepal. Firewood is still a major source of cooking fuel in both the countries. Day lighting Illumination level in maximum houses is low resulting into low visibility.

Key Words: Traditional cooking Place, Day lighting, housing typology, cooking fuels

INTRODUCTION

Vernacular houses are excellent demonstration of passive architecture. They use locally available material, craftsmanship, rich tradition, construction techniques suitable for local climate thus they follow bio climatic strategies and low-cost housing techniques etc. Agriculture is the major occupation in rural villages and people spend most of the time on the fields. Rural vernacular houses are studied on the basis of day lighting, Study focusing on daylight highlights, optimization methods of day lighting using lighting simulations (Haqparast and Maleki, 2014) , Climate responsive strategies of Iranian houses were analyzed with application of the building elements and solutions to bring daylight into different parts of traditional courtyard houses and it is concluded that adopting traditional strategies will even enhance the quality of modern houses as well (Nabavi, Ahmad and Goh, 2013).A study focused on lighting performance in courtyards of vernacular architecture in Mediterranean region identified that courtyard had influenced positively to semi open and indoor spaces (A. Michael et.al., 2017). Day lighting analysis of vernacular houses of Guizhou Province, China identified folk customs, topography and other factors which influence on architectural day lighting (Xuan, 2013).

Vernacular housing designs were analyzed as a part of building physics and identified that under extreme climatic conditions the measures may not be sufficient (Nguyen et al., 2011) . Energy performance in ancient vernacular houses were analyzed and made an effort to make an extensive data base which included energy performance of traditional building techniques, which also address cost, material availability and cultural traditions (Zhai and Previtali, 2010). A case study approach was adopted to understand sustainable design principles of a vernacular dwelling in Thanjavur, India. The paper reviews examples of vernacular architecture and its building element in Kavrepalanchowk, Nepal and being analyzed in qualitative manner to understand the application of bioclimatic design strategies (Bodach, Lang and Hamhaber, 2014) . A study conducted in Suggenahalli village of India to understand the thermal comfort in naturally ventilated vernacular dwellings using Fanger's Predicted Mean Vote (PMV) and Humphrey's adaptive thermal comfort and proposes aggregated PMV model (Shastry, Mani, and Tenorio, 2016) .Qualitative analysis of passive environmental control of vernacular Kerala Houses were analyzed and study provides a positive results showing thermal comforts maintained for all seasons ((Dili, Naseer and Varghese, 2010) . A study is conducted in vernacular houses of Coastal regions of India and analyzed qualitatively and quantitatively and houses proved to be best for thermal indoor climate irrespective of outdoor climatic conditions ((Shanthi Priya et al., 2012). Solar passive techniques in vernacular houses (n =150) of northeast part of India has been analyzed by considering temperature, humidity, illumination levels and building design parameters. The study provided range of comfort temperature for different seasons. The study also identifies housing performance during winters was comparatively low (Singh et al., 2010).

A study focused on use of alternative cooking fuels for vernacular houses emphasized more on implementing available administrative policies to improve the cooking sector (Bisu, Kuhe and Iortyer, 2016). A study conducted in rural part of Buladana District, Maharastra about present and future cooking fuel patterns and found that, maximum household prefers firewood as a major cooking fuel (Deshmukh et.al., 2014). Cost benefit analysis conducted on seven alternative cooking fuels in rural Indian households and results shows that biomass was most preferred fuel amongst all (Patel et al. 2016). Rural floodplain areas of Bangladesh shows that 42% of the people use only biomass and 53% used kerosene along with biomass fuels (Md. Danesh Miah et.al., 2009). The present paper is an effort to analyze the rural houses of countries from India and Nepal with respect to housing typology, passive strategies, day lighting and use of alternative cooking fuels.

METHODS

Study Area

The Study was conducted in rural houses of few villages of Karnataka and Kavrepalanchowk of India and Nepal respectively. The objective of the study was to analyze the typology of the cooking places in both the countries. Two houses from Mudar, three houses from Karkala district Mangalore, India (Fig.1) and seven houses in each from Kushadevi and Malpi of Kabhrepalanchok District in the Bagmati Zone of central Nepal (Fig.2) were selected for the study. Indian Villages were visited in January 2016 and Villages of Nepal were visited in the month of March 2016. Climate of both the Indian villages are similar and similarly of the Nepalese villages. Brief profiles of villages of both the countries are as shown in Table.1 below.

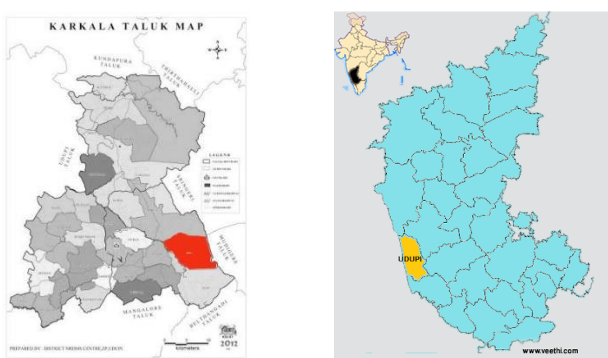

Fig:1. Location of Mala and Mudar Villages in India
Source: mapsofindia.com

Fig.2: Location of Kushadevi and Malpi Village in Nepal
Source: https://en.wikipedia.org/wiki/Kushadevi

Table.1: Brief Profile of the villages

Name	Samples (Nos)	Max. Floors	Head Quarter	Climatic Zone	Altitude (M)	Latitude /Longitude	Population	Households (Nos)	Temp.	Rain fall (mm)
Mala	2	1	Karkala	Tropical	80.79	13.2151/74.996	5998 (2011)	1338	24ºC to 38ºC	4372.70
Mudar	3	1					6088(2011)	1356		
Kushadevi	7	3	Kabhrepalanchok	Sub Tropical	1495	27.58/85.46	6268(1991)	1201	-1ºC to 33ºC	1300
Malpi	7	3					3033(1991)	571		

DATA COLLECTED

The data is collected with regard to room dimensions, opening details, roofing patterns, material used and quality of the light inside the room, spatial organization, openings details, quality of day lighting etc. Data related to use of cooking fuel, time spent in the kitchen areas etc. were surveyed and recorded for further analysis. Carpet areas and opening details were calculated and windows to floor area ratios are being calculated to analyze the efficiency of existing windows. Day lighting has been monitored at certain intervals with the help of Luxmeter and spot specific minimum and maximum is recorded to observe the inside illumination level.

DISCUSSIONS

The typology of rural houses differs from region to region. Local climatic conditions, availability of material, topography, and culture influences the typology to the greater extent. Houses studied in both the countries were different from each other and follow few of the principles required for the place. Houses of Mala and Mudar villages were having only ground floor whereas houses in Kushadevi and Malpi villages have maximum of three floors. Kushdevi and Malpi villages situated on the hilly terrain and were difficult to get more horizontal plain areas due to which the houses were more vertical than the horizontal. Mala and Mudar village situated on the Coastal region of Karnataka, and they face maximum rainfall due to which maximum houses have sloping Mangalore tiled roof. Maximum heights of the Indian houses are 9’0” whereas houses of Kavrepalanchowk varies from 5’8” to 6’7”. Reducing the height made the total volume of the space minimal which helps in not only reducing the material usage but also it reduces heating load of the spaces in extreme winters. Opening sizes are optimal in all the houses to reduce the material cost.

Maximum people spend their early morning and late evening at their houses. Kitchen and living places are more active areas as compared to others. Indian villages have separate cooking place whereas kitchen of maximum houses in Kavrepalanchowk have shared with common spaces (Fig.3). Cooking place helps to heat other common spaces simultaneously, and in most of the house's biomass was used as s major cooking fuel.

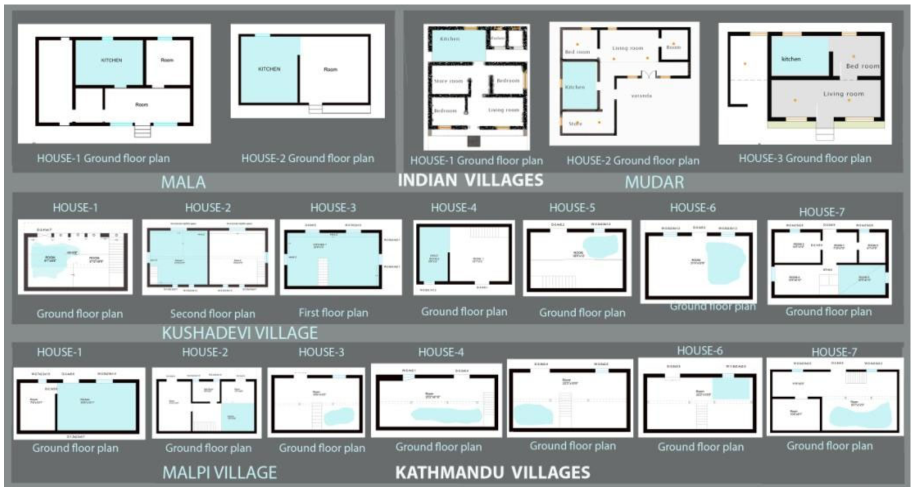

Fig.3: Location of Kitchen in houses of Indian and Kathmandu Villages.

Table.2: Type of fuel used in India & Kathmandu houses

Country	**Name of the Village**	**House**	**Carpet Areas (Sq ft)**	**Window Areas (Sq Ft)**	**Window to Floor Area Ratio (Wr/Fr)**	**Height (ft)**	**Door sizes**	**Location**	**Cooking fuel used**
India	**Mudar**	**House - 1**	76.7	12	16%	9'0"	2.6x6.0	Ground Floor	LPG
		House - 2	56	5.44	10%	9'0"	2.72x6.0	Ground Floor	Fire wood
	Mala	**House - 1**	86.01	6.16	7%	9'0"	2.6x5.9	Ground Floor	Fire wood
		House - 2	81.9	9.28	11%	9'0"	2.75x5.9	Ground Floor	Fire wood
		House - 3	43.26	5.24	12%	9'0"	2.75x5.9	Ground Floor	Fire wood
Katmandu	**Kushadevi**	**House - 1**	No separate kitchen , Merged into living space			5'9"	4.4x3.6	Ground Floor	Fire wood + LPG
		House - 2	113.36	29.7	20%	6'7"	2.6x3.4	Second Floor/ Top Floor	Bio Gas +LPG+ Fire Wood
		House - 3	No separate kitchen , Merged into living space			6'6"		First Floor/ Top Floor	Bio Gas +LPG+

									Fire Wood
		House - 4	87.75	5.46	6%	5'8"	6.0x5.1	Shifted from Top Floor to Ground Floor due to Earthquake	Fire Wood +LPG
		House - 5	No separate kitchen , Merged into living space			6'1"	3.4x5.2	Shifted from Top Floor to Ground Floor due to Earthquake	LPG+ Fire Wood
		House - 6	No separate kitchen , Merged into living space			6'1"	3.2x5.3	Ground Floor (only one floor)	LPG+ Fire Wood
		House - 7	129.99	8	6%	6'9"	3.2x5.9	Ground Floor	LPG
	Malpi	**House - 1**	No separate kitchen , Merged into living space			6'4"	3.4x5.6	Ground Floor	LPG+ Fire wood
		House - 2	161.5	0	0	6'4"	2.5x5.3	Ground Floor	LPG+ Fire wood
		House - 3	No separate kitchen , Merged into living space			6'7"	3.0x5.2	Ground Floor	LPG+ Fire wood
		House - 4	No separate kitchen , Merged into living space			6'3"	3.2x5.4	Ground Floor	LPG+ Fire wood
		House - 5	No separate kitchen , Merged into living space			6'4"	3.8x5.4	Ground Floor	LPG+ Fire wood
		House - 6	No separate kitchen , Merged into living space			6'2"	3.0x5.5	Ground Floor	LPG+ Fire wood
		House - 7	No separate kitchen , Merged into living space			6'0"	3.3x5.0	Ground Floor	LPG+ Fire wood

The results show that biomass fuel is still used as the main cooking fuel in both the countries. There was a shortage of supply of LPG during Post Earthquake in Nepal which made the people to depend on multiple cooking fuels. Other alternatives fuels were biomass fuel and biogas plant. Maximum houses have installed biogas plant which uses human waste to produce the cooking gas. Villages in India are still using biomass as a cooking fuel, which produces the smoke and made the cooking areas darker.

The study further extended to monitor illumination levels inside the cooking areas. Measurements are taken at certain grids and minimum and maximum illumination level inside the cooking area is monitored and the readings are as shown in Fig. 3. Out of twenty houses more than 73% of the houses have very less illumination level that ranges from 0-10 lux, 33% of houses have lux level ranging from 10-20 and 7% of the houses have illumination level ranging from 20-30, 30-40 and 60-70.

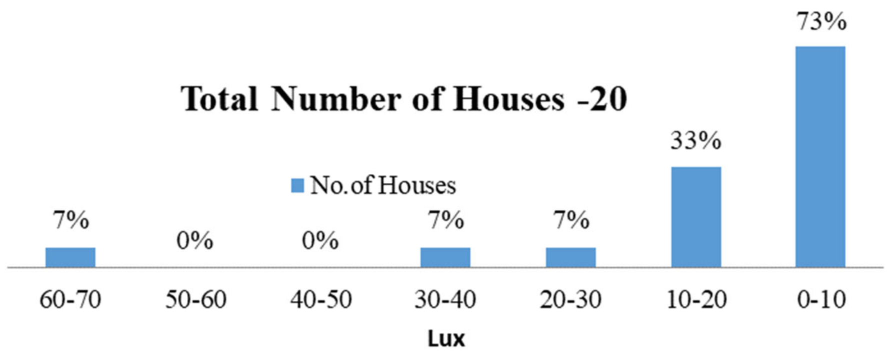

Fig.3: Illumination level inside the cooking places

CONCLUSION

The present study is analyzed the cooking places of rural villages with respect to spatial organization including carpet areas and opening details, day lighting illumination along with cooking fuel used. Data is collected from twenty houses from two villages from India and Kavrepalanchowk region. Housing typology differs from Indian villages to that of Nepal. Maximum houses in Indian villages spread horizontally whereas Kathmandu villages are seen more vertical. Maximum floors in villages of Kavrepalanchowk are two to three floors whereas Indian villages have only ground floors. Opening sizes are optimal in all the houses and heights of the rooms are comparatively low in Kathmandu houses to reduce the heating loads. Firewood is used as one of the major cooking fuels in both the countries. Other alternatives like biomass and biogas are also used along with LPG. Illumination level is low in maximum houses.

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IMPACT OF THE HEIGHT OF ROOF SHADING ON BUILDING ENERGY PERFORMANCE IN INDIA

Kuladeep Kumar Sadevi[1], Avlokita Agrawal[2]

[1] Research Scholar, Indian Institute of Technology Roorkee, Roorkee, India, skumar@ar.iitr.ac.in
[2] Associate Professor, Indian Institute of Technology Roorkee, Roorkee, India, avlokita@ar.iitr.ac.in

ABSTRACT

The Roof is the building's external surface that receives the highest solar irradiation compared to other external envelope surfaces. Roof shading has been identified as an effective passive strategy to cut down heat ingress and reduce building cooling loads in tropical climates. This study intends to verify the impact of the height at which the shading layer is provided above the structural Roof on the building's cooling load and thus energy consumption. A reference office building for the Warm-Humid climatic place of India is identified as the base case for this study, and the building is simulated using the whole building energy simulation software 'DesignBuilder'.. A total of 160 simulations are conducted by varying the roof U-Value between 0.2 W/m^{2}K and 4 W/m^{2}K and the height of the roof shading in the range of 0.5m to 8m at an interval of 0.5m. The results confirm that the height of roof shading is an important element to consider in passive envelope designs. The energy consumption of the building increases with the height of the roof, regardless of the roof insulation level. However, the impact is significant on an uninsulated roof and the impact reduces when the insulation level is increased. Furthermore, the impact of roof shading height is influenced by other factors, which may have a varied impact at different roof shading heights. This study offers the framework for recognising the importance of roof projections on appropriate orientations to optimise shading.

Keywords: Roof Shading, Passive Cooling, Energy Efficiency in Buildings, Roof Heat Gain, Building Energy Codes.

INTRODUCTION

The Roof receives the maximum solar insolation in tropical buildings compared to the other envelope surfaces. The primary step involved in designing energy-efficient buildings and nearly zero-energy buildings is to reduce the energy demand through passive means (Omar *et al.*, 2017)(Roslan *et al.*, 2016). Several passive design strategies have been identified to reduce the heat gain through the Roof. However, literature review studies on passive roof strategies roof shading through double roofs are found to have the least number of studies (Abuseif and Gou, 2018). Also referred to as Parasol roofs, the double Roof is a common strategy in traditional tropical buildings. Roof shade through the second roof layer with ventilated air gap helps cut down the solar radiation received on the roof surface. Further, the accumulated heat is eliminated through convection by the air movement between the roof layers. Such designs are efficient, especially in the warm and humid climatic zones (Haase and Amato, 2008)(Halawa *et al.*, 2018).

In India, architects have explored roof shading as a passive cooling strategy over the years. The High Court Building at Chandigarh, India, conceived by the famed architect Le Corbusier includes a double roof providing the benefits of shading and convection heat dissipation through the air movement between the roofs. Another example of such a strategy by architect le Corbusier is Villa Shodhan (1951-1956) at Ahmedabad in India (Sendai, 2005). Some of the recent examples in India, as shown in Figure 1 include the MoEF building in New Delhi, The V-IT Park at Hyderabad, ITM School of Business at Gwalior, and TCS IT Park Office buildings at Chennai.

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Figure 1: (a) MoEF building in New Delhi (Source: www.nzeb.in) , (b) The V-IT Park at Hyderabad (source: https://www.thehansindia.com) , (c) ITM School of Business at Gwalior (Source: http://itmuniversity.ac.in), and (d) TCS IT Park Office buildings at Chennai (mgsarchitecture.in)

ROOF SHADING – A PASSIVE ENVELOPE DESIGN FEATURE

A survey-based study (Sadevi and Agrawal, 2019b) on different envelope design features for energy efficiency in India indicates that the roof shading (parasol roofs/ pergola) is the most considered design feature at the early design stages.

The double-skin envelopes are gaining popularity as a passive cooling method (Biwole, Woloszyn and Pompeo, 2008; Kharrufa and Adil, 2012; Omar *et al.*, 2017; Abuseif and Gou, 2018). A secondary roof layer is provided above the primary Roof with a ventilated air gap in between, offering an increased thermal resistance (Zingre, Wan and Yang, 2015; Zingre, Yang and Wan, 2017a). The secondary roof shields the primary roof from the incident solar radiation. Heat transfer between the secondary and primary roofs is impeded by the air gap. Air can move in and out of the open-ended air gap, which aids in the convection heat transfer process. Despite the air's comparatively modest thermal conductivity (0.025 W/m-K), the air gap's equivalent insulation contributes significantly and occasionally even entirely to the total thermal efficiency of double-skin roofs (DSR). For open-ended DSR, the amount of equivalent insulation offered by the air gap changes according on the external environment conditions (e.g., wind speed, the temperature of the surrounding atmosphere, etc.). Earlier studies(Sadevi and Agrawal, 2019b, 2019a, 2020) indicate that the provision of roof shading and roof insulation together provides negative performance of the Roof, even though both the measures have a positive impact individually. However, the study did not consider the variation of the shading height on the thermal performance of the roof assembly.

The envelope heat gain calculations prescribed in the ASHRAE Handbook of Fundamentals (ASHRAE, 2021) indicate that the heat gain through an envelope component depends on the sol-air temperature. The sol-air temperature depends upon the properties of the Roof and the weather conditions, such as dry-bulb temperature and incident solar radiation. Thus the shading elements have a pronounced impact in modulating the diurnal sol-air temperatures.

NEED FOR THE STUDY

With the stringent targets to cut down the global carbon emissions, there is a need for every building to be built in the future to be highly energy-efficient and possibly a net-zero / nearly-zero energy building. In the process, the provision of solar PV has become inevitable to produce the energy to meet the building energy needs. The roof area is typically favourable for providing solar PV for optimum renewable energy generation. As discussed above and showcased in Figure 1a, the design of rooftop PV integrated with shading elements has become the primary approach to the new-zero energy buildings. Further, there is an additional benefit of designing buildings to integrate the rooftop PV into the roof shading structures to reap the benefits of shading, PV generation, and the terrace's functional usage over the roof area. While the building energy codes prescribe the provision of roof insulation as the mandatory criteria to comply with (Bureau of Energy Efficiency, 2017), the benefits of shading and its impact on the thermal performance of the Roof with and without the roof insulation need attention (Zingre, Yang and Wan, 2017b).

Height of roof shading as a parameter
While roof insulation is a direct and practical option for meeting the required roof U-Values, this study is based on the notion that roof shading has a positive influence by reducing incident solar radiation and thus minimising the need for additional roof insulation. The study on the impact of roof shading (Sadevi and Agrawal, 2020) confirms that energy consumption increases when shading and insulation are provided together compared to insulation alone. Hence, it is evident that the impact of shading height and insulation should not be examined in isolation.

Studies on double roofs indicate that the distance between the primary roof and the secondary shading roof impacts the thermal behavior of the roof assembly. However, the previous studies (Biwole, Woloszyn and Pompeo, 2008; Zingre, Yang and Wan, 2017a; Wang, Chen and Li, 2019) have been conducted with the gap height between the two layers of the Roof to be not more than 1 meter. However, considering the roof area's functional usage, the height of roof shading needs to be above the height of human activity. Even the provision of rooftop PV is being combined with the shade layer to avoid solar PV taking up too much space on the Roof. Hence, there is a clear requirement to comprehend the effect of shading height on the thermal performance of a building's Roof.

HYPOTHESIS AND OBJECTIVE

Research question and hypothesis
Since the impact of the shading is significantly dependent upon the height at which the shading layer is provided, this study inquires about the impact of shading height for various levels of insulation(Various U-Values of the Roof). This study hypothesizes that the height of roof shading can impact the energy consumption due to varying amounts of incident radiation over the Roof due to the varying sun position with time. Further, the impact of roof shade needs to be verified for the Roof with various levels of insulation (by varying U-Values)

The objective of the study
This study aims to understand the impact of the height of shading (over the Roof) on the building energy performance for various roof insulation levels for a warm and humid climatic place of India.

METHODOLOGY

A reference building as defined by a survey-based study by Bhatnagar et al (Bhatnagar, Mathur and Garg, 2019) is referred to as base case model to assess the impact of roof shading. A high-rise reference building with defined building level attributes as prescribed by Bhatnagar et al, such as building geometry, occupancy schedules, activity, and active cooling systems, is constructed to arrive at this base case building scenario. All the building parameters related to Envelope design, such as WWR, U-Value of the walls, and glazing properties, are considered as per prescribed threshold levels in ECBC code for Warm and Humid climatic conditions.

For the energy consumption analysis, the base building as per ECBC is simulated using 'DesignBuilder' software which uses EnergyPlus simulation Engine. 'DesignBuilder' is widely accepted Whole Building Performance software that has the capability to do an hourly analysis considering the weather conditions and sun position at each hour. Since the sun position and the seasonal variation in weather conditions vary all through the year, the total energy consumption of the building is considered as the objective variable (dependent variable) to assess the impact of the various combinations of the height of roof shading and insulation levels. The height of the Roof is varied from 0.5 m to 8.0 m at an interval of 0.5m measuring from the external surface of the primary Roof. The maximum height is considered 8m which is more than twice the typical floor height for practical use, in order to cover the complete range of height that has considerable impact based on sensitivity analysis. The various combinations of shading height and the U-Value of the Roof considered for the study are shown in Figure 3.

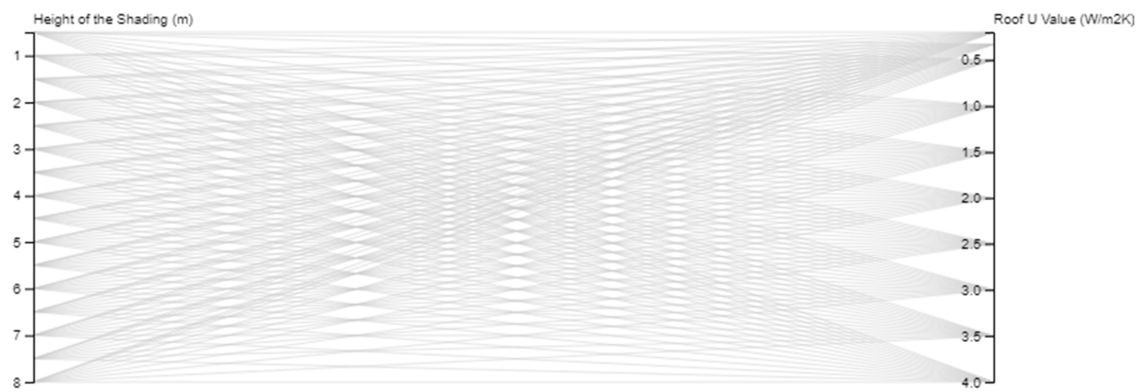

Figure 3: All the combinations between Roof shading height and Roof U-Value

The base building is modeled with a break-up of spaces into perimeter zones and core zones as specified in the reference building (Bhatnagar, Mathur and Garg, 2019). Because the height of the roof shade has a variable impact on the perimeter zones of different sides (North, East, South, and West) due to seasonal differences in sun-path, the cooling load of each perimeter zone is validated for all simulated situations. The findings are then analysed to see how varied shade heights affect different degrees of Roof U-Values.

Base Case Building Specifications:
A high rise typical office building model is established with a total floor area of 31,381 m^2, spreading over 9 floors above grade, with an aspect ratio of 2:3. Two basement floors are considered in this study and the conditioned area is provided only for the office areas excluding the service zones as shown in the Figure 4. Kolkata is considered as the representative city for warm and humid climatic zones (Bhatnagar, Mathur and Garg, 2019).

The parameters of the building considered as per ECBC prescriptions as follows:

- Window to Wall Ratio: Though the reference building consists of 30% WWR, maximum allowed WWR in ECBC ie, 40% is considered for the base case.
- Window Sizing: The windows are provided equally on all the four directions and in the form of a single horizontal band meeting the WWR.
- Exterior Wall Construction: Exterior wall construction having U-Value of 0.4 W/m^2K. is considered.

Roof Construction: The roof assembly is considered to be comprised of 'Roof tile + Extruded polystyrene (Thickness to be varied based on the desired U-Value of the roof in respective iteration being studied) + Concrete (200mm) + Cement Plaster (10 mm)' (Outer to inner surface).
Glazing is provided as per the ECBC specifications. Even though the reference building specifications are more stringent than the ECBC prescriptions, the ECBC prescribed values are considered for the window parameter.

- U-Value: The maximum prescribed U-Value of 3 W/m^2K is considered.
- SHGC: The maximum prescribed SHGC of 0.27 is considered for the base case building.
- VLT: The specified minimum value of 0.27 is considered for the VLT of the glazing.

- LPD: The lighting power density is considered as 9.5 W/m^2.
- Occupancy and daylight controls: As per ECBC specifications.

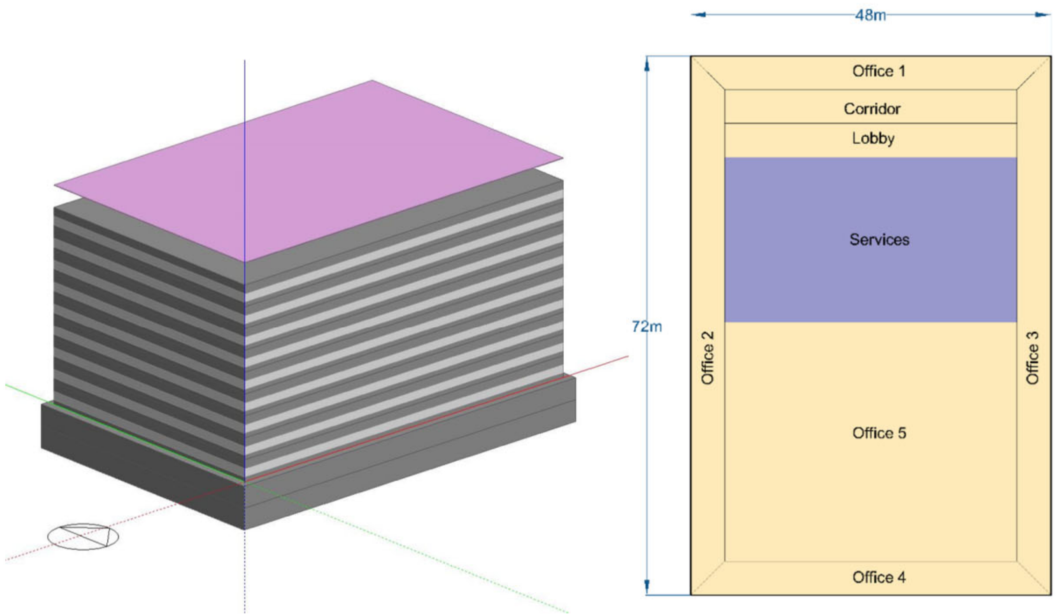

Figure 4: Base case model indicating the roof shade over the building (Left) and the typical floor plan showcasing various perimeter and core zones.

Some of the other generic parameters considered for the base case scenario based on the identified reference building criteria for warm and humid climatic conditions are:

- HVAC systems: Air cooled VAV system is considered with a COP of 5.6. No economisers, demand control ventilation and energy recovery are considered.
- Occupancy: 14 m^2/ Person.
- Ventilation: 2.5 L/s/Person + 0.3 $L/s/m^2$ wherever applicable.
- Thermostat Set point: 25°C Cooling/ 20°C Heating
- Thermostat Set Back: 30°C Cooling/ 15°C Heating
- Orientation: The building is oriented in order to align longer axis to East-West Direction, while the reference building specifications mentions the building's azimuth as non-directional.
- Plug Load:16.4 W/m^2

With all the above mentioned parameters, the base building is created using the 'DesignBuilder' software. The basic-case model is simulated using 'DesignBuilder' and the 'EnergyPlus' simulation engine. Design Builder generated an IDF file (input data file) was then used for Energy Plus simulations. The 3D view of the base case generated with the design builder programme is shown in Figure 4.

Limitations of the study:
The simulation tool 'Designbuilder' used for this study allows the shading elements to be modelled as a component block. However, the typical component blocks in the software tool are constructed in such a way that they do not absorb or transfer heat in any way, and their only influence on building surfaces in simulations is linked to shading and reflection of short-wave solar radiation and light (DesignBuilder, 2022). Hence, the study assumes that the shading material has no impact on the intermediate heat transfer between the shading roof layer and the primary roof layer. Further, the roof shading extent is limited to the roof area in this study. However, the projection of roof beyond the building line as shown in Figure 1 (a) may shade the walls in the respective direction and thus helps in further reducing the heat ingress through walls and windows.

SIMULATION RESULTS AND DISCUSSION

The reference building's Energy Performance Index (EPI) is 142 W/m^{2}K (Bhatnagar, Mathur and Garg, 2019), which is confirmed against the base building's EPI of 142.34 W/m^{2}K. Further, the iterations as explained in Figure 3 are simulated and the results indicating the EPI for different zones are plotted in Figure 5 - Figure 10

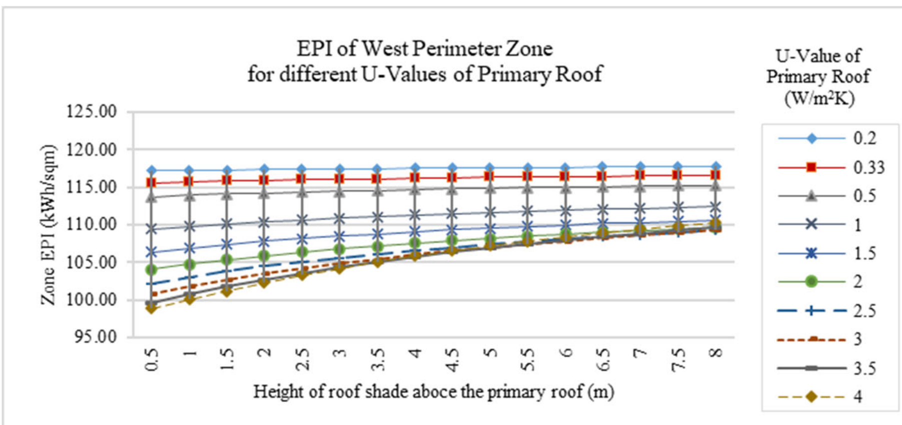

Figure 5: EPI of West Perimeter Zone (Top floor) for different U-Values of Primary Roof and different heights of roof shading

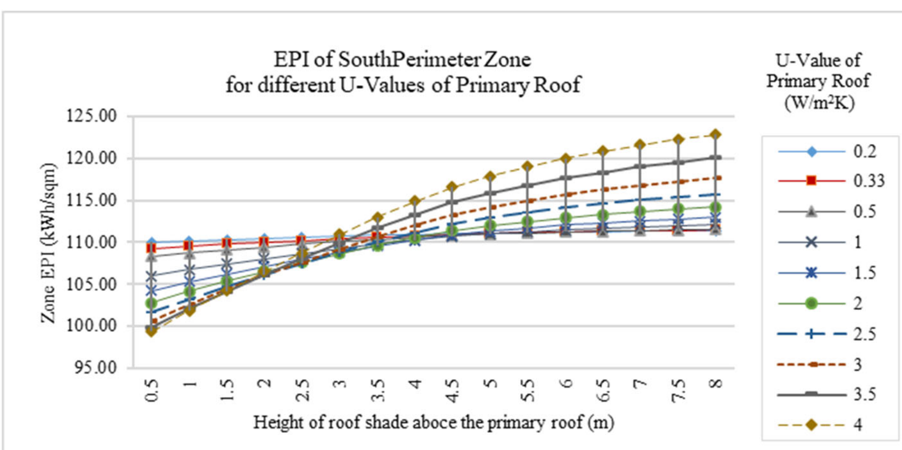

Figure 6: EPI of South Perimeter Zone (Top floor) for different U-Values of Primary Roof and different heights of roof shading

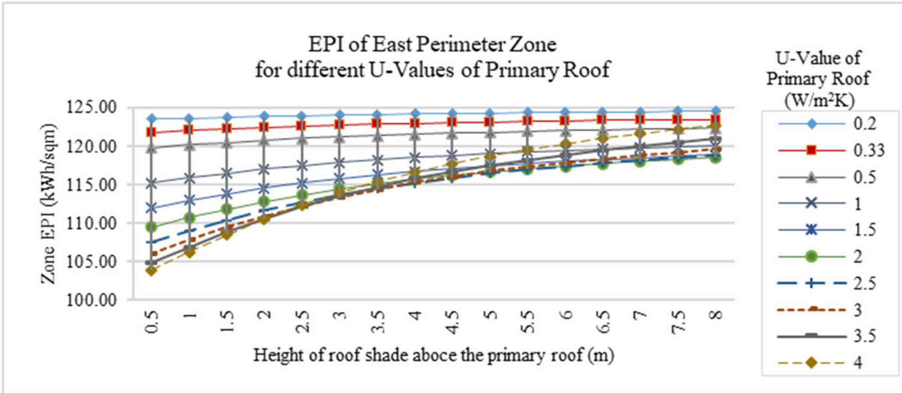

Figure 7: EPI of East Perimeter Zone (Top floor) for different U-Values of Primary Roof and different heights of roof shading

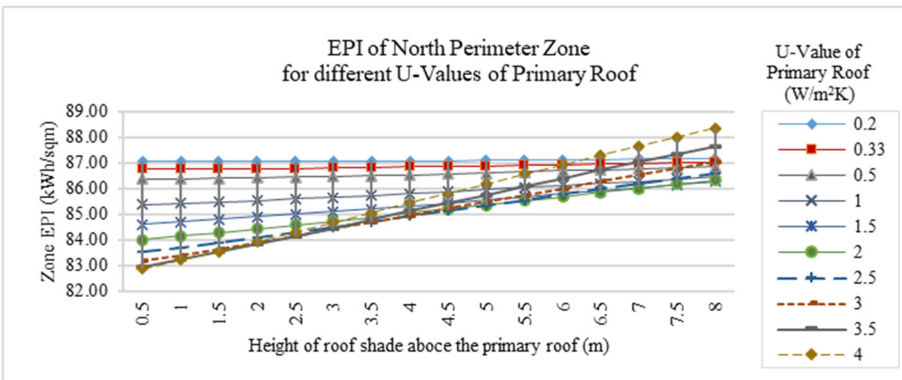

Figure 8: EPI of North Perimeter Zone (Top floor) for different U-Values of Primary Roof and different heights of roof shading

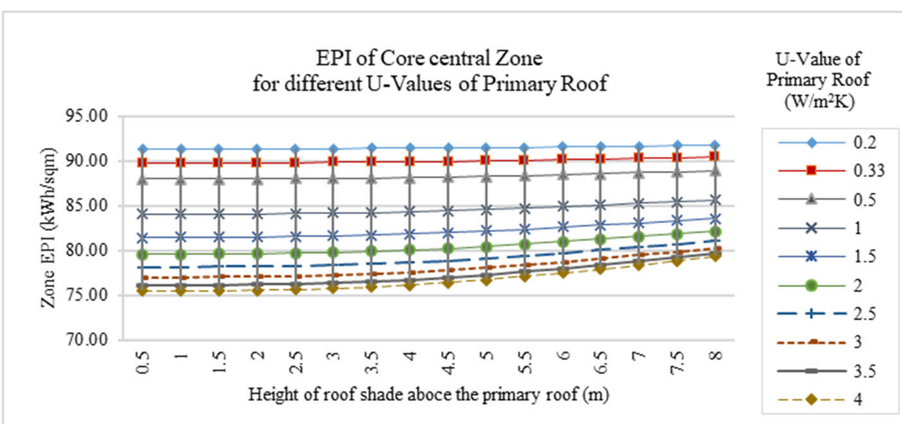

Figure 9: EPI of Core Zone (Top floor) for different U-Values of Primary Roof and different heights of roof shading

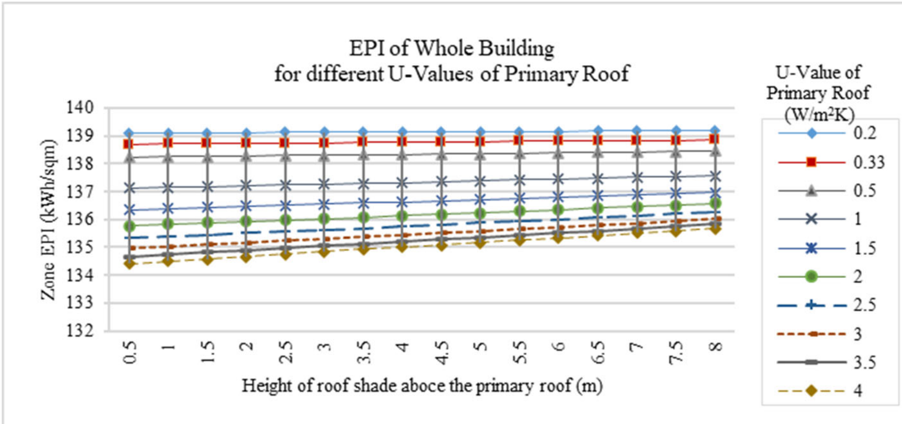

Figure 10: EPI of Whole Building for different U-Values of Primary Roof and different heights of roof shading

The following are the inferences from the simulation results:
For any height of roof shading, and for all the zones studied, the EPI of respective zones is not impacted by maximum of 1%, except for the south perimeter zone which is impacted by 2%. However, the same is in the range of 4.79% (core zone) up to 22% (south perimeter zone) for the uninsulated roof (U value of 4 W/m^{2}K). Hence, the energy consumption of the building increases with the increase in height of the roof shade for various roof insulation levels, but the impact is high for an uninsulated roof.
The building level results indicate that the provision of shading over an uninsulated roof (U Value of 4 W/m^{2}K referring to a bare reinforced concrete roof of 150 mm) performs better compared to the insulated roof alongside shading. This phenomenon stands true for all the zones studied, until the roof shade height of 3m. The results strengthen the findings of earlier study by authors (Sadevi and Agrawal, 2020) that the uninsulated roof with roof shading is the best performing scenario, irrespective the height at which the shading is provided over the primary roof.
The result chart of south perimeter zone, as shown in Figure 6 indicates the highest variation of the EPI values with the variation in height of the shade. This attenuates to the sun-path diagram of the location (Kolkata) which confirms the position of sun to be towards south for most of the year.
The regression analysis conducted with insulation and roof height as independent variables and building level EPI as dependent variable indicate that the average coefficient of determination (R-squared) between the simulated EPI and the predicted EPI as 0.92, for a 95% confidence interval with p values below 0.05. Further, the high correlation of 0.99 between the cooling loads of the core zone (major occupied zone of each floor) of top floor and the total energy consumption confirms the causation for overall change in the total energy consumption is attenuated to the Roof's thermal behaviour.
The East, West and South perimeter zones showcase similar trend in the change in EPI with the change in height of roof shade. As the height increases, the EPI is indicating a logarithmic growth. However, the same has been observed to be linear and less intense for the north zone and core zone. The variation in the impact for different orientation provides an opportunity to further investigate the need for projecting the roof shading on different directions based on respective impact on roofs thermal performance.
The results also indicate that the variation in the energy performance of the perimeter zones which are 4.5 m wide is being highly impacted after a certain height of roof shade. Since the heat gain is proportionate to the solar irradiation, which in turn depends upon the sun-path varying all through the time, the depth of perimeter zone with respect to the height of roof shade is an important aspect to consider.

Scope for further research:

The following are set of observations from this study which needs further attention and leaves a scope for further research:

It is observed from the results that the height is not a standalone factor that impacts the thermal performance of the roof but the height of the shading layer with respect to the length and width of the roof surface.
The location and latitude, which affects the sun path throughout the year, has a significant impact on the roof's energy efficiency. As a result, this research should be expanded to different locations and climatic zones in order to confirm the impact of sun path and varying climatic conditions on the roof's thermal behaviour.
As indicated in the limitations section, the simulation software 'DesignBuidler' employed in this work does not account for the roof shade material's conductive and convective behaviour. Hence, the impact of the shading material on the roof's thermal behaviour demands more investigation.

CONCLUSION

The research reveals that the height of roof shading is an important element to consider when designing a passive envelope for energy efficient building. For any roof insulation level, the energy consumption of the building increases as the height of the roof shade increases. For an uninsulated roof, the impact is significant, and the impact diminishes as the insulation level increased. Furthermore, the influence of the height of roof shading is dependent on the other elements, which may have a different impact with different roof shading heights. This research lays the groundwork for recognising the necessity for roof projections on suitable orientations to improve the shading influence. Because the impact of the height of roof shade is also influenced by the sun's trajectory and the climatic type of the site under study, more research is needed at various latitudes and climatic zones.

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A STUDY OF THE RELATION BETWEEN ROOM ASPECT RATIO AND THE WWR ON VARIOUS DAYLIGHT METRICS

Aaditya P. Sanyal[1], Indra Kumar Singh[2], Ratna Ghosh[3]

[1]Assistant Professor, Department of Architecture, Planning and Design, IIT (BHU) Varanasi, apsanyal.apd@iitbhu.ac.in
[2]Associate Professor, Department of Architecture, Planning and Design, IIT (BHU) Varanasi, indra.apd@iitbhu.ac.in
[3]Research Scholar, Department of Architecture and Regional Planning, IIT Kharagpur, India ar.ratnaghosh@kgpian.iitkgp.ac.in

ABSTRACT

Lighting has a very fundamental role in overall well-being and building energy consumption. As a means of natural lighting, daylighting plays an important role in the well-being of the occupants. The building aspect ratio and orientation of the fenestration plays a very significant role in the penetration of daylight into the interior spaces of a built-up space. Appropriate window position is essential in providing a healthy and comfortable indoor environment. Although window wall ratio (WWR) specifies the amount of window opening required for providing adequate daylighting, sufficient daylight levels may not be obtained due the room aspect ratio and the wall bearing the opening. This paper investigates relationship between size, orientation and aspect ratio for different side-lit room geometries in Indian context.

A climate-based approach was chosen for multiple scenarios with room aspect ratios varying between 1:1 to 1:2 and Window Wall Ratios (WWR) increasing from 10% to 40%. Several models were developed and the effect of these parameters on the various daylighting metrics is evaluated by means of DesignBuilder and are discussed. The observations were analysed using climate-based daylight metrics, namely, spatial daylight autonomy (SDA) and annual sunlight exposure (ASE). The results of this study suggest that room geometry parameters, window position and window orientation should be carefully addressed at the design stage. Proper understanding of fenestration orientation and wall bearing the fenestration combined with other factors such as room geometry and size will increase the spatial daylight autonomy while eliminating the glare due to sunlight exposure.

Keywords: daylighting; climate-based daylight modelling; room aspect ratio; DesignBuilder

INTRODUCTION

Background

Daylighting is a highly effective passive strategy due to its effectiveness in the reduction of energy consumption and also due to its visual comfort benefits (Wirz-Justice, Skene and Münch, 2020). Several factors contribute to the comfort conditions for users in any building type. One of them is the daylight, which plays a vital role to provide light indoors during the daytime naturally. This inclusion of daylight in indoor spaces automatically reduces the usage of the artificial means of lighting and thus, cutting the energy costs. Daylighting also provides a positive influence on the energy conservation of buildings and the well-being of the occupants (Webb, 2006),(Aries, Aarts and van Hoof, 2015). According to recent surveys (Willis, 1995), daylight access is highly valued by occupants. The benefits due to daylighting go beyond subjective preferences (Wirz-Justice, Skene and Münch, 2020). Daylight has always been viewed more as a right and necessity rather than as an amenity, historically as well (Kerr, 1865). Many inter-related parameters like window size and glazing properties, shading, room aspect ratio, and orientation have a significant effect on daylighting implementation.

Over the past two decades several green building rating systems, such as the Leadership in Energy and Environmental Design (LEED), GRIHA, and IGBC Rating systems have evolved which allocate credits to projects with good access to daylight and views (Tang, Foo and Tan, 2020), (Council, 2013),(Bonde et al., 2018). Daylight has a positive influence on our routine tasks by controlling our biological clock which regulates physiology and performance (Li, 2010). Using daylighting measures effectively can help in reducing the energy consumption of a building and therefore a reduction in the carbon footprint can be achieved (Al Horr et al., 2016).

Climate-based daylight modelling (CBDM): a short overview

Techniques were in development around two decades back which modelled the annual daylighting profiles using the same weather data files that were used in thermal modelling (Mardaljevic, 2000),(Reinhart and Herkel, 2000). Usage of the climatic data helped include the prevailing external conditions which was the foundation of building performance simulation and was given the name of climate-based daylight modelling (CBDM) (Mardaljevic, 2006). Some of the frequently used metrics include Spatial Daylight Autonomy (sDA), Useful Daylight Illuminance (UDI) and Annual Sun Exposure (ASE).

sDA is a specialised version of the DA which is defined as the percentage of the task area that meets a minimum of daylight illuminance level for a fraction of operating hours per year. IESNA recommends that a daylight levels of 300 lux are nominally acceptable by occupants for at least 50% of the occupied duration (DiLaura et al., 2011). It must also be mentioned that sDA does not incorporate glare or direct solar exposure. The metric ranges from 0% to 100% of the total floor area, with a range between 55%-74% suggesting a nominally accepted daylighting. Values higher than 75% is targeted in regularly occupied spaces, whereas a minimum of 55% is preferred in less-occupied spaces (Lee, Boubekri and Liang, 2019), (Peronato et al., 2015).

As sDA does not specify the upper limit on daylight levels, ASE assesses the amount of space exposed to direct sunlight which may become a source of visual discomfort or glare. Calculation is performed to determine duration (in hours) for which the percent of indoor space exceeds a specified lighting level (Nabil and Mardaljevic, 2006). Typically, the percentage of space where the illuminance level is more than 1000 lux for 250 annual occupied hours is calculated (Lee, Boubekri and Liang, 2019). In order to reduce the associated glare and thermal discomfort, low values of ASE are recommended (Wymelenberg Van Den Kevin and Mahić Alen, 2015). This metric is generally used alongside sDA to quantify the risk of visual discomfort.

Research Intent

This paper presents the influence played by the aspect ratio on the daylighting levels for side-lit rooms in small to large habitable rooms of residential context with a climate-based daylighting modelling (CBDM) approach. Previous literature fails in suggesting appropriate research on impact of daylighting levels due to the room size, aspect ratio and WWR and needs in-depth analysis to a greater extent using dynamic daylighting metrics.

This paper conducts daylighting simulation studies for multiple combinations of room size, room aspect ratio, building orientation and WWR. As India has a variety of climatic zones, the study was limited to national capital New Delhi. The location is situated in the north of the country. An analysis through Climate-based daylight modelling would be useful in creating a deeper understanding of the variations and necessary adaptation in increasing the possibilities of using natural light while considering the factors related to building geometry along with variations related to climatic zones.

RESEARCH MATERIALS AND METHODS

This study implemented a comparative parametric analysis by employing computer simulation using the energy analysis software DesignBuilder. The modelled geometry was located at an intermediate floor of a multistorey residential building and was side lit. Varying room sizes starting from 8.0 m^2 to 45.0 m^2 were developed for preparing the simulation models. Two daylighting performance indicators were evaluated and analysed. The methodological workflow is shown in Figure 1.

Aims, scopes and scenarios

Effect of room aspect ratio on indoor daylight levels in multiple scenarios and contexts

Analysis Parameters

Room Size = 8.0 m^2, 25 m^2, 45 m^2
Room Aspect Ratio = 1:1, 1:3, 1:5, 1:2
Window to Wall Ratio (WWR) = 10%, 20%, 30%, 40%
Window position = Along long wall and short wall
Orientation = North, East, South, West

Climate based Daylight Simulation

Spacial Daylight Autonomy (sDA)
Annual Sunlight Exposure (ASE)

Analysis of Simulation Results

Comparision of Results with focus on various parameters
Combining observations from sDA and ASE

Discussion and Conclusion

Conclusion of Design Recommendation to determine the most efficient alternative

Figure 1: Methodological workflow of the conducted study
Source: Authors

Room orientation, room aspect ratio, internal floor area, Window-to-Wall Ratio (WWR) and window position were varied as indicated in Table 1. The modelled rooms were considered as an intermediate floor in a multistorey building; hence no external obstructions were taken into consideration.

Table 1: Variables used for parameter analysis
Source: Authors

Parameter	Variable
Orientation	North/ East/ South/ West
Internal Floor area (in m^2)	8.0, 25.0, 45.0
Aspect Ratio	1:1/ 1:3/ 1:5/ 1:2
Window to Wall Ratio[1] (WWR)	10%/ 20%/ 30%/ 40%
Window position	Long wall/ Short wall

[1] Based on internal wall area

Room Geometry

Three room areas with varying aspect ratios were modelled, details of which are listed in Table 2. The internal room height was maintained at 2.8 m. for all simulation models. Multiple options for the plan depths were considered with varying room aspect ratios. The room sizes for each aspect ratio with relation to the room areas are shown in Table 2.

Table 2: Room area, dimensions, and aspect ratio of each modelled room geometry
Source: Authors

Room Area (in m^2)	Aspect Ratio							
	1:1		1:1.3		1:1.5		1:2	
	L	B	L	B	L	B	L	B
8.0	2.8	2.9	2.5	3.2	2.3	3.5	2.0	4.0
25.0	5.0	5.0	4.4	5.7	4.1	6.1	3.5	7.1
45.0	6.7	6.8	5.8	7.8	5.4	8.3	4.7	9.6

The simulations models were developed with window openings on the long wall and the short walls alternatively as displayed in Figure 2.

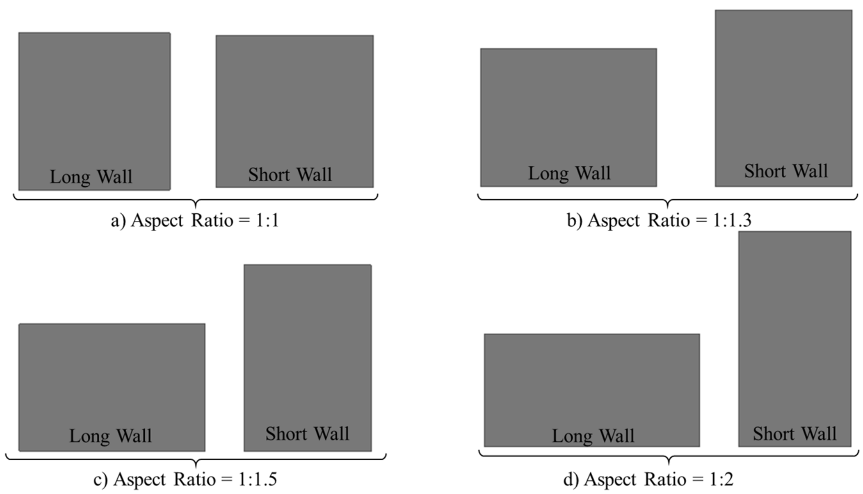


Figure 2. Plan of rooms with area 8 m^2 displaying the position of openings
Source: Authors

Window specifications

For the purpose of this analysis, the sill height is considered to 0.9 m. The lintel is considered at 2.1 m. from the finished floor level, thereby providing a fixed window height of 1.2 m. Figure 3 depicts a sample of the models developed with the three room sizes. Regular shading devices of depth 300 mm were used in the simulation models.

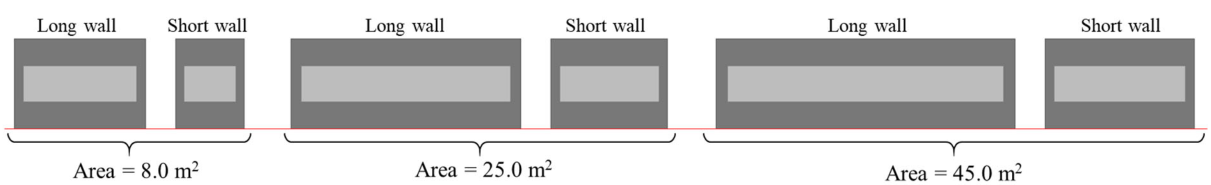


Figure 3. Elevation of each room size with WWR 40%
Source: Authors

Window to wall ratio (WWR) specification

Another parameter adopted for this study was the window to wall ratio (WWR). WWR is an important criterion as it determines the percentage of an exterior wall that is occupied by external glazing. The WWR was varied between 10% and 40 % in 10%-point increments. Figure 4 depicts the window openings of WWR 10% to 40% for room with aspect ratio 1:2 and areas 8 m^2, 25 m^2 and 45 m^2 respectively. The workplane height was fixed at 0.80 m.

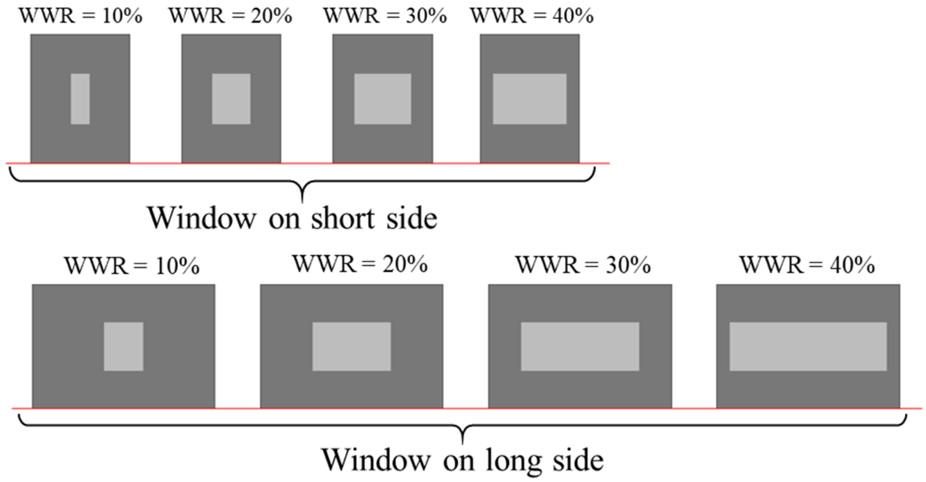


Figure 4. Illustration of window openings for room of area 8 m^2 having aspect ratio 1:2
Source: Authors

The model glazing consisted of double-glazed-unit (DGU) with a combination of two panes of generic blue 6 mm glass separated by 13 mm air cavity. The visual light transmittance (VLT) of the glazing was 0.505. The height of the glazing for the simulation models was kept constant at 1.2 m.

Analysis Tool and settings

This paper used the DesignBuilder simulation program (v6.0) fir carrying out the daylighting simulation of the examined cases. The analysis tool uses the most recent tool Climate Based Daylight Modelling (CBDM). CBDM allows designers the opportunity to evaluate the dynamics of daylight environment. The simulations were performed in New Delhi (28.6ºN, 77.21ºE) for working hours of 8:00 am to 6:00 pm. The following daylight metrics have been determined with the DesignBuilder simulation program:

Spatial Daylight Autonomy (sDA): The illuminance threshold identified during simulation is considered as 300 lux. sDA values of over 55% are considered adequately illuminated for the purpose of this paper (IESNA, 2013).

Annual Sunlight Exposure (ASE): The indicator value for ASE is considered as 1000 lux. Typically, the percentage of space where the illuminance level is more than 1000 lux for 250 annual occupied hours is calculated. Values exceeding 10% are considered to have the potential for discomfort (IESNA, 2013).

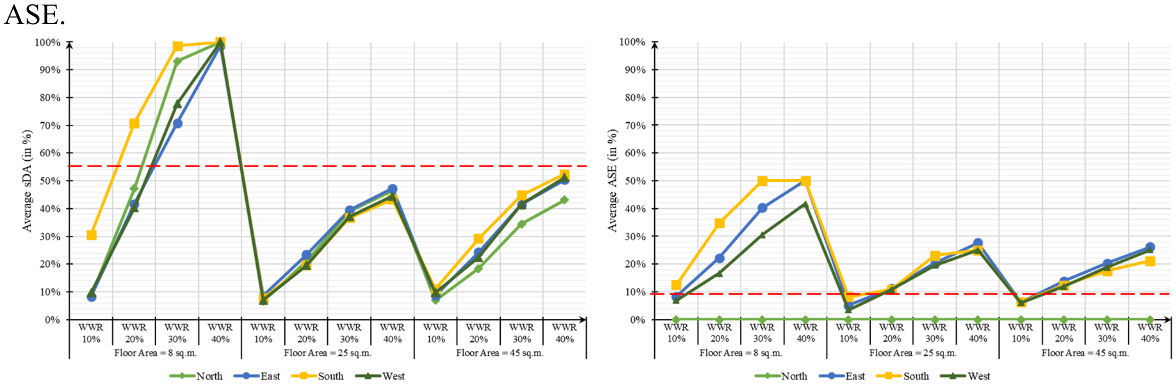
SPATIAL DAYLIGHT AUTONOMY (SDA) AND ANNUAL SUNLIGHT EXPOSURE (ASE) RESULTS

In total, 768 annual daylight simulations were conducted to assess the daylight performance of the models. Using the simulation software DesignBuilder, analysis was performed for New Delhi with the parameters listed in Table 1. The window-wall ratios have been varied between 10%-40% and the rooms have been analysed with four room orientations and four room aspect ratios. The simulations were performed determine the sDA and the ASE levels. The metrics were determined as a percentage of the area being analysed. The results from the simulations are discussed in these sections.

Table 3 Results of sDA and ASE (in %) for window located along short/long wall in rooms with aspect ratio 1:1
Source: Authors

Metric	Orientation	Floor Area = 8 sq.m.				Floor Area = 25 sq.m.				Floor Area = 45 sq.m.			
		WWR 10%	WWR 20%	WWR 30%	WWR 40%	WWR 10%	WWR 20%	WWR 30%	WWR 40%	WWR 10%	WWR 20%	WWR 30%	WWR 40%
sDA	North	8%	47%	93%	100%	7%	21%	39%	46%	7%	18%	34%	43%
	East	8%	42%	71%	99%	9%	23%	39%	47%	9%	24%	42%	50%
	South	31%	71%	99%	100%	8%	20%	37%	43%	11%	29%	45%	52%
	West	10%	40%	78%	100%	7%	20%	37%	45%	10%	23%	42%	51%
ASE	North	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	East	8%	22%	40%	50%	5%	11%	20%	28%	6%	14%	20%	26%
	South	12%	35%	50%	50%	8%	11%	23%	25%	6%	12%	18%	21%
	West	7%	17%	31%	42%	4%	11%	20%	25%	6%	12%	19%	25%

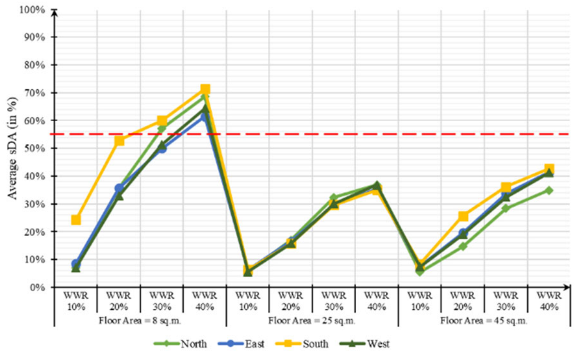
Simulations for rooms with aspect ratio 1:1 (Figure 2a) with window placed on the short wall and long wall produce similar results (Table 3) for both sDA and ASE as the length and breadth are similar for the all the floor areas (refer Table 2). Least sDA is demonstrated for WWR 10% which gradually increases with increase in WWR. This is true for individual floor areas, but the sDA levels tend to reduce when the floor areas are increased from 8 m^2 to 45 m^2 (Figure 8a). Increasing the WWR from 10% to 40% in each floor area specified shows an increase in ASE levels, but overall, a decrease can be seen as the floor areas are increased (Figure 8b). Increasing the WWR admits more sunlight which shows a larger area of the rooms exposed to direct sunlight which would lead to discomfort due to glare. A correlation can be drawn from the above discussion simulation results of sDA and ASE as higher value of sDA leads to a higher value in ASE.



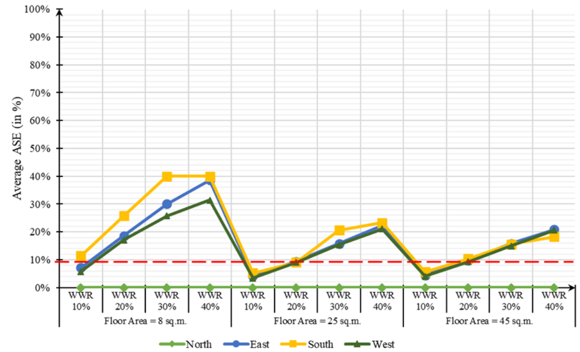
sDA simulation results ASE simulation results

Figure 8. Results of (a) sDA and (b) ASE simulation for room aspect ratio 1:1
Source: Authors

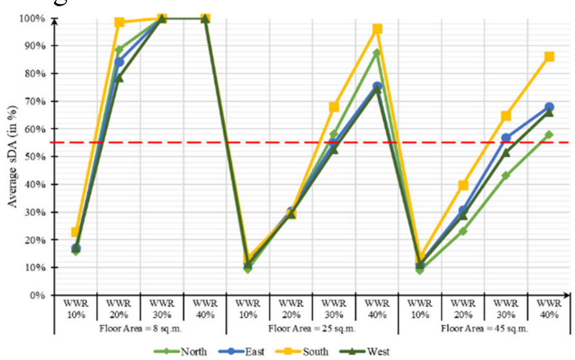
Simulation results for models having room aspect ratio 1:1.3 (Figure 9) with window located on the short wall (Figure 9a1) suggest the smallest room area of 8 m^2 has the highest sDA ranging between 7%-70%, while the other two room areas (25 m^2 and 45 m^2) have similar sDA values ranging between 5%-40%. Increase in WWR shows in an increment of the sDA and ASE values with WWR 40% showing the highest values.



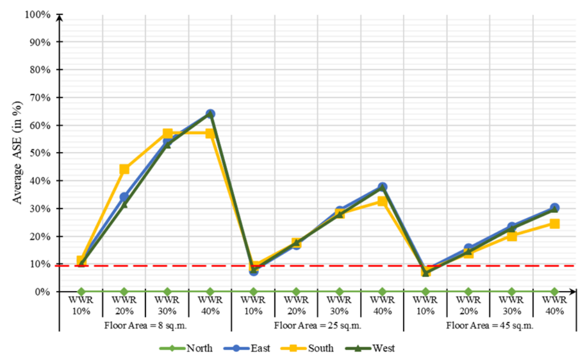
sDA simulation results for window located along short wall



ASE simulation results for window located along short wall



sDA simulation results for window located along long wall

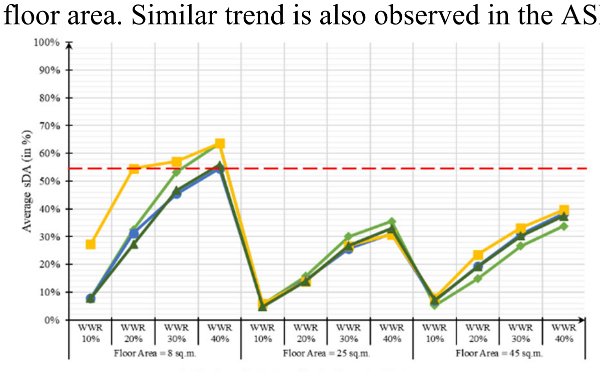


ASE simulation results for window located along long wall

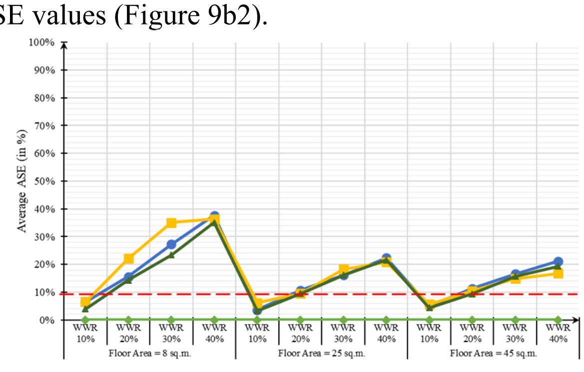
Figure 9. Results of sDA and ASE simulation for window located along short and long wall with room aspect ratio 1:1.3

Source: Authors

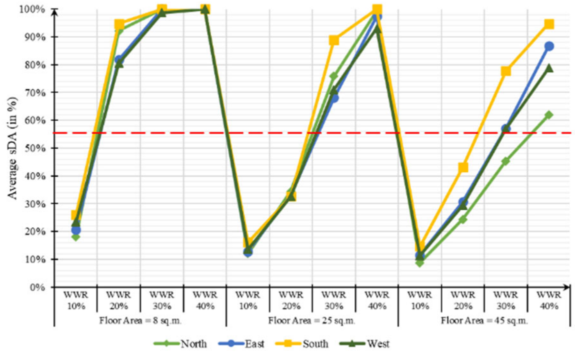
Positioning the openings on the long wall has a positive impact on the sDA (Figure 9b1) values as values higher than 55% are observed in the room areas analyzed, although the sDA values reduce with increase in floor area. Similar trend is also observed in the ASE values (Figure 9b2).



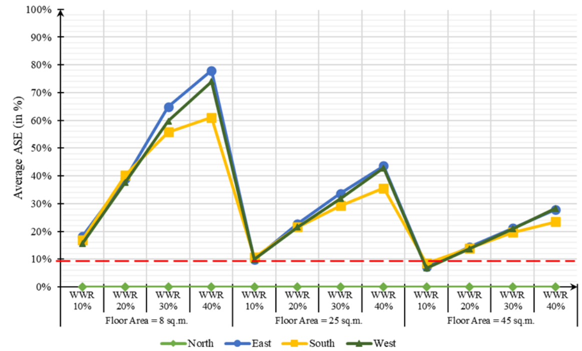
sDA simulation results for window located along short wall



ASE simulation results for window located along short wall



sDA simulation results for window located along long wall

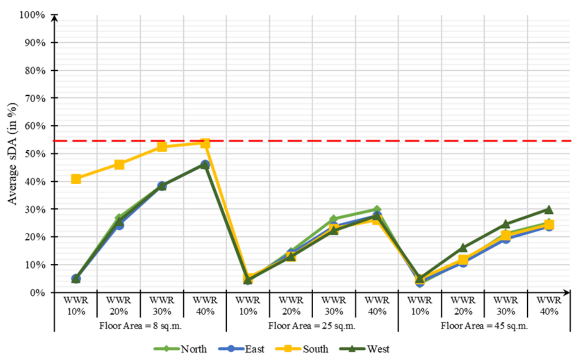


ASE simulation results for window located along long wall

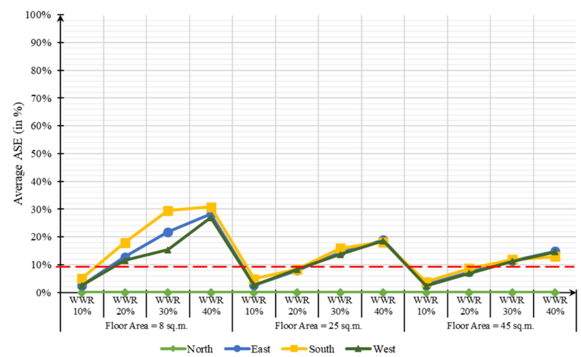
Figure 10. Results of sDA and ASE simulation for room aspect ratio 1:1.5

Source: Author

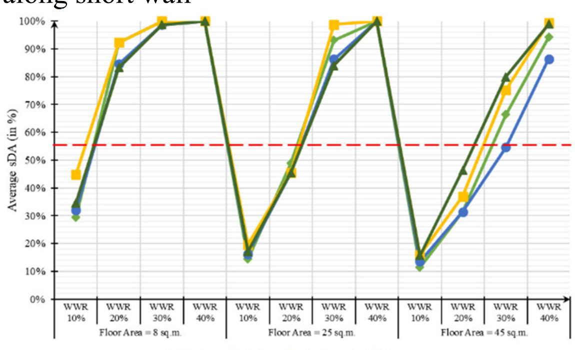
Daylighting analysis data for rooms with aspect ratio 1:1.5 (Figure 10) with window positioned on the short wall (Figure 10a1) suggest that very few cases under room area have sDA levels higher than the recommended level. On the other hand, although the ASE values (Figure 10a2) are above the specified level, but the values fall within a range of 4%-38%. With models analysed for room aspect ratio 1:2 (Figure 11), windows placed on the short walls (Figure 11a1) depict sDA values lower than the recommended level for all the three floor sizes. Increasing the floor area leads to a reduction in the sDA values to almost 30%. The ASE values (Figure 11a2) are lower than 30% which is quite close to the recommended level.



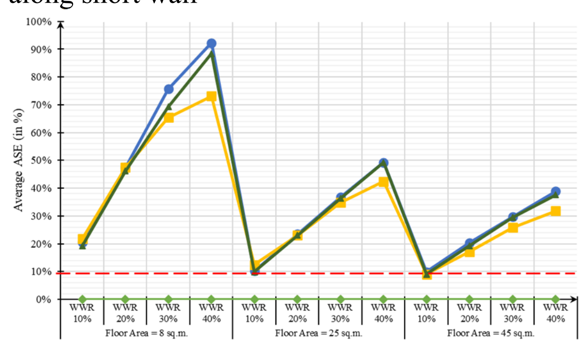
sDA simulation results for window located along short wall



ASE simulation results for window located along short wall



sDA simulation results for window located along long wall



ASE simulation results for window located along long wall

Figure 11 Results of sDA and ASE simulation for room aspect ratio 1:2

Source: Authors

Window placed on the short wall have smaller size opening which reduces the penetration of daylight with reduction in the sDA values, but also has a positive impact on the solar exposure by reduction in the ASE values. An increase in the room depth has serious detrimental issues on the daylight, although the areas with high sunlight exposure are also reduced. Openings placed on the south show sDA levels show the highest sDA levels and the least values are shown by when windows are placed on the east and west orientation. ASE values tend to be lower with openings placed in the south and north orientation.

CONCLUSION

This paper demonstrated the room aspect ratio and the window location have a significant impact on the daylight levels. This has been verified using two different daylighting metrics, namely, spatial daylight autonomy and annual sunlight exposure. The rooms were modelled with side lit wall and exposed to the external climate. The usage of CBDM has also shown its applicability in this study.

Increase in the WWR is a beneficial aspect for increasing the daylighting levels, however, additional measures are required for controlling the glare as well. Rooms with windows oriented towards the north and south show better daylight autonomy with equally good daylight usable space. Room size and room aspect ratio certainly plays a major role in determining the daylight levels. Rooms with larger depths have lower daylight levels as compared to the rooms with shallow depths.

Rooms with windows positioned on the long walls have better daylight levels as compared to windows located on the short walls. This fact holds even when the room depths are increased. Glare due to daylight can be controlled at the design level by several measures, namely, altering the window orientation, changing the window bearing wall.

As compared to the metric daylight factor, which would have given same daylight levels irrespective of the building orientation, CBDM certainly demonstrates its capability in creating a richer understanding of daylighting and its impact on interior spaces. A healthy balance between sDA and ASE is essential for providing daylighting of indoor spaces while avoiding glare. The results of this study suggest that room geometry parameters, window position and window orientation should be carefully addressed at the design stage. Proper understanding of fenestration orientation and wall bearing the fenestration combined with other factors such as room geometry and size will increase the spatial daylight autonomy while eliminating the glare due to sunlight exposure. Future studies can further explore the inclusion of detailed shading devices as a means of eliminating glare while increasing the daylight levels and the impact of room aspect ratio on the thermal comfort levels.

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STRATEGIES FOR EFFECTIVE RESIDENTIAL BUILDING ENVELOPE DESIGN THROUGH PASSIVE MEASURES IN THE HOT AND HUMID CLIMATE OF KOLKATA

Sreerupa Deb[1],

[1] Associate Professor, BMS School of Architecture, Bangalore, Karnataka, India, sreerupa.d@gmail.com

ABSTRACT

The economic progress over the last few decades have resulted in greater demand on energy sources and enhanced dependency on fossil fuels. The burning of fossil fuels has contributed to the increased Greenhouse Gas emissions leading to drastic climate changes. The COP26 At Glasgow has reiterated the need for the developed and developing countries to achieve their committed NetZero Target. Every country needs to work on energy efficiency and sustainability to mitigate the effects of climate change and India is no exception. The building sector is a consumer of approximately 40 % of the total energy production and approximately half of that is consumed for heating and cooling the interiors of buildings. Therefore, there are a lot of opportunities for adopting active and passive energy conservation techniques towards achieving energy efficiency in buildings. While active components deal with the energy consuming building systems, there are a plethora of options in the passive vernacular techniques which can contribute naturally to reducing energy consumption and improving thermal comfort. Passive techniques are based on the climate and context, location and building typologies. In this paper the author tries to study and analyse the passive techniques that have evolved in the building envelope of the residential sector in the warm and humid city of Kolkata. The effort in this paper is to extract the relevant passive design techniques for building envelopes rooted to the present-day advancement in materials and techniques applicable to Kolkata's climatic conditions. This paper has attempted a modified building envelope design effective for the climate of Kolkata adopting passive design strategies.

Key words: Passive techniques, building envelope, Warm and humid climate, thermal comfort

INTRODUCTION

The rapid industrialization and development in science and technology has led to rapid economic growth and enhanced comfort levels contributing to an increased demand on the energy sector. The increase in energy demand is a global concern since the consumption of fossil fuel as an energy source has contributed to the increased Greenhouse Gas (GHG) emissions. This is the major reason (Shukla & Sharma, 2018) for the rise in global temperature leading to climate change. The COP 21 at Paris set the limit on global warming at 1.5 degrees Centigrade as compared to pre-industrial levels. The COP26 at Glasgow has further reiterated developed and developing nations to come together to achieve their committed NetZero target. Every country needs to work on energy efficiency and sustainability to mitigate the effects of climate change and India is no exception.

The building sector consumes approximately 40% of total global energy production and has enormous energy conservation potential to lower the energy demand in major energy consuming sectors (Shukla & Sharma, 2018). The increased energy demand is a global phenomenon due to lifestyles fueled by economic growth. Since conventional fossil fuel is the main contributor for increased Greenhouse Gas emissions, the depletion of limited non-renewable sources has necessitated the urgency to explore sources of renewable and clean energy. With an increasing concern for energy efficient and sustainable buildings, there are a lot of opportunities for adopting active and passive energy conservation techniques. The active components deal with various building systems like HVAC, lighting systems, electrical systems. However, it is the passive techniques that contribute naturally to reduce energy consumption and improve thermal comfort. Passive techniques are governed by the climatic, socio-cultural and economic factors which are major contributors in decision making. Although ‘Green’ and ‘Active and Passive’ components are the need of the hour the good design practices for proper siting of buildings w.r.t.orientation, climate responsiveness, context, natural ventilation and daylighting and vernacular techniques are also being classified as passive components along with rainwater harvesting, clean energy sources etc.

This paper tries to study and analyse the passive techniques that have evolved over the years in the building envelope of the residential sector in the warm and humid city of Kolkata. But with globalization the relevance of the local vernacular techniques has been lost. The large number of products and systems available for innovative building envelope design requires application of building science compared to dependency on past precedents.

Aim and Objective

This paper aims to look at the building envelope design through strategies of passive measures in the climate of Kolkata which can improve the thermal comfort of the residents. The author tries to study the passive techniques that have evolved over the years in the residential building envelope in Kolkata. Secondly, to understand the relevant passive design parameters for building envelopes coherent to the present-day advancement in building science. Thirdly, to strategize probable modifications in the building envelope through the application of building science using passive design techniques.

Limitation

The paper identifies the strategies and comes up with a proposal for the building envelope of residential projects for Kolkata’s climate conditions. However, the limitation of this study is that the effectiveness of the revised envelope design has not been quantified and evaluated.

LITERATURE REVIEW

A literature review was conducted to understand and ascertain the climate and context and the architectural features of the traditional houses of Kolkata. The traditional houses were primarily driven by vernacular techniques and materials. Subsequently with large scale urbanisation and change in the climate socio political and economic conditions the housing sector underwent a drastic change. Another factor that affected this was the advancement in building and material sciences.

Climate

The National Building Code of India (NBC) 2005 and the Energy Conservation Building Code (ECBC) 2017 have classified India into 5 climatic zones as seen from Fig 1. Kolkata is categorised in the Hot and Humid Climatic zone. Although the annual mean temperature of Kolkata is around 27 degrees Celsius, summers are hot and humid with the temperature in the range of 32-35 °C. However, during dry spells, the temperature often exceeds 40 °C. The highest-recorded temperature is 43.9 °. Winter tends to last for only about two and a half months, with seasonal lows dipping from 12 °C to 14 °C between December and January. The lowest-recorded temperature is 5 °C. Monsoons in Kolkata extend between June to October and the average annual total is 1,582 mm. The month of July has maximum precipitation. The relative humidity varies between 60% to 85 %.

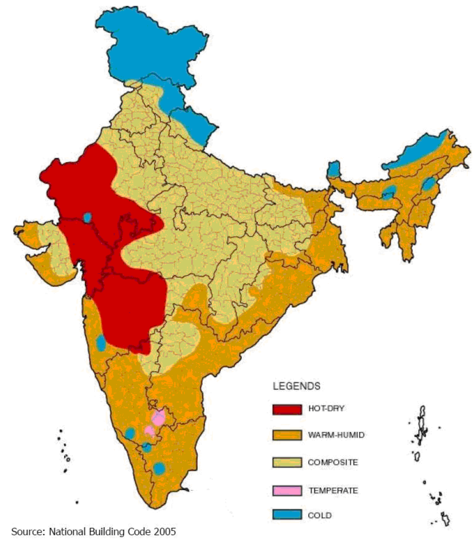
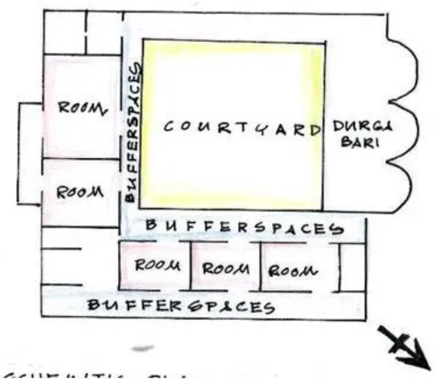


Fig 1
Source: National Building Code 2005,

Traditional architecture
Bengal's rich cultural history and the socio-cultural scenario prevailing during colonial and post-colonial times had a great influence on the way architecture evolved. Bengal's social structure encouraged joint families where family members across different generations cohabited and lived in the same house sharing all common functions and activities. The mansions of the wealthy had their own architectural features. Climate and local materials played a major role in the evolution of the architectural characters and spatial distribution of these residences.

The social and climatic conditions encouraged the residential design to be inward looking. The functional spaces were segregated into private and public zones. There was a central courtyard with the colonnaded veranda overlooking the courtyard. The courtyard was open to the sky facilitating cross ventilation through various spaces and allowing hot and humid air to escape facilitating heat loss and a glimpse of the sky. The humid conditions necessitated large windows and doors to allow cross ventilation to cool the indoor spaces. The windows had wooden movable louvers which offered privacy and allowed wind circulation. The public zones were utilised for all community celebrations and family functions. The semi-covered veranda on the courtyard and the roadside allowed privacy and also facilitated ventilation and minimised solar heat gain into the habitable indoor spaces. The materials used were mainly clay bricks, wood, and bamboo with decorative moulded work in terracotta. Using bamboo or timber members below the roof or broken glazed tiles on the roof helped to minimise the heat gain from the roof. The orientation of the houses along with the surrounding greenery and waterbodies assisted in minimising the heat gain and facilitating heat loss. The passive design adopted for the building envelope during that time was sensitive to the climate of the region and technology and construction materials of the time.



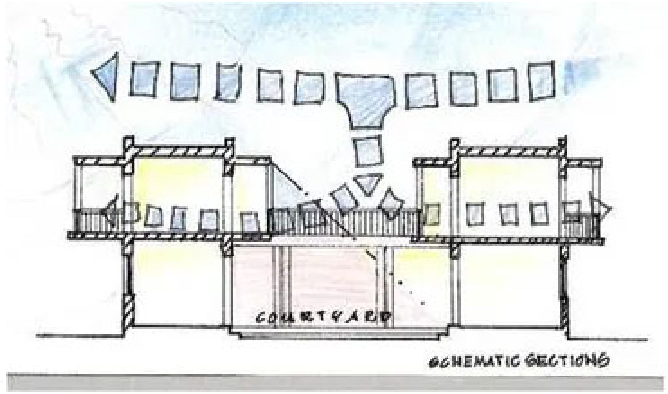


Fig 2: A typical joint family house of Bengal **Fig 3:** A schematic section

However, over time the joint family broke up into nuclear families as members moved for better opportunities and privacy and community activities were restricted to festivals. Since land area is limited and the density of population is high the large joint family colonial houses gave way to apartments. The architectural characters of these buildings have a global feature, but lost the local vernacular flavour. The local materials were replaced with RCC and glass. Climate responsiveness was restricted to double walls occasionally with recessed windows and balcony.

The RCC structures with infill brick panels, large, glazed windows or glazed facades and high dependency on active systems like HVAC to maintain the indoor thermal comfort has been a drain on the energy sources and is largely responsible for the increased GHG emissions and environmental hazard. The innovations in building and material science and construction technology has brought in a large number of options for building envelope design commensurate with the times which can actually improve the thermal comfort through passive techniques.

Passive design features

Building envelope separates the harsh external environment from the conditioned internal spaces giving comfort to the residents. The integration of the building envelope with passive design parameters gives an opportunity for an energy efficient architecture along with environment friendly construction materials. A passive way to attain energy efficiency in buildings is by modifying the building envelope to suit its climate and context. Building envelope consists of **roofing systems, wall assemblies and fenestrations (all openings), frames, shading devices, glazing and insulation specifications and foundations** which separates the external climatic conditions from internal conditioned spaces.

The **principles of Passive House Design** are as follows which shall be modified based on the climate and location of the building. (Omrany & Marsono, 2015)

- Insulation of walls
- Eliminating thermal bridges
- Airtight construction
- Ventilation
- High performance windows
- Optimization of passive solar gain
- In addition to the above there are other factors of building envelope which contribute to good design practices along with being passive design strategies like
- Building orientation, context, and topography
- Climate responsiveness, colour of external surfaces and building forms
- Wall features, Thermal Mass and External shading devices
- Glazing types and specifications
- Window size and orientation and Window floor ratio

- Green and Vernacular materials, green roofs etc
- Passive techniques like Moisture Management etc.

all of which enhance sustainability and energy efficiency of buildings and mitigate the negative impact of buildings on the environment.

METHODOLOGY

The methodology adopted by the author was to conduct a survey among practicing architects in the hot and humid climatic conditions like Kolkata to understand the parameters considered by them for building envelope design and the importance of passive systems. A questionnaire was prepared to gather the information. The sample size is approximately 100 and 10 responses were obtained.

Qualitative analysis

The data collected was analysed qualitatively by assigning relative weightages to the parameters. Then the raw scores and weighted scores were calculated, and a graph was generated to understand which factors had the highest influence in the decision making process. The questionnaire for the survey was short and explored the most commonly used passive design techniques and its relevance among the professionals.

Parameter 1 - Building orientation along with building form
Parameter 2- Importance of climate responsiveness in building envelope
Parameter 3- Design details like chajjah, cavity walls, insulation and shading devices
Parameter 4- Design details like Glazing criteria and fenestration design (DGU, U value, SHGC)
Parameter 5- Importance of Daylighting, Wall to Window Ratio(WWR) & Wall to Floor ratio (WFR)
Parameter 6- Importance of green, smart and vernacular materials.
Parameter 7- Importance of passive techniques in design
Parameter 8- Has the passive design techniques improved the thermal comfort of design spaces ?

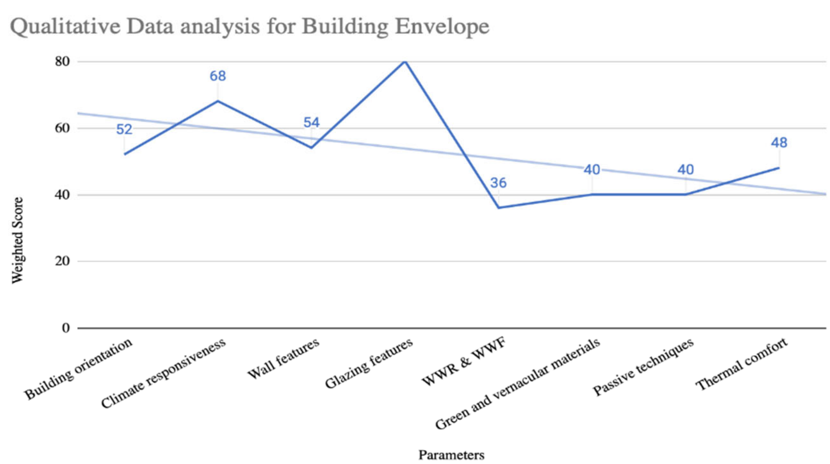


Fig 4 - Qualitative data analysis of the parameters affecting Building Envelope Design . Source: Author

The analysis indicated that although the good design practices were considered like orientation, context, climate responsiveness, vernacular techniques and the glazing specifications while designing buildings, the passive techniques for building envelope design is yet to be largely adopted.

The parameters were determined based on the discussion the author had with practicing architects over telephonic conversations and personal interactions. The outcome of the analysis may be different if the parameters and the relative weightages are changed in a different survey. However it was felt that at the present moment the trend indicated in the graph will be similar unless the importance of building science and material science is given the importance it deserves in the present environmental conditions.

IMPACT OF BUILDING PARAMETERS ON SUSTAINABLE ENVELOPE DESIGN

A passive building may be defined as a building which is built to achieve thermal comfort without depending on the active systems. The hot and humid climatic conditions that prevail in Kolkata creates discomfiture in indoor conditions. To counter that the design approach will be to *resist and minimise heat and moisture gain and facilitate heat loss*. Considering that, building design also must evolve keeping up with the innovations in building science, technology, and material science of the present day. The scorching heat wave and the unprecedented deluge in India in 2022 is a grim reminder of the drastic effect that climate change can cause if not addressed with alacrity. The approach to improved building envelope design is to manage rather than prevent and allow an acceptable threshold within the design parameters. In the table below the author has tried to understand the relevance of the passive design parameters for the building envelope in the backdrop of hot and humid climatic conditions of Kolkata.

TABLE 1: The passive design parameters and their implication in building envelope design in Hot and Humid climate

SL NO	PARAMETERS	IMPACT ON BUILDING ENVELOPE
1	**BUILDING ORIENTATION**	*Building orientation* in addition to being a good design practice is important to ensure that all functional spaces get adequate benefits of the natural elements like the sun and the wind. The cool breeze in Bengal is mostly from the South and the preference of buildings is to be South facing to maximize the cool breeze effect.
2	**CLIMATE RESPONSIVENESS**	
2a	Ventilation	Wind direction of Kolkata is the main parameter for performance of natural ventilation. Adequate cross *ventilation* gives comfort and the location of doors and windows, and their sizes govern the efficiency of ventilation. The prevailing wind direction in Kolkata is predominantly South. Large windows in the South with ample cross ventilation openings will assist in taking away the heat and cool the spaces.
2b	Building Forms	Building forms determine the wall surfaces that will receive the maximum solar radiation and the design elements that will mitigate the effects of the same like skin walls, louvers, recessed windows etc.
2c	Colour of external surfaces	The *external wall surface* is preferred to be of *light coloured finish* to reflect maximum solar radiation.
3	**WALL FEATURES**	
3a	Thermal Mass	Lightweight construction with low *thermal mass* is suitable in the proposed climatic condition to reduce heat storage. Aerated concrete blocks have insulating properties and are easily workable too.
3b	Shading devices	Overhangs and projections with light shelf, louvers, fins, or egg crate *shading devices* with recessed windows are suitable to reduce the direct solar radiation into indoor spaces.

SL NO	PARAMETERS	IMPACT ON BUILDING ENVELOPE
3c	Wall configurations	Cavity walls, Hollow brick/block walls or double walls with insulation materials may be explored with solutions for dampness since the climate has high humidity levels.
4a	**GLAZING**	*Glazing properties* of windows and *the window design* plays an important role in controlling the Solar heat gain of the interior spaces. Glass with lower SHGC (Solar heat Gain coefficient) will help in reducing the cooling loads of the active systems. Soft coated low e glass which controls solar radiation is suitable for hot climates which minimizes the solar radiation into space. Such glazing is best used in *IGU (Insulated Glazed Units)* which protects the coating and is manufactured under controlled dehumidified conditions.
4b	Aerogel Glazing	An alternative like *Aerogel Glazing* may also be explored which gives translucent windows and *superinsulation glazing* by reducing the U value substantially.
5	**WALL WINDOW RATIO AND WINDOW FLOOR RATIO**	
5a	Window size and orientation, WWR and WFR	The window size and orientation to be determined based on the prevailing wind directions and climate. The *window-floor ratio* is recommended to be 15-20% and the Wall - window ratio is recommended to be 40% in hot and humid zones
6	**GREEN & VERNACULAR MATERIALS**	
6a	Roofs	*Roofs* have a large surface area exposed to solar radiation. Therefore, adequate steps must be taken to ensure minimum heat transfer is allowed. Insulation at the roof level can either be overdeck or underdeck. Vermiculite concrete can be used as an effective roof insulation. The concept of Green Roof completely or partially if adopted can help in keeping the spaces below cooler and reduce the effect of heat island in urban areas. Using light coloured broken China mosaic tiles can be used which are high in solar reflectivity and have a high SRI (Solar Reflective Index) value. Treating the roof with *high albedo* reflective paint which minimizes heat transfer is a popular option for roof treatment.
6b	Insulation	*Insulating the walls* can minimise heat gain but considering the humid conditions it will lead to mold growth which will adversely affect the Indoor Air Quality and insulation degradation. However, the option of integrating Phase Change Material (PCM) in RCC structure or Hollow Clay bricks can be explored to minimise the thermal heat gain. The PCM uses the heat to change its state within a certain temperature range thereby preventing thermal transfer to inside spaces. The PCM should preferably be provided in the external walls to be effective.
7	**PASSIVE TECHNIQUES**	

SL NO	PARAMETERS	IMPACT ON BUILDING ENVELOPE
7a	Thermal Bridge	*Thermal Bridge* is the thermally weak areas in the building envelope through which heat transfer happens like the joints between the external walls and the floor, or the balcony. Insulation can prevent thermal bridging and minimise the heat gain of internal spaces. But insulation with conventional insulating materials is not the solution in a typical humid condition, the envelope design must minimise the points of Thermal bridge and make the envelope design thermal bridge free.
7b	Airtightness and thermally broken frames	Building envelopes accommodate fenestrations for air circulation, but it needs to be *airtight* to prevent any leakage of heat transferred from outside to inside. Therefore, the design of the windows should have *thermally broken frames* with reinforced polyamide strips. This prevents heat transfer through window frames while maintaining the *airtightness* of the building envelope.
7c	Moisture Management	Ingress of moisture or water combined with the building materials can cause damage to the building and the conditions desired. Instead, an approach to manage in case it finds its way inside will be a positive method to deal with moisture ingress like the pressure moderated rainscreens with drainage planes and drainage spaces and pressure rain screens with the drainage plane and drainage spaces. (Kesik, 2016)
7d	Turbine ventilation	Providing *turbine ventilation* in the roofs integrated with a solar operated fan will help to extract the hot air from the highest point of the building thereby facilitating a continuous air movement.

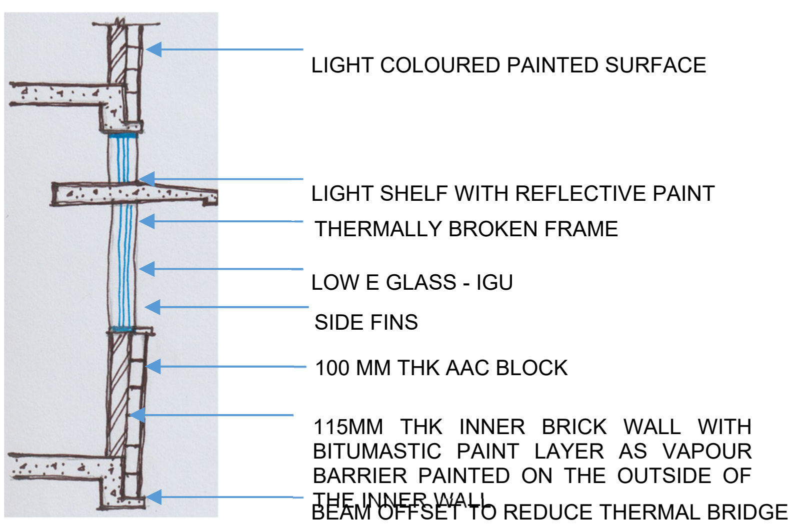


Fig 8: A proposed section of Building Envelope in the Hot and Humid Climate of Kolkata
Source: (BEE, ECM2 Technical Information Warm Humid)**,** (BEE, Building Envelope Solutions Set (v1.0) for Eco Niwas Samhita 2018, 2021)

CONCLUSION

The paper has identified the parameters of building envelope design through passive measures and has attempted to understand the impact these parameters have on the building envelope design in the hot and humid climatic zones. Passive design of the building envelope needs to have the following considerations – control of heat flow, air flow, moisture, and water ingress inside the building and the challenge is to balance these to mitigate the effect of climate to a large extent and reduce the dependency on active systems. An attempt has been made to propose an effective solution of the building envelope, which *understands the past, respects the present and proposes for the future.* To that effect a proposed section of the building envelope has been worked out. However, the effectiveness of the building envelope based on passive strategies discussed above can only be justified once an evaluation is done. A study to that effect may be taken up subsequently which will justify the passive parameters considered in this paper.

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ADAPTIVE EXTERNAL SHADING SYSTEM FOR BETTER DAYLIGHT BALANCING WITH HEAT GAIN FOR THE COMPOSITE CLIMATE OF DELHI NCR

Jyoti Luthra[1], A. Meenatchi Sundaram[2]

[1] Phd scholar, National Institute of Technology, Tiruchirappalli, India, jyotiluthra.vaka@gmail.com
[2] Associate Professor, National Institute of Technology, Tiruchirappalli, India, meenatchi@nitt.edu

ABSTRACT

The indoor environment quality of habitable rooms in residential buildings is defined by good daylighting and thermal comfort, i.e., visual and thermal comfort. Shading systems play a crucial role in manipulating these aspects to enhance the indoor environment. Past studies have shown that external shading systems are more effective in controlling heat gain than internal ones. The fixed external shading systems block the required daylight along with radiation before it reaches fenestration glazing, they cannot balance the varying requirement of light and heat during different climatic seasons. Residences in the composite climate with varying seasons require adaptive shading systems to optimize daylight and heat gain for internal spaces. A successful daylight design is not just to be seen as filling the space with abundant daylight but as a careful balance of useful light and heat gain. In contemporary residential buildings, a trend toward big, glazed windows (higher WWR) is seen irrespective of the room's orientation which further emphasizes the need for external adaptive shading systems. The study develops, analyses, and compares two types of external adaptive louver shading systems i.e., EALS (External adaptive louver screen) and EALA (External adaptive louver awning), for optimum daylight and heat gain as per seasonal requirements for west orientation. This study utilizes recommended monthly louver angles derived from a previous simulation study for a single space of a typical apartment building in Delhi NCR. The recommended angles allow occupants to make an informed decision by adjusting louvers manually to reduce heat gain and enhance useful daylight (UDI) conditions for the indoor environment. The study utilized ladybug and honeybee plugins for simulation. The results showed that monthly adjustments of external adaptive shade enhance indoor daylight conditions significantly and reduce heat gain.

Keywords: External adaptive louver shades, monthly recommended angles, Useful Daylight Illuminance (UDI), reduce heat gain, window wall ratio (WWR)

INTRODUCTION

Shading Devices for Residential Buildings

The design of a shading device should consider multiple factors that is climate, orientation, heat gain, daylight, aesthetics, maintenance, and so on. Window shades provided in residential buildings are mostly fixed type (horizontal overhangs, vertical fins, or a combination of two) to prevent direct solar radiation into the interiors during the summer season. A fixed shading device blocks the direct radiation however may allow diffuse component of solar radiation into interior space. Internal shading systems (curtains or blinds) are therefore mostly used by unaware occupants to maintain the balance between views, daylight, and heat. Generally, occupants are more inclined to get the views, then next desired level of daylight, and finally; disregard the heat component it brings in. A successful daylight design is not just to be seen as filling the space with abundant daylight but as a careful balance of useful light and heat gain. In contemporary residential buildings, a trend toward big, glazed windows (higher WWR) is seen irrespective of the room's orientation which further emphasizes the need for external adaptive shading systems.

LITERATURE REVIEW

Adaptive Shading Devices for Residential Buildings in Composite Climate

The government is considering mandating the Eco Niwas Samhita, Energy Conservation Code for Residential Buildings (ECBC-R), for new residential developments. As per BEE, residential buildings account for 24% of India's total energy consumption, and this move will save INR 1,20,000 crore worth of electricity by 2030 by avoiding the generation of 300 billion units (Economic Times, 2022). The Eco Niwas Samhita code incorporates external shading as an essential building envelope element to reduce SHGC equivalent with external shade and energy consumption. It also advises a maximum WWR of 0.4 and minimum VLT for different WWR ranges to maintain a balance of heat and light in the indoor space as per climate type (ENS, 2018). A study by BEEP reveals the current trend of increasing WWR in contemporary residential developments in various states of India. For a few states, the WWR range is as high as 50 - 70%, which neglects the code requirement completely (BEEP, 2022). A successful daylight design is not just to be seen as filling the space with abundant daylight but a careful balance of useful light and heat gain, this critical balance can be achieved by the traditional passive strategy of external adaptive shading systems (Walter Grondzik et al., 2010). Guidelines for Energy Efficient Multi-Storey Residential Buildings explain that the concept of external movable shutters is not entirely new to India. Traditionally, external movable shading systems were an integral part of the building envelope as either louvered shutters, bamboo screens or awnings, etc. in all parts of the country. The use and availability of such systems have reduced considerably (BEEP, 2014). External Movable Shading Systems (EmSyS) manual provides information on available external adaptive shading systems and classifies such systems into three categories – retractable awnings, vertical screens, and shutters (BEEP, 2021). The pictures below show a few examples where occupants installed such systems post-occupancy as per the requirement to maintain a balance of light and heat from the openings during different seasons. Incorporating such systems during the design process would provide better occupant control over the indoor thermal and visual environment along with considerable energy savings.

Figure 1: Types of external adaptive shades examples
Source: Author

The literature review indicates that there is a need for further research in external adaptive shading systems, especially in the Indian residential sector. This passive strategy not only benefits new construction, but existing residential buildings can also be retrofitted and benefit enormously from such systems. Authors believe that there is a need to develop contemporary systems to address this gap, so this study develops, analyses and compares two types of external adaptive louver shading systems i.e., EALS (External adaptive louver screen) and EALA (External adaptive louver awning) to optimise daylight and heat gain.

METHODOLOGY

This is an extension of the study conducted previously where two types of external adaptive louver shading systems i.e., EALS (External adaptive louver screen) and EALA (External adaptive louver awning) were developed, analysed, and compared to identify monthly louver angles that improved indoor environment quality and saved energy. This study further explores the visual impact of both types of external adaptive shading systems. The study attempts to understand this in terms of balancing heat and daylight by analysing sunlight hours and useful daylight illuminance (UDI) on monthly basis, both numerically and graphically for a better indoor thermal and visual environment. The study is conducted for a west-oriented typical bedroom with a glazed sliding opening and balcony in the composite climate of Delhi NCR. The sequence of steps in the methodology is as follows:

Background of the Study
The city Gurugram is one of Delhi's major satellite cities and is part of the National Capital Region. Gurgaon's nearness to the capital, international airport, land availability, and job opportunities make it an ideal location for real estate growth. It was expected to house more than 2500 Highrise residential towers before 2031. Many of the newly added residential towers, especially high-end projects, are having more than 30 floors. With such rapid development, the daily energy demand is rising proportionately every year.

Study Area – Gurgaon Sector 28 and Neighbourhood
Considering the background, Gurgaon's sector 28 and neighbourhood is selected to understand the existing and under construction apartments. It is observed that many high-rise apartments have large, glazed windows (with or without balconies) with a high window wall ratio (WWR), irrespective of the orientation of the buildings. Also, occupants of the apartments on higher floors tend to keep internal curtains drawn during the day. A few apartments were also seen with additionally installed external adaptive shading measures like awnings, mats, green cloth, etc. to control incoming solar radiation and improve the indoor environment. From typical floor plans, one bedroom with west facing balcony is considered for the study.

Climate of Delhi
Delhi, located at coordinates 28.70° N, 77.10° E experiences a composite climate and has three seasons, namely summer, monsoon, and winter. It is predominantly cooling dominant climate with more cooling degree days (CDD) than heating degree days (HDD). A major part of the year requires shading from harmful solar radiation, whereas the sun is desirable for the few winter months. January is the coldest month with an average temperature of 14°C, and June is the hottest month with an average temperature of 33°C. Figure 2 provides monthly climatic data. Figure 3 shows the sun path diagram overlapped with the temperature. In figure 4, the sky dome shows mostly diffuse radiation from the north direction throughout the year.

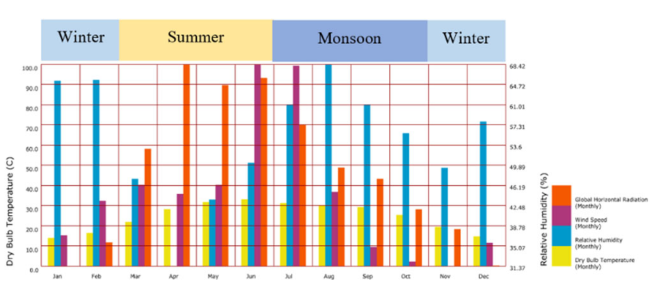


Figure 2: Monthly climate data and seasons.
Source: Author

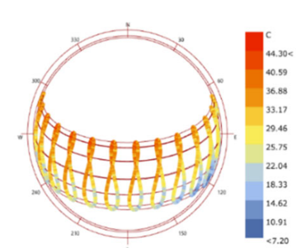


Figure 3: Annual sun path with temperature.
Source: Author

Building Model set up for Simulation Study

A single bedroom with a west-facing glazed opening and balcony is considered for simulation study and analysis. Fixed parameters including room size and other properties for simulation study are as follows:

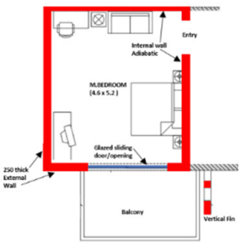


Figure 5: Typical bedroom.
Source: Author

Table 1: Model details.

Model Description	Properties
Room Size (Area)	4.6m X 5.2m
Room height	3.25m
Glazed opening (Sliding door) size	2.77m X 2.7m
Glazing 6 mm thick clear glass	0.771 (solar transmittance), 0.8884 (Visible transmittance), 0.840 (Emissivity)
External Walls (2 Nos.)	250 mm thick
Internal Walls (2 Nos.)	115mm thick (Adiabatic)

Design of External Adaptive Louver Shades (EALS and EALA) for Improving Indoor Environment

As part of the previous study, two types of external adaptive systems were designed and are considered for this simulation study. EALS (External Adaptive Louver Screen) (Figure 7a)- Louver size and spacing are 100 mm each to maintain the projection factor equal to 1 (as per Eco Niwas Samhita Code). The louvers are flexible and can be adjusted to the desired angle as needed.

EALA (External Adaptive Louver Awning) (Figure 7b) - A 1.5 m wide awning integrated with 100 mm wide, and 100 mm spaced movable louvers is designed parametrically using grasshopper plugin. The louver and awning angle can be adjusted as per the desired angle.

Simulation Process

Figure 6 shows the simulation process to obtain results on monthly sunlight hour analysis (for June and December) and UDI values monthly and annually (both graphical and numerical). The steps in the simulation workflow are explained further:

Step 1: A typical bedroom is modelled in google sketch up and imported in rhino software for the simulation study, room size (4.6m X 5.2mX 3.25m) with west facing balcony. Balcony is with glazed sliding door opening of size 2.77m X 2.7 m (WWR – 46%).

Step 2: Design of shading devices i.e., EALS and EALA. The depth and spacing of louvers is fixed (100 mm – width and 100 mm – spacing). Louver size and spacing are the same for EALS and EALA, the dimension and spacing selected makes the Projection Factor = 1 (best case as per the Eco Niwas Samhita to reduce $SHGC_{eq}$ for any shading system)

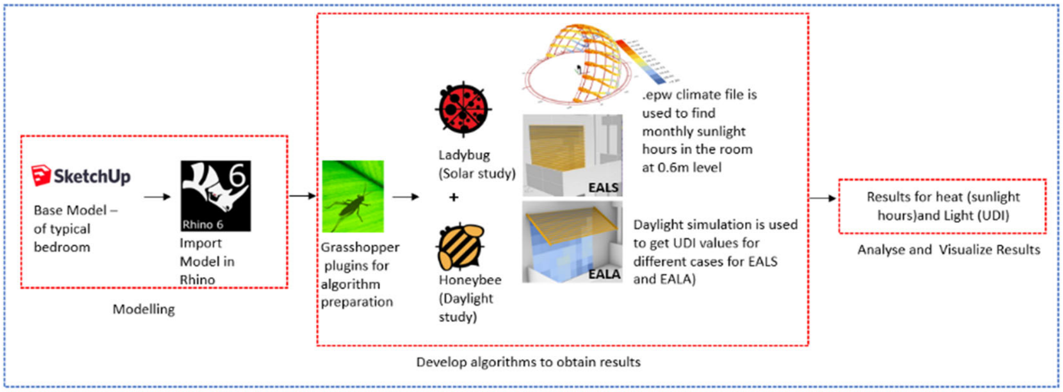


Figure 6: Simulation process
Source: Author

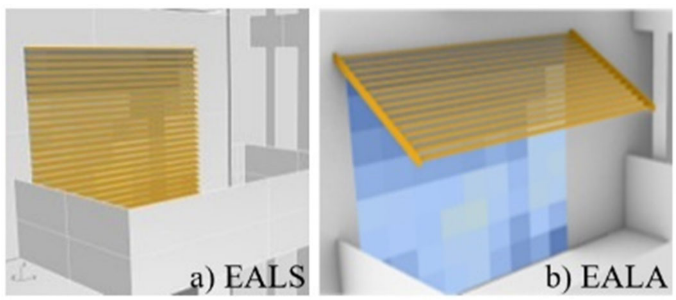


Figure 7: EALS and EALA
Source: Author

Cases Considered	Description
Case W1 – WS	Without Shade
Case W2 - EALS @ 0° angle	External adaptive Louver Screen at 0° angle (horizontal position)
Case W3 - EALS @ SA	External adaptive Louver Screen at selected angle
[illegible]	[illegible] Louver (selected angle)

Table 2: Cases considered

Step 3: Using ladybug plugin in grasshopper - sunlight hour analysis is conducted for the room for two critical months June and Dec for 5 cases (west) as mentioned in table 2.

Step 4: Using honeybee plugin in grasshopper – for daylight analysis, UDI values are derived for the same five cases mentioned in table 2 and visualised on the plan with room furniture layout. Monthly selected angles of EALS and EALA used are derived from the previous study.

Step 5: Simulation parameters used for daylight analysis are listed in table 3 below:

Table 3: Radiance parameters and reflectance considered for daylight simulation

Quality	**ab**	**ad**	**as**	**aa**	**ar**
2	7	1500	100	0.1	300
Reflectance	**Walls**	**Floor**	**Ceiling**	**Louver**	
	0.5	0.2	0.7	0.5	

Where, ab is ambient bounces, ad is ambient division, as ambient sampling, aa is ambient accuracy and ar is ambient resolution.

RESULTS AND DISCUSSION

Improvement in Sunlight Hours on the Glazed Opening

Duration and intensity of solar radiations (direct and diffuse) on the openings govern the major amount of heat intake (solar gain) within the room and impact the indoor thermal and visual environment. It is analysed in the simulation study that installation of EALS and EALA and adjusting monthly angles results in considerable improvement in the number of sunlight hours both on opening and inside the room. Figure 7 illustrates the improvement in the sunlight hours on the opening with the use of both types of external adaptive shading systems for the cases mentioned in table 2.

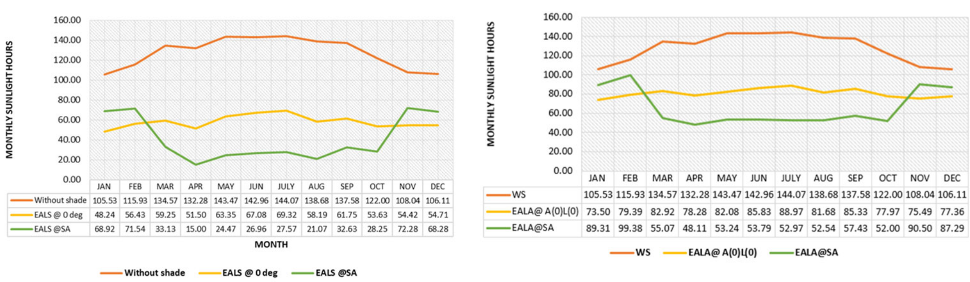


Figure 7: Monthly sunlight hours on the glazed opening

Improvement in Sunlight Hours in the Room

Figure 8 shows the improvement in the sunlight hours (600mm above floor level) with the use of external adaptive shading devices, EALS and EALA, for critical months of summer and winter i.e. June and Dec. The simulation shows that there is considerable improvement in the number of sunlight hours both for summers and winters by adjusting the louvers at selected monthly angles (selected louver angles used for simulation are results derived from a previous study). However, EALS performs better in summer as compared to EALA.

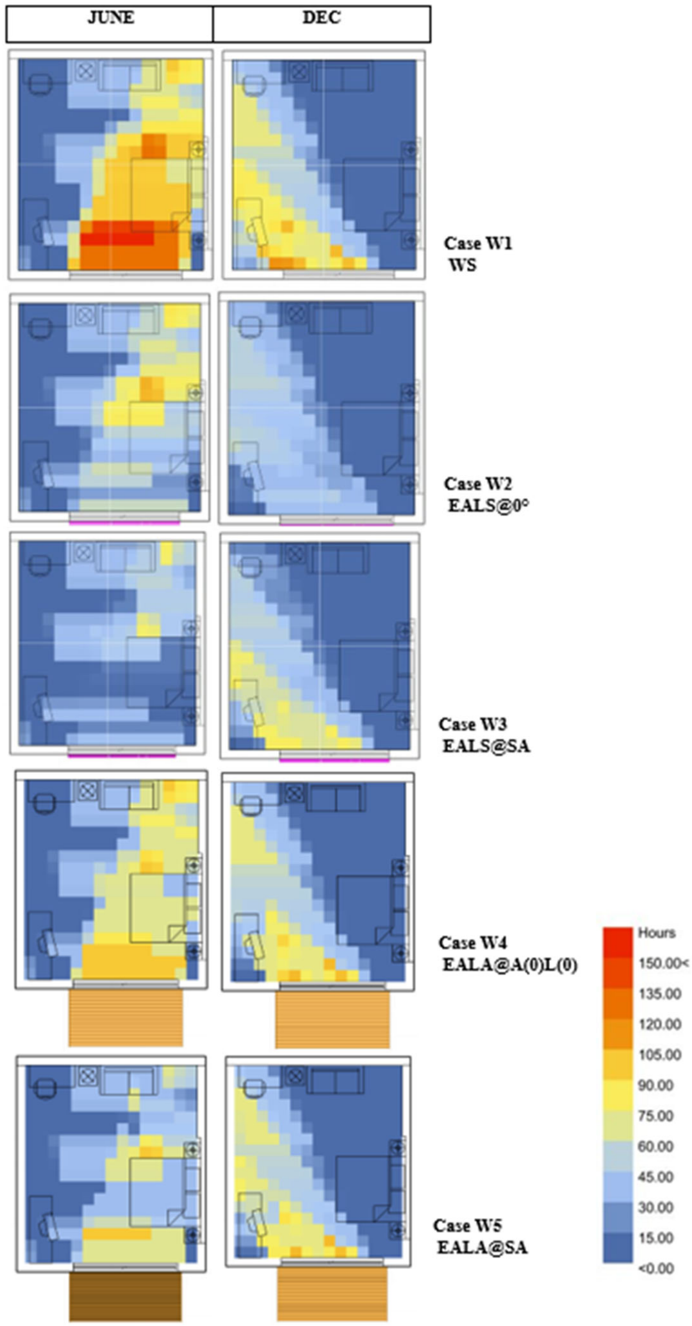
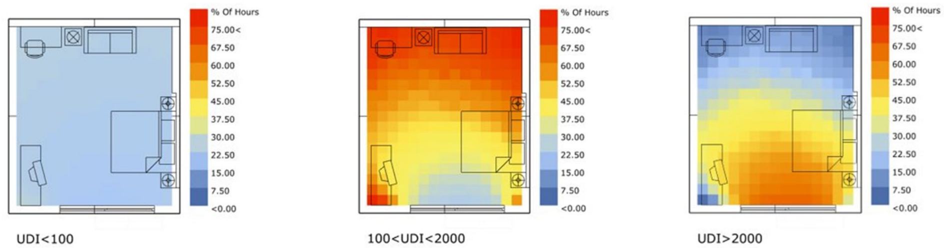


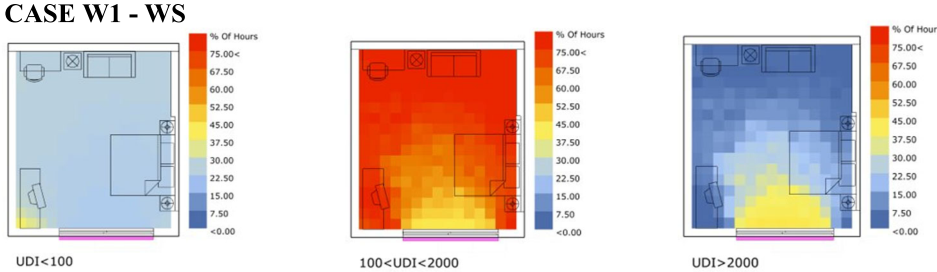
Figure 8: Sunlight hours in the room for months June and Dec
Source: Author

FALL **USEFUL** **EXCEED**



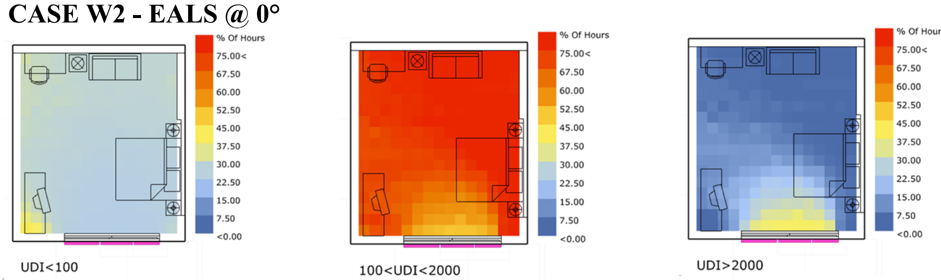
UDI <100 = 19.52 % **100< UDI < 2000 = 49.74** **UDI > 2000 = 30.69 %**

CASE W1 - WS



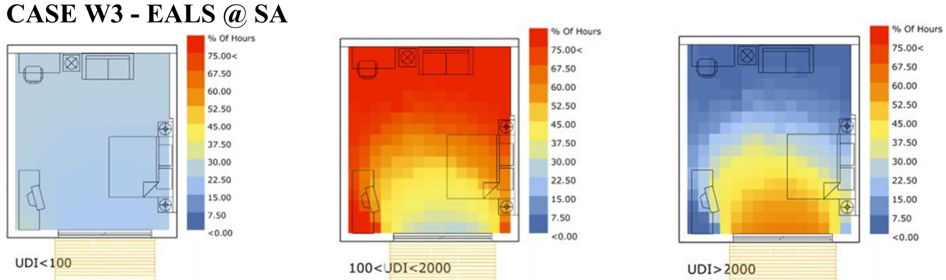
UDI <100 = 21.20 % **100< UDI < 2000 = 67.20** **UDI > 2000 = 11.58 %**

CASE W2 - EALS @ 0°



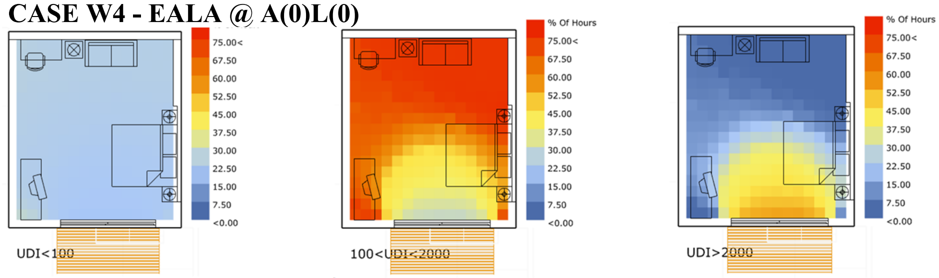
UDI <100 = 23.59 % **100< UDI < 2000 = 69.42 %** **UDI > 2000 = 6.98 %**

CASE W3 - EALS @ SA



UDI <100 = 20.50 % **100< UDI < 2000 = 60.22** **UDI > 2000 = 19.31 %**

CASE W4 - EALA @ A(0)L(0)



UDI <100 = 21.11 % **100< UDI < 2000 = 62.90** **UDI > 2000 = 15.96 %**

CASE W5 - EALA @ SA

Improvement in Useful Daylight Illuminance (UDI)

As per Useful Daylight Illuminance, the annual occurrence of daylight between 100 lux to 2000 lux on a workplane is considered useful. The same range is used for the simulation study to find out useful daylight in the master bedroom. The test plane considered for analysis is 600mm above floor level and the hours are from 6:00 am to 6:00 pm. Figure 9 illustrates the results for UDI for the master bedroom. For case W2 (EALS @ 0°), there is a 17.46% improvement (from W1) in useful daylight for analysed hours. For case W3 (EALS @ SA), there is a further improvement of 2.22% in useful daylight. Also, there is a considerable reduction in the overlit percentage of hours when daylight exceeds the required levels, i.e., 2000 lux. The number of overlit hours is decreased by 19.11% (EALS @ 0°), which is beneficial. It is further improved by 4.6% for (EALS @ SA), making it only 6.98% of analysed hours. Over-lit hours may result in glare, which should be analysed further through ASE metrics. For Case W4 - EALA @ A(0)L(0), there is a 10.48% improvement in useful daylight for analysed hours. With EALA@ SA, it further improves by 2.68%. The number of overlit hours are decreased by 11.38%, which is beneficial. It further improves by 3.35% with EALA@SA. However, for cases W3 and W5, the average value does not provide an actual picture, and a monthly study of UDI is conducted for better understanding. Table 4 below shows UDI monthly study results. It can be seen that the excess daylight is much less for the summer months with the use of EALS@SA.

Table 4: Monthly UDI values for EALS@SA and EALA@SA

	EALS@SA			**EALA@SA**		
	UDI <100	**100<UDI<2000**	**UDI>2000**	**UDI <100**	**100<UDI<2000**	**UDI>2000**
JAN	26.42	59.78	13.77	24.87	56.27	18.85
FEB	19.72	62.68	17.57	18.65	56.07	25.16
MAR	24.44	69.74	5.77	21.97	63.89	14.13
APR	29.05	66.47	4.45	22.19	61.62	16.13
MAY	19.87	77.50	2.63	16.51	69.36	14.11
JUNE	20.04	76.64	3.36	16.23	68.98	14.74
JULY	18.94	78.68	2.35	17.65	68.75	13.51
AUG	21.22	77.20	1.55	18.75	68.03	13.26
SEP	19.65	76.53	3.81	19.05	68.18	12.84
OCT	25.35	71.58	3.06	23.12	64.98	11.92
NOV	29.98	56.46	13.64	27.15	52.78	20.08
DEC	28.35	59.82	11.76	27.19	55.89	16.78
Average	**23.59**	**69.42**	**6.98**	**21.11**	**62.90**	**15.96**

As per the room furniture layout, daylight exceeds on the bed (UDI>2000), i.e. for almost 45 – 50 % of analysed hours in case W1. Near the window, it exceeds almost 70% of the duration analysed, which would result in visual discomfort due to excess daylight. The situation is improved in the case of W5 (EALA@SA) but shows the best results in the case of W3 with EALS@SA.

CONCLUSION

As per the simulation study, external adaptive louver shading systems appear to be promising solutions for glazed openings in managing radiations and improving daylight conditions thereby improving the thermal and visual indoor environment followed by a reduction in energy (as per the previous simulation study conducted). It allows the occupant to manage the indoor environment (both thermal and visual) as per the seasonal requirement of composite climate. There is a need for further research in this area especially in the

Indian context by conducting more field studies for validation, design, and comparison of more types of external adaptive shading systems. Further research would not only help improve the thermal and visual indoor environment by personal control but lead to contemporary versions of the traditional Indian shading system back into practice thereby saving energy in the residential sector through design intervention.

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FUTURISTIC GREEN HOSPITAL: NEO PARADIGM

Pooja Meriam

B.Arch Student, BMS School Of Architecture, Bangalore, Karnataka, India, poojameriam@gmail.com

ABSTRACT

Healthcare centers stereotypically use auxiliary resources and cobble more waste. The potency of environmental driven strategies to improve auxiliary management is of censorious significance in the evolution of sustainable healthcare facilities.This paper tries to aim at redefining Hospital architecture as it is becoming a necessity in the upcoming advanced medical and healthcare segment.Focusing on sustainable practices while designing Healthcare Centers will improve the well-being of the building and its occupants.By emphasizing Sustainable Architecture in designing futuristic Healthcare Center, subsuming a Neo Sustainable Paradigm will provide a best in class healing milieu. It calls for the appraisal of architectural practices, discipline and implementations in the field of medical science and built environment to fabricate a better infirmary and healing units. It's time we question and rethink on the lines, on how sustainability can proffer to a better living and to a healthier built form ?

Keywords: Healthcare, Psychological well-being, Biophilic design, Sustainability practices, Eco-friendly environment and community.

METHODOLOGY

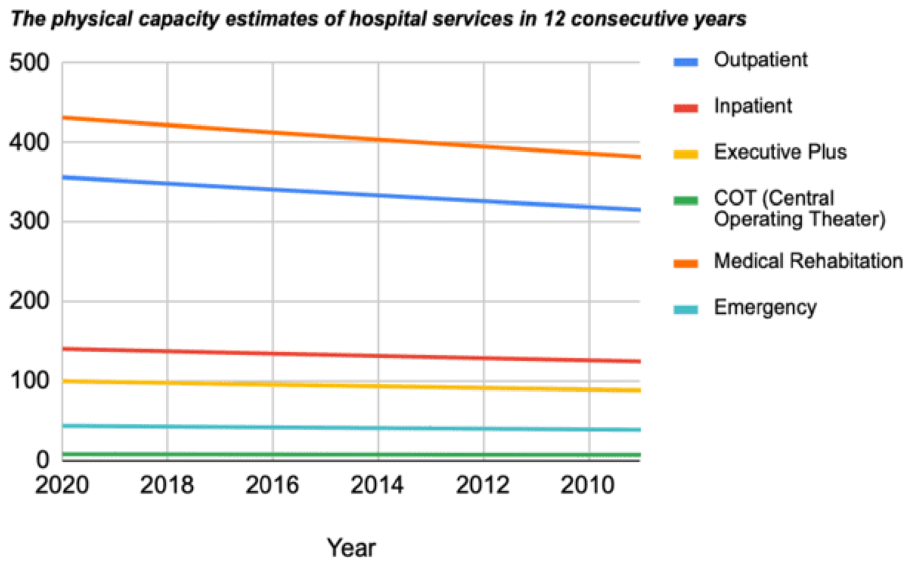
The methodology confines to a comprehensive qualitative analysis and literature review perusal.The modus operandi is to evaluate design aspects for Futuristic Green Hospitals by implementing sustainable practice in the infirmary sector.

DISCOURSE AND PANACEA

This research paper is scrutinized to identify all parameters,corollary and infer Biophilic Design to the infirmary building and bridge a holistic approach to sustainable architecture in the medical sector. This review recognises the approach to architecture on the aspects of catering to a healthy milieu and wellbeing for both the occupants and the environment / diminishing the carbon footprint.

PROLOGUE

Can a building be a healing factor ? As an Architect can we contribute for the betterment of in-patients in Healthcare ? Definitely, it's time to re-think and strategize new action plans for a neo paradigm for futuristic hospitals and healthcare centers. Buildings influence the well-being of inmates as well as the ecosystem.
Hospitals are an essential service in any community.We must look away from the conventional stereotypical hospital and healthcare setups. It is observed that over the years the flow of patients and their inmates' occupancy duration in hospitals has drastically increased over the years in time.



Graph1: The physical capacity estimates of hospital services in 12 consecutive years.
Data Source : Procedia Social AND Behavioural Science Green Building Design Concepts of Healthcare Facilities on the Orthopaedic hospital in the tropics.

Table 1: The physical capacity estimates of hospital services in 12 consecutive years
Data Source : Procedia Social AND Behavioural Science Green Building Design Concepts of Healthcare Facilities on the Orthopaedic hospital in the tropics.

Year	Outpatient	Inpatient	Executive Plus	COT (Central Operating Theater)	Medical Rehabilitation	Emergency
2009	314.91	124.24	88.18	7.22	381.25	38.73
2010	318.41	125.62	89.15	7.3	385.48	39.16
2011	321.94	127.01	90.14	7.38	389.76	39.6
2012	325.52	128.42	91.14	7.47	394.09	40.04
2013	329.13	129.85	92.16	7.55	398.46	40.48
2014	332.78	131.29	93.18	7.63	402.88	40.93
2015	336.48	132.75	94.21	7.72	407.36	41.39
2016	340.21	134.22	95.26	7.8	411.88	41.85
2017	343.99	135.71	96.32	7.89	416.45	42.31
2018	347.81	137.22	97.39	7.98	421.07	42.78
2019	351.67	138.74	98.47	8.06	425.75	43.25
2020	355.57	140.28	99.56	8.15	430.47	43.74

Barriers to create "green hospitals" Greg L Roberts, in his article "shades of green" has cited different barriers to green health facilities, which are as follows:

System redundancy: Requirement of secondary and tertiary backup systems to make sure that operations do not cease during an emergency.
Regulatory compliance- Health and safety regulations and building codes became a barrier for hospitals to adopt sustainable practices.
Operational hours: Health facilities function uninterruptedly throughout the year.
Infection control: Hospitals require strict infection control protocols which often are against sustainability practices.
Ventilation rates: More frequent air changes are required in a hospital as compared to other commercial office spaces.

Accreditation and licensing demands: Compliance with central, state and accreditation standards might prevent facilities to make environmentally sound choices.
Intense energy and water use: Health care uses 2.1 times more energy per square foot than commercial buildings, and hospitals typically use 80-150 gallons of water per bed per day.
High-volume waste stream: About 0.5 Kg of hazardous waste is generated per bed per day.
Chemical use: Hazardous chemicals used to clean and disinfect, sterilize equipment, treat certain diseases and for laboratory research and testing can be toxic and hazardous.
Life cycle: The exteriors of hospital buildings can last long, but interiors require renovations every few years.

A survey conducted by Health Facilities Management (HFM) in collaboration with the American Society for Healthcare Engineering (ASHE) and the Association for the Healthcare Environment (AHE) in 2013 identified many barriers/ challenges that prevent hospitals from adopting environmentally sustainable practices; the top five among them are: competing investment or spending priorities, inadequate staffing for initiatives, underfunded operations and maintenance budgets, perceived higher costs over traditional materials or systems and time limitations.

VISION GREEN HOSPITAL

Our prospects are free of boundaries, we always fail to bridge the alliance of man world to the natural environment or eco friendly operations.Hospitals, Rehabilitation centers, Healing centers in the near future will subsequently undergo mutation due to the ever changing living patterns and unexpected outrageous pervasive break across the world.Particular attention needs been devoted to the role of infection control, staff performance, and the built environment ramifications especially after the recent COVID-19 global pandemic.

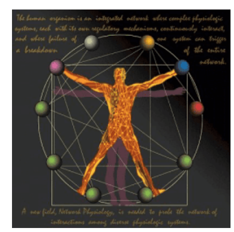
"Green Hospital" abstraction is becoming a cynosure for all eyes. Sustainable designs take precedence specifically for healthcare centers gaining to ameliorate increased interest and cognizance.This swift approach to eco healthcare is predominantly focused around diminishing the carbon footprint of hospitals and thereby implementing a "Green Building" design approach into the healthcare environment to ameliorate and fostering patients and convalesce occupants to tranquility and solace.

Incorporating green practices in infirmary and rehabilitation centers will have a prominent impression in both mankind and the built environment. Green Healing centers would boost the wellbeing by incorporating a sanative course of action by availing natural resources and maneuvering eco friendly stratagem. Implementing green and sustainable practices can intensity a positive and accelerate the curing process of patients. A pragmatic architectural approach to sustainable and green healthcare centers can ensure to create a comfortable and positive healthing environment aiding to enhance patients well-being and comfort which results in a swift curative process. Impending natural and environmentally friendly design schemes can result in a healthy building and yield a positive impact to the surrounding environment.

Lets comprehend how Green Hospital architecture can influence on two aspects and its impact:
Psychological impact on individuals (Patients, visitors and working staff) ➞ Speedy curative period.
Building Efficiency & Energy Efficient Services in hospitals ➞ Eco-friendly milieu.

Source: Khoo Tech Puat Hospital, Singapore

PSYCHOLOGICAL IMPACT



Introducing Biophilic Architecture in hospital and healthcare centers can impact directly in the stress reduction, foster the well being of the patients, and improve the mental-physical-emotional state of the patients. Being close to nature will speed up and improve the healing period of the patients.The more the inclusion of nature by weaving nature and the landscape within the hospital premises, it improves the patient's curative timeframe.

Healing Garden

The influence of Healing Gardens has been proved to bring down the stress levels.A study conducted by Toone (2008) has evaluated that healing gardens can improve psychological well being and researchers in Dell manifested that the users experienced curtailing stress levels in healing gardens comparatively then staying indoors . Healing Gardens can be transformed to a meditation garden to stay in tranquility.Healing gardens will undoubtedly play a vital role for any user category : the specially-abled users, palliative patients, rehabilitation therapy etc Adding natural ethos such as water bodies, greenery, flowering plants can concoct a psychological healing ethos for users. Human acquaintance with nature can diminish the negative effects of human health and well-being (Grinde and Patil, 2009; Maller et al., 2006; Wadsworth et al., 2010; Abdelaal, 2019). Biophilic speculation has been thrived to scrutinize the perspective of human biological inclination to nature (Jiang, 2020; Wijesooriya and Brambilla, 2020; Kellert and Wilson, 1993; Wilson, 1984). Natural elements that are necessary for brain evolution (Rolls, 2012; Irons, 1998; Yeom et al., 2020).


Source: Khoo Tech Puat Hospital **Source:**www.shepherd.orgAtlanta Brain and Spinal Cord Injury Rehabilitation Facilities | Shepherd Center

Intensive Care Unit - Connecting Nature

The ICU could be effectively designed by allowing patients to embrace nature. The windows could face the landscape and Garden which will offer a serene and solace backdrop yielding to tranquilize the anxiety and trauma of patients.


Source:https:*PhilipsLOTUS Neonatal Intensive Care Unit | Philips* ***Source :****Good Earth PlantsPlants and Healing: Hospitals "Greening Up" Healthcare - Good Earth Plants*

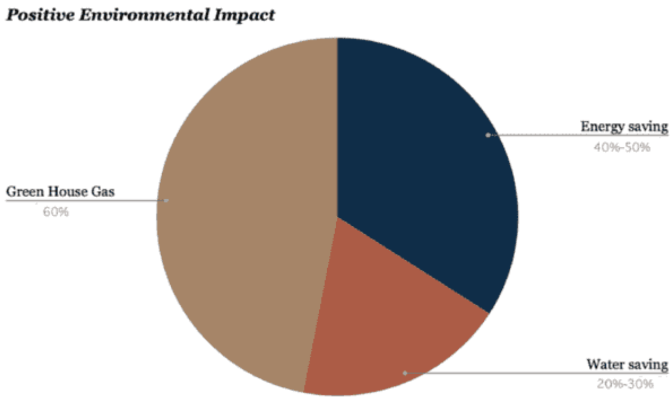
Integrative hospital care - Service in home environment

Hospitals facilitating a combination therapy could diminish the overall cost of treatment and fasten the recovery period.Collaborating western health care along with the local practice pertaining to that region, this can help to optimize the curative process. Designing an integrated hospital to provide both curative and preventive care with a prototype *"service in home environment"* by bridging palliative care and ayurvedic care could enhance quality of life for patients and reduce long term hospitalization. Collaborating Allopathy and Local Regional Medical treatment (Example: Ayurveda / Chinese practices) to patients needs an avant-garde perception which could be a game changer to the medical industry in time to come. Habituating hospitals to an integrating health approach by bridging Ayurveda and Allopathy for patients battling diseases.

Interior Design Flexibility

Redefining Hospital architecture is becoming a necessity in the upcoming advanced medical growth. Designing hospital layout and spaces under modular concepts which could be redefined to adapt to the changing needs and situation. Modular concepts like*"the capsules*" which could vary in size and layout could be adopted. The capsule can be easily replaced when required.

BUILDING EFFICIENCY MILESTONE



Tangible Benefits

- Preserve natural resources
- Leverage onsite non-conventional energy resources
- Reduce Carbon footprint
- Improving Air Quality and Ventilation
- Implementing Automated Technology
- Solace indoor environment and ambience
- Use of eco fabrication and materials indoors
- Connecting With Nature
- Lush Landscaping and green roofing
- Medical waste treatment and disposal system
- Waste reduction and recycling

Energy Efficiency

Hospitals operate 24 hours a day, seven days a week and 365 days a year. To provide high quality care the hospitals will eventually consume more energy.Hospitals consume significant energy use for numerous clinical processes,heating water, temperature and humidity controls for indoor air, lighting, ventilation and with associated significant financial cost and greenhouse gas emissions. The prime scheme to be implemented for green hospitals is to streamline to an energy efficient lighting systems in hospitals which can minimize energy expenses upto 40% - 50%.Switching over to using LED bulbs,hospitals can achieve 80% energy save compared to conventional lighting. LED bulbs contain toxic free elements.Artificial intelligence use of sensors for lighting can be used in hospital rooms and corridors depending on the occupancy flow. By leveraging renewable resources , photovoltaic cells can facilitate the generation of electricity.

Air Quality

Apart from opting energy effective methods, hospitals can concoct designs that penetrate maximum daylight exposure into the spaces and allow natural ventilation to flow in, this way the building stays healthy.Green hospitals must persuade on efficient management of energy resources, improve diagnostic potency and positively cater to patients' treatment throughout the year.

The courtyard can function as a buffer zone to house all interim hustle and bustle without interveing internal areas. Courtyards also facilitate climatic moderation and simultaneously serve visual retreat and acoustic buffers.The user group can enrich their acquaintance oculary transparency from indoor to outdoor.The orientation of the courtyard has a direct influence on the ventilation or wind speed with the interplay of factors such as solar angles and wind direction.From the inference of Meir,et al. (1995) has culminated that the precise orientation of the courtyard can enhance thermal comfort.

Ameliorating the air quality is an important aspect of design in green hospitals. Hospitals are constantly exposed to pathogens and bacterial microbes. Hospitals typically use HEPA filters for treatment of bacteria in air. Implementing UV HEPA filters in ducts and HVAC systems can help to decontaminate the minutest nano microbe particles. Certain UV spectrum of light can annihilate microbes and this will help to purify the air. Techniques which facilitate to achieve green hospital functioning are to monitor carbon dioxide levels at regular intervals in the atmosphere, evaluating HCHCs Hydrochlorofluorocarbons and halons. Implementing the HPFC Hybrid Power Factor system improves the performance and dependency on X-Rays and MRI apparatus. It maintains an equitable load in electrical setup. Adopting HVAC Heating Ventilation and Air Conditioning systems, hospital spaces should be designed and planned to control individually using VAV Variable Air Volume systems for better energy efficiency. Exploring effective methods of diminishing air contaminants,germs and toxics in the building.

Building Quality

Paucity in appropriate insulation in the roofing, wall,etc could impact the patient's well-being causing discomfort and vaxation to the inmates due to solar heat conductance during summer. High-performance Insulation performance can be attained by incorporating. Non-XPS (extruded polystyrene) Insulating Concrete forms since it has recyclable content and excellent environmental features in the hospital Building envelope. Design of facade envelopes can reduce energy consumption. Using Zero VOC materials and natural materials such as types of brick - hollow brick,clay brick, rammed earth bricks and compressed earth block,Autoclaved aerated concrete (AAC). Use of eco fabrication and materials indoors. Implementing design elements such as use of high-efficiency windows, insulated roofing.use of locally available materials and certified wood products. Availing natural materials and environmental friendly can lead to less energy production,transportation and erection on site. Subsequently leading to a health and eco friendly building envelope in the ecosystem.

Inhouse Oxygen Supply Plant service oriented

Installing essential service commodities like Oxygen supply plants within the hospital setup to generate medical grade oxygen. The oxygen supply plant is ready on site to cater to the patients and serve a great support in peak demand during critical care, ICU units and surgical units. This will lead to lesser dependency on external sources.

Acoustic Treatment

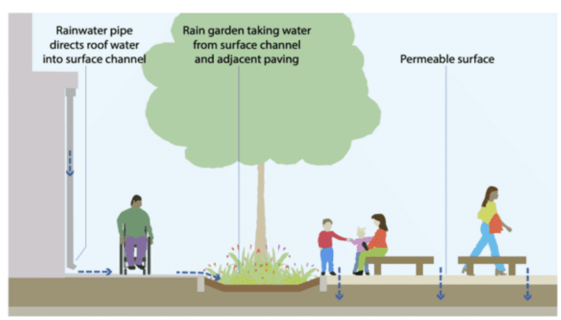
There is a need for acoustic treatments in hospitals. Hospitals do face a problem of noise being heard across the adjacent rooms and corridors, which can cause discomfort and anxiety to other inmates.Mineral wool is the best eco friendly recommended insulation choice. SoundProofing and sound masking is essential in Hospital acoustic treatment.Soundproofing an MRI room to reduce the noise from X-ray machines is just as necessary.Acoustic treatment can help to keep a balance in the mental well-being of the occupants and avoid fluctuations in blood pressure and anxiety levels.

Water Efficiency

Implementation of water management and a focusing on the reuse of resources, hospitals can achieve saving water upto 20% - 30% . Use of sensor taps, flushing and showers can eliminate wastage of water thereby reducing water flow upto 50% when compared to traditional washbasin faucets.

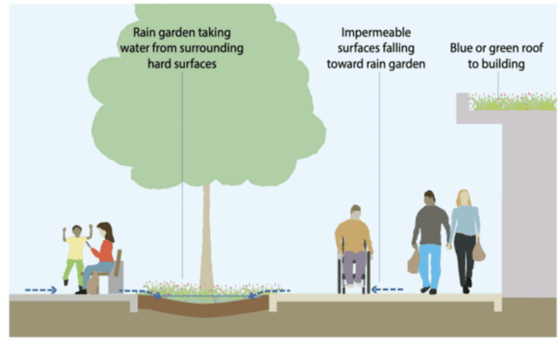
We must move a step forward in incorporating rainwater harvesting techniques in the hospital building.

Figure Permeable surface and rain garden



Choosing Green roof is an eye catching and interesting approach to facilitate rainwater harvesting. Blue roofing is presently quite an obscure technique but blue roofing is a much more effective and sustainable approach to roofing. It helps to store rainwater effectively and also insulate the building envelope thereby providing good thermal comfort.The Rainwater once collected from the impervious surfaces and roof and then diverted to a percolation pit which will eventually rejuvenate the ground water table naturally.Utilizing water efficient techniques for landscaping on site such as xeriscaping.

Figure SuDS features on the roof and ground

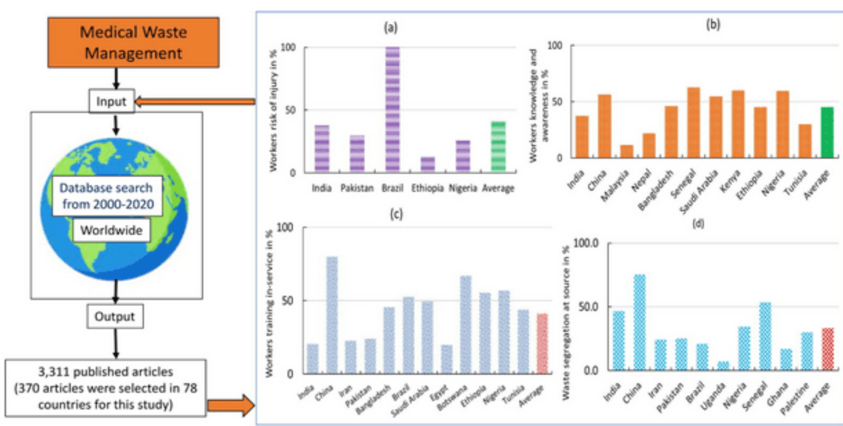


Adopting Sustainable Drainage systems SuDS create attractive and aesthetically pleasing green infrastructure thereby reducing the risk of flooding , water contamination and water clogging in hospitals and healthcare units. Inculcating Sustainable practices in hospital buildings can improve the citiznen's quality of life and well-being which sequels to a hygienic environment & healthy society.

Source:*https://www.london.gov.uk/sites/default/files/reimagining_rainwater_in_hospitals_nov20_1*

Waste Management

Reducing on site pollution and waste discarding.Waste reduction through recycling bio waste.e-waste and conducting a waste audit. Biomedical waste disposal is a challenging issue across the world. Various countries adopt different bio-waste disposal systems be it the Landfilling method, microwave radiation method, pyrolysis and chemical treatment. The upcoming technology in treatment of Bio-waste is the Photocatalysis waste treatment which can eradicate pollutants at a greater potential. It is a secure and a cleaner disposal method. Use of biodegradable material even in making of PPE kits is another strategy of sustainable practice. On-site waste treatment plants can help to reduce the risk of contamination of neighborhood zones and water thereby building a cleaner environment.
WasteWater from hospitals should be treated before being discharged to other water sources. Nano-Based technology or nanotechnology has gained its importance in liquid waste treatment. Nanomaterials ranging in size 1 - 100 nm can be decontaminated by opting for Nanotechnology waste treatment. It is an eco-friendly and low cost reduction tactic.

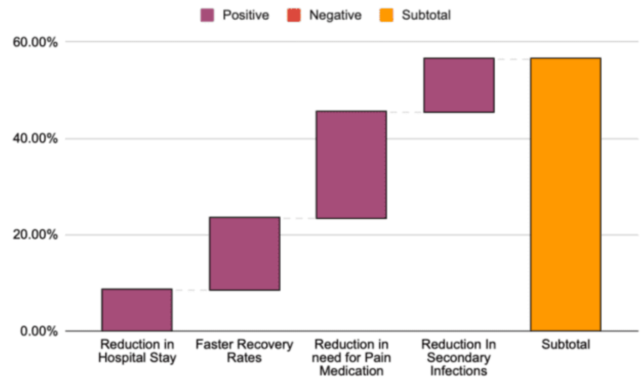


Source:*Medical waste: Current challenges and future opportunities for sustainable management*
Narendra Singh,Oladele A. Ogunseitan & Yuanyuan Tang

EPILOGUE

Redefining Hospital architecture is becoming a necessity in the advanced medical growth.
A Sustainable and Green Architectural approach to healthcare centers can ensure to create a comfortable and positive healthing environment aiding to enhance patients well-being and comfort which will result in a swift curative tactic. Opting to eco-friendly sustainable design practices will yield a positive impact on the surrounding environment.

Emphasizing and implementing Sustainable Architecture in designing futuristic Healthcare Center, subsuming a Neo Sustainable Paradigm will provide a *Best in Class Healing Milieu.*



Source:*Khoo Tech Puat Hospital*

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SUSTAINABLE CONVERSION OF WASTE SEASHELL TO PARTIAL REPLACEMENT OF AGGREGATES IN CEMENT MORTAR: A REVIEW

Gayathri S Shivakumar[1], Sophia M[2]

[1]Associate Professor, BMS School of Architecture, Bengaluru, India. ashagayathri@gmail.com
[1]Research Scholar, Depart ment of Civil Engineering, CMR University, Bengaluru, India
[2] Assistant Professor, Department of Civil Engineering, CMR Institute of Technology, Bengaluru, India. sophia.m@cmrit.ac.in

ABSTRACT

Sustainable concrete is done using alternative materials obtained from natural resources, recycled materials, bio-waste and industrial by products. Seashell is an excellent lightweight alternative building material. Investigations have been experimentally carried out using different types of shells obtained from natural and by mariculture. Waste Seashells can replace aggregate in mortar and cement concrete. Seashells have been used as a partial to total replacement to fine and coarse aggregates in concrete. The literature review on seashells aggregate mortar presents an overview of the physical, mechanical, and thermal properties of seashell aggregate mortar. The addition of seashell aggregates in mortar reduces the physico-mechanical properties of the mortar. The understanding of the seashell aggregates mortar provides a base for further investigations.

Keywords:c Seashell Aggregates, Sustainable mortar

INTRODUCTION

Sustainable concrete is green concrete which can achieve high performance by using alternative raw materials along with the conventional materials in the concrete mix. Demand for use of natural resources has resulted in the search of alternative natural materials which in turn has given scope for utilisation of waste materials, industrial by products and recycled materials to produce sustainable concrete [1]. Green concrete – a concept which takes into consideration of the environmental aspects with respect to sourcing of raw materials, design mix and structural designing, construction process, maintenance etc. [2].

Iin the production of green concrete, the waste materials that are mainly used are agricultural, industrial, and municipal wastes, which are activated through either physical, chemical or their combination [3], [4]. One such material is seashells – which show good performance in physical and mechanical properties [5].

The exoskeleton of molluscs such as snails, oysters, clam, scallop, periwinkle, cockle, abalone, shrimp, etc are known as shells. They may be of sea or freshwater origination. Shells may be obtained naturally or cultured. Naturally obtained shells also contributes to the growth of cottage industries in the manufacture of artifacts. The aquaculture and mariculture industry play an most important role in supply of sea food to the food industry [6]. However, considerable waste in the form of seashell is produced [7]. Seashell wastes when left untreated for long period of time leads to microbial decomposition releasing hydrogen sulphide, ammonia and amines leading to environmental hazards and waste management [8].
Shells plays an very important role in the growth and development of human culture in the form of currency, aesthetic construction, medicinal purposes, amulets and jewellery, utensils for storage and cooking, etc. [9], [10].

Many investigations have been conducted on utilization of shells in construction through waste management [11]. The seashell can be an eminent solution to the construction industry as a sustainable alternative building material which can partially replace each component – cement, coarse aggregates and fine aggregates - in the form of powder or crushed particulate [24].

In the construction industry, Shells from Oyster, clam, cockle, mussel, Peruvian and queen-scallop are utilized as re placement for cement and coarse aggregate, also Coral Reef is used in replace the fine and coarse aggregates.[12],[13]. The experimental investigations conducted on the physical properties of concrete made from natural aggregates when compared to the regular conventional cement concrete is higher [14].

Fig. 1 VariousTypes of SeaShells: (a) Oyster shell; (b) clam shell; (c) razor shell; (d) scallop shell; abalone shell; (e) shrimp shell [24]

PARTIAL REPLACEMENT OF FINE AGGREGATES IN MORTARS

Physical Properties:

Yang, E.I. et al noted that the mixture of oyster shell particulates and cement paste, do not affect the hydrate property and performs only a role of fill in the mortar matrix [19]. The mortars with partial replaced fine aggregates containing seashells were also found to be more workable [23]. As the ratios of replacement of the seashell particulates increased, it was found that the final setting times also increased to that of the control mortars [21]. The water content in capillary pores present in the cement paste results in drying shrinkage in the mortar [24].

Mechanical Properties:

The most sustainable application of seashells in construction industry is the replacing of natural aggregates used in the production of mortar and concrete. Various experimental investigations reveal that the main criteria to determine the maximum level that can be the replacement of aggregates(fine) by seashell particulates is to obtain the mortar without compromising on the workability of the mortar and its strength[15], and due to the angular shape property in seashell aggregates additional cement paste is needed to obtain the required workability [16, 17, 19]. Yang et al. [19] studied that the 28 days compressive strength of 5%,10%, 15% & 20% replacement of aggregates(fine) in cement mortar reduced by increasing the ratio of the seashell aggregates

Edalat et al.'s [11] investigations showed decreased workability due to the increase in water absorption since the fine particulates coat the fine aggregates leading to impairing the aggregate-cement paste bond. The compressive strength of mortar increases with duration . The flexural strengths also increased with age. The studies made by Safi et al. [20] showed that the fluidity of mortar slightly decreased depending on the percentage replacement was a result of angularity in the shape of crushed seashells against the spherical shape in sand which promotes the movement [Fig. 1].

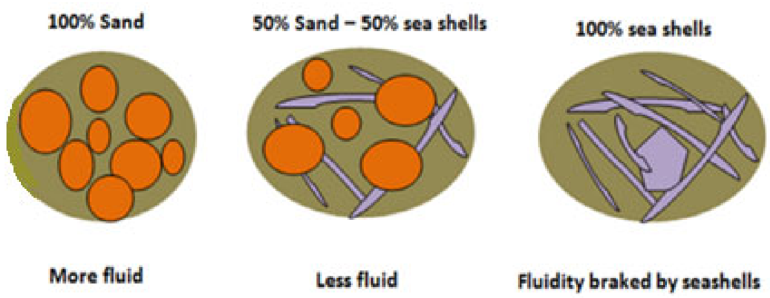

Fig. 2 Effect of angular form of crushed seashells on fluidity [20].

Thermal Properties:
Lertwattanaruk et al. used cockle shells in mortar and found out that it exhibited low thermal conductivity when compared to the control mortars as shown in Fig. 2 [21]. It was observed that the increase in the replacement of shells (percentage) reduces the thermal conductivity of the mortar due to the lower specific gravity of the shells. It was also noticed that as the density of the mortar reduced the porosity levels increased and hence the reduction in the thermal conductivity.

Ez-zaki et al developed eco-friendly mortar using mussel shell wastes as partial replacement for sand, found out that an increase in shell powder up to 60% resulted in 34% reduction of thermal conductivity and considered it as an effective and sustainable method to improve thermal insulation. He also attributed this property to low specific surface area which leads to the increase in the size of capillary pore which thereby reducing the thermal conductivity and increases the thermal insulation [22], like the results obtained by Lertwattanaruk et al.

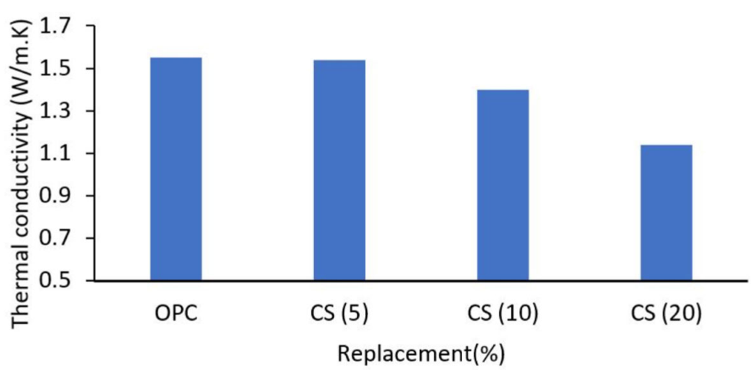

Fig. 3 Thermal conductivity of mortars with ground seashell partial replacement for fine aggregates [21].
OPC – Ordinary Portland Cement
CS (5) – Cockle Shell mortar with 5% replacement of fine aggregates
CS (10) - Cockle Shell mortar with 10% replacement of fine aggregates
CS (15) - Cockle Shell mortar with 15% replacement of fine aggregates

CONCLUSION

It has been observed from studying the physical properties that the workability in fresh mortar decreases with the increase in the percentage of up to 50% seashells replacement as fine aggregates. The studies on mechanical properties shows that there has been a substantial reduction of dry shrinkage due to the evaporation of water through capillary action through the pores. The initial compressive strength along with flexural strength is found to be low, however there is an increase in compressive strength and flexural strength with age. The test results studied shows a decrease in thermal conductivity however there has been an increase in thermal insulation due to the reduced pores

SCOPE

Seashells, used as partial replacement of conventional fine aggregates, exhibits better thermal properties giving a chance to be further explored and investigated with an aim to increase the sustainability features in the building or structure to make a better living condition.

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HYDRO-GEN: AN ATTEMPT TO REIMAGINE ALTERNATIVE URBANISM AT THE CONJUNCTION OF SUSTAINABILITY AND ARTIFICIAL INTELLIGENCE

Sri Keshava Tanguturi[1], Sunny Bansal[2]

[1] Student, Department of VSPARC, Vellore Institute of Technology, Vellore - 632014, India (tangukesh@gmail.com)
[2] Assistant Professor, Department of VSPARC, Vellore Institute of Technology, Vellore - 632014, India (ar.sunnybansal@gmail.com)

ABSTRACT

In this Anthropocene age, Countries characterized in increasing their efforts to reduce carbon emissions, everything from how we generate and use energy to how we travel and even how we live in our homes are evolved – due to which our life and habits drastically change to time. In this era, nurturing the overall sustainable living style has made a massive impact in the overall carbon emissions. One of them is the Hydro-Gen project. In the city of India, Kochi – Hydro-Gen city: aspires to construct an eco-city powered by hydrogen fuel and renewable energy sources. Residents may live, work, and manufacture green energy products for everyday use. This initiative is critical in promoting sustainable living and its standing as a research and innovation Center in Kochi. The two-phase program completes the integration of Project Hydro-Gen's goals to the city. Phase I entails creating developed urban areas inside the city to influence the prospective neighborhood. In Phase II, the envisioned urban tissues and communities are linked by Artificial Intelligence (A.I) involved in transit, energy consumption, and information transmission. Though the initiative is critical in establishing and spreading the new adaptation of services with A.I, it further aims to build an eco-city powered by hydrogen fuel and renewable energy sources. Project Hydro-Gen believes in efficiency plays a key role in maintaining the energy demands for which future technologies, such as a digital operating system for the city's infrastructure could be of great advantage. The paper focuses on bringing the essence of importance in planning in reducing carbon emissions on city scale and additionally analyses with proposals of A.I integrated societies in the city Kochi. Hydro-Gen will be a home for those who wish to develop a paradigm for sustainable living while following the principles of sustainability, Incubation, Transit-Oriented Development and Human centric planning[38].

INTRODUCTION

The world is urbanizing at an unprecedented rate. Cities have become the center of economic and social life, as well as the primary focus of energy consumption and carbon dioxide emissions. The United Nations reports that more than 50% of the world's population now lives in cities, and that number is projected to increase to 66% by 2050. (Wu et al., 2016) According to the World Bank, urban areas are responsible for more than 70% of global energy consumption and generate more than 80% of global carbon dioxide emissions. Efforts to reduce these emissions have largely been focused on measures to improve the efficiency of energy use in cities[39] (agency, 2015)

In fact, the world has come up with ways to tackle the situation by making use of renewable energy sources and energy systems, from urban planning to individual buildings. This led to reflect Project Hydro-Gen – the city powered and regulated by green energy and artificial intelligence.

[38] Hydro-Gen: An attempt to reimagine alternative urbanism at the conjunction of sustainability and artificial intelligence. (Thesis paper submitted to VIT by the author) Tanguturi Sri Keshava.

[39] The International Energy Agency (IEA)

Project Hydro-Gen:

Hydro-Gen offers a fresh perspective on the future. It's an attempt to achieve something beyond renewable energy, food, and shelter. It is a mission to recreate alternative urbanism at the correlation of sustainability and artificial intelligence using principles of sustainability, Incubation, Transit-Oriented Development and Human centric planning.

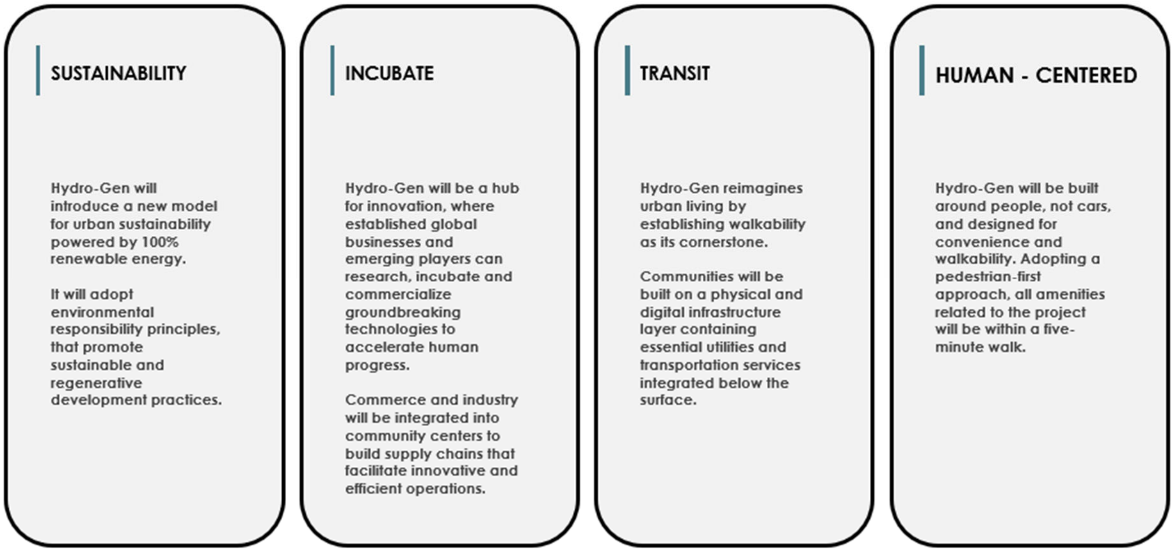


Figure 1: Principles of Hydro-Gen.
Source: Author

Green Hydrogen in Urban Design

Cities are at the cutting edge of the green economy, continually reinventing themselves to fulfill the demands of their citizens while also ensuring long-term sustainability. Cities, on the other hand, are at a crossroads: with the need to expand infrastructure to accommodate a rapidly growing population, cities face a difficult choice: expand with traditional infrastructure that contributes to the climate crisis or invest in the future and build a climate-friendly and resilient city. The answer is simple: investing in the future and constructing climate-friendly cities is the only choice. The use of green hydrogen in urban architecture is one of the most promising avenues for making cities more environmentally friendly.

Today, the most intriguing method to employ green hydrogen is to incorporate it into urban design. Although technology is currently too fresh to have a significant influence on our cities, the promise is evident. Green hydrogen will enable us to construct contemporary cities in which the sole byproducts of our structures and infrastructure are clean water and breathing air. (Ruf, 2018)

Artificial Intelligence in urban development

Artificial intelligence (AI) has the potential to improve many aspects of urban life, from city planning to the delivery of services. The ability to leverage AI in the city could help to reduce parking shortages, increase public safety and reduce traffic congestion. The adoption of AI in the city could also improve the efficiency of services, such as the management of transportation systems, healthcare, and building energy use. This would help to increase the quality of life for residents, enhance the economy and increase the competitiveness of cities on a global scale.(Allam and Dhunny, 2019)

Hydro-Gen is the conjunction of both using green hydrogen and artificial intelligence in providing durable and sustainable urban development.

PROJECT STUDIES

A critical examination of urban initiatives such as Auroville, Agro Food Park, and ReGen Villages has enriched the paper's goal of achieving sustainability through their planning and design tactics. ReGen Villages, Denmark: Food production is increased by the use of A.I in farming practices, with farming proposed as a side hustle of the residents' everyday lives (Villages). Auroville's galaxy-themed urban layout enticed soft mobility (non-motorized transportation) (committee). Agro Food Park: A carbon positive city, with clean water, air, soils, and energy that serve as a constant source of economic and ecological innovation and regeneration, so establishing an energy loop (Partners, 2015). The project's objective of achieving self-sufficiency through various techniques extends to the goals of city Hydro-Gen (Kochi).

HYDRO-GEN CITY KOCHI

Why Kochi?

The seaside city of Kochi, India is poised to become a leading player in the production of green hydrogen. The city has already made significant strides in the adoption of renewable energy and is now looking to build on that progress by becoming a hub to produce green hydrogen. The city has the potential to become a leading player in the green hydrogen economy due to its abundance of renewable resources, its existing infrastructure, and its commitment to environmental sustainability. The city has recently begun using green hydrogen to power some of its buildings. This is a very important step, as it shows that the city is willing to invest in new, cleaner technologies. The city's investment in green hydrogen is part of a larger trend of cities around the world investing in clean energy.

From this prospect the following factors impacted the evaluation of city Kochi as a Hydro-Gen city.

- Global and regional connections
- The rate of urban development
- Accessibility to Green Hydrogen manufacturers
- Level of adaptability to the usage of green hydrogen
- Level of capacity to execute TOD
- Tourism magnet
- Density of population
- Initiatives on reducing carbon emissions.

Hydro-Gen should also be able to influence the further urban development of the city, Kochi with population more than 600,000 is on verge of becoming one of the crucial cities of south India with their economic growth and a huge influx of migrants. And with initiatives towards green hydrogen in public facilities altogether favored the polices of project Hydro-Gen in Kochi (corporation).

Septa Sense

Analyze the nature and perception of the city from the perspective of evolution and living environment in current and future situations. The paper required a bandwidth to compare different parts of cities in order to comprehend the city and discover the best location for expansion in the city. "Septa Sense" was invented to define a categorizing system that contained a set of parameters and boundaries for analyzing the neighborhood.

To investigate the city Kochi, septa sense follows the steps below:

Step 1: Divide the city into smaller sections using roads, terrain, and railway tracks. (Perception of the visual)

Step 2: Using the seven factors, assess the separated portions.

Step 3: Assign classes to the various segments of the city.

Step 4: Analyze the growth pattern and shortlist the prospective segments influencing the most on future urban development.

Classes Allocation

'Any segment that scores more than or equal to 5 gets qualified for that class which is defined below.

- **CLASS α (Alpha):** Rich in the naturalness of the settlement or Rich in an environment with a human change.
- **CLASS β (Beta):** Rich in culture, tradition, or vernacular elements.
- **CLASS γ (Gamma):** Rich in infrastructure. (Both social and economic)
- **CLASS δ (Delta):** Has a high scope of development
- **CLASS λ (Lambda):** Has no scope of development

Note: A settlement could come under two or more classes according to the qualifications of the site'.(Tushar arora et al., 2022)

Step 1

Kochi city is separated into 13 settlements by physical borders like as highways, canals, junctions, bridges, and terrain.

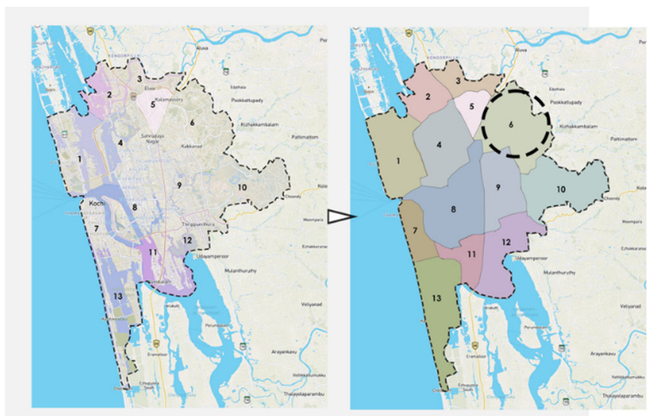


Figure 2: Kochi visual division.
Source: Author

Step 2

The separated settlements are then assessed using seven septa sense parameters. The table below illustrates the appraisal of settlements with an example.

S.NO	FACTOR	9	7	5	3	1	SCORE
1	**Population density**	>4000/sq.km	3000-3500/sq.km	2000-2500/sq.km	1000-1500/sq.km	<400/sq.km	7
2	**Economy**	Very High in contributing to profitable income	High in contributing to the profitable income	Good in contributing to profitable income	Poor in contributing to profitable income	Very poor in contributing to profitable income	5
3	**Culture & vernacular elements**	Excellent in maintaining their culture or character/ Possess very rich vernacular elements.	Very good in maintaining their culture or character/ Possess very good vernacular elements.	Good in maintaining their culture or character/ Possess good vernacular elements.	Poor in maintaining their culture or character/ Possess some vernacular elements.	Very poor in maintaining their culture or character/ Possess very few or no vernacular elements.	3
4	**Energy**	Very High in consuming energy (water, electricity)	High in consuming energy (water, electricity)	Average in consuming energy (water, electricity)	Low in consuming energy (water, electricity)	Very Low in consuming energy (water, electricity)	5
5	**Biodiversity**	Very less/ No change in the naturalness of the settlement. (or) excellent in contributing to the environment through human change.	Less change in the naturalness of the settlement. (or) good in contributing to the environment through human change.	50 % change in the naturalness of the settlement. (or) average in contributing to the environment through human change.	70 % change in the naturalness of the settlement. (or) poor in contributing to the environment through human change.	90 % or more change in the naturalness of the settlement. (or) worse in contributing to the environment through human change.	5

Figure 3: Septa sense parameter study.
Source: Author

Majority land-use – Industrial, Commercial, Residential

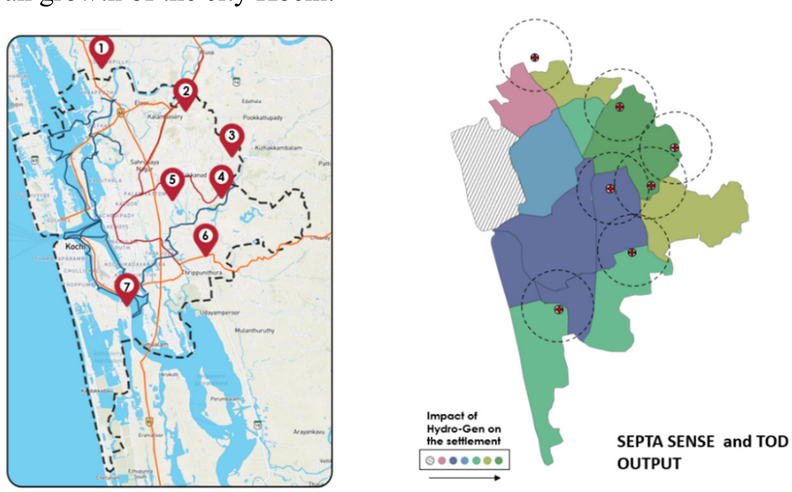
Topography & physical features – relatively steep and water features are stopping the growth of urbanization.
Settlement classes from the analysis **– [α, γ, λ]**
This process is then advanced to all separated 13 segments of city Kochi.

Step 3
To assign septa sense classifications to the 13 separated localities. Any class-related aspect must be considered while designating settlement classes.
For example, Settlement 6 [Table 3]

Population density – 7
Land use – Residential, Institutional & Commercial
Economy – 5
Culture and Vernacular elements – 3
Energy – 5
Topography – relatively steep and water features are stopping the growth
Biodiversity – 5
Any parameter exceeding 5 qualifies for their respective class. Therefore, for the above situation –It could possess classes **α, γ, and λ.**

Step 4
With the classifications assigned to each settlement, a plan illustrating the qualities of each community might be constructed. With this, one may discover development potential based on Hydro-Gen's goals.

Kochi – TOD & Septa Sense Study
Barcelona demonstrated a high population density per square meter while releasing significantly lower levels of carbon (Alain Bertaud), and Project Hydro-Gen believes that Transit Oriented Development played a critical role in decreasing carbon emissions in terms of mobility and land use. The project Hydro-Gen was able to pick prospective locations by analyzing the patterns of Kochi's transportation system, which include metro ways, waterways, and roads, and blending that study with septa sense output of Kochi. These selected settlements are integrated with current and forthcoming public transportation and are also most likely to influence future urban growth of the city Kochi.



'From [figure 2] one could identify how the integrated information is used to select seven prospective locations for integrating the concept of Hydro-Gen.

1. **Varapuzha**: Highway transit – Residential Typologies
2. **Kalamassery**: Highway, road metro transit – Residential and institutional Typologies
3. **Kakkanad:** Highway transit – Residential and institutional Typologies
4. **Chittethukara:** Road metro, water metro transit – Residential and commercial Typologies.
5. **Vennala:** Highway transit – Residential Typologies.
6. **Thrippunithura:** Highway and road metro transit – Residential Typologies.
7. **Edakochi:** Water metro transit – Residential and commercial Typologies.'[40]

As a result, prospective communities will be subjected to Hydro-Gen principles. The Kalamassery settlement was chosen as the location for a Hydro-Gen pilot project.

PHASE IMPLEMENTATIONS

The pilot settlement along with other six settlements undergo in developing their urban tissues in two phases of project Hydro-Gen to the context of their locality.

Phase I
Hydro-Gen, with the selected seven Kochi settlements, assigns each settlement with their unique essential activities and proposals in accordance with URDPFI rules. As envisaged, these settlements will have a significant infrastructure value, including future technology services on-site. As a result, large population density may be accommodated while maintaining excellent living quality and infrastructure value. Though the selected sites do have a mobility and transit network, minimal changes are implemented before the onsite proposals concerning the context. These later effects the nearby communities.

Phase II
The proposed urban tissues are now linked to multi-disciplinary transit networks that span crucial areas of the city. This permits the use of public transportation to make it simpler to commute to private ones. These seven settlements are linked through information transparency so that A.I may improve its methods of managing the settlements.

HYDRO-GEN: KALAMASSERY PROJECT

Using the transit-oriented development concept, the site Kalamassery has the potential to construct a transit loop that connects inhabitants to adjacent public transportation networks. The loop's primary purpose is to connect this neighbourhood to the city's broader transit system, making it more accessible by public transportation. Furthermore, the Hydro-Gen proposal suggests minimizing motorized transportation and enabling a soft mobility friendly (non-motorized transport) neighbourhood.

Population Density & Requirements (building programme)
According to the URDPFI guidelines of Kochi, the average gross population density is 32 per hectare in the year 2001 and is projected to be increased to 51.32 per hectare in the year 2031. (Municipality) With the knowledge of the intensity of the increase in population density, the estimated population density for the Kalamassery urban settlement in the year 2031 is 174 persons per 10 acres. With the density, one could identify the necessary requirements from Urban & Rural Development Plan. Formulation & Implementation (URDPFI) guidelines

Site

[40] Hydro-Gen: An attempt to reimagine alternative urbanism at the conjunction of sustainability and artificial intelligence. (Thesis paper submitted to VIT by the author) Tanguturi Sri Keshava.

The whole idea of urban planning is based on transit-oriented development, with the distinction between non-motorized and motorized modes of transportation playing a significant part in producing a pedestrian-friendly environment. Transit-oriented development is implemented at the site level. A route that connects the Eastern collector road to the Western arterial road via Hydro-Gen's site. A loop connecting the arterial roads and major arterial roads for the Hydro-Gen feeder bus. This bus assures that the site's occupants use their handy public transportation by collecting them at proposed Hydro-bus stations around the area. These Hydro-Bus stations are proposed along the Figure 5 loop. This provides Kalamassery locals with a consistent and easy link to public transportation.

Figure 5: Hydro-Bus feeder loop – Kalamassery.
Source: Author

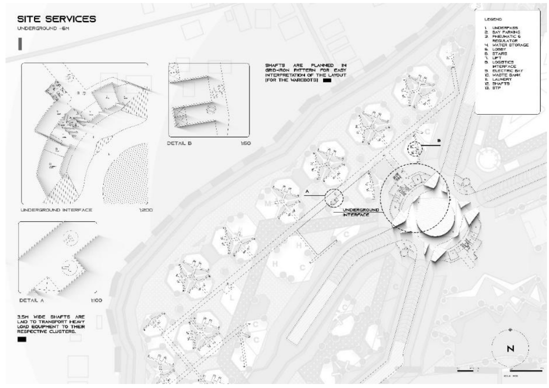
Aside from that, Hydro-Gen hopes to achieve a planning concept with no pedestrian-motorized intersections. This is accomplished by orienting routes at various levels. Considering design factors for offering smooth pedestrian transportation and automation services. A motorized underground corridor with a complex to maintain automation and A.I underground works as a solution. This provides continuity on the ground floor by utilizing soft transportable amenities for public interactions with seamless automation and A.I services.

Figure 6: Kalamassery Site plan.
Source: Author

Site Services

Since transportation is managed by changes in the roadway network, the installation of the service complex is served by an underpass. The service sector complex is proposed at the intersection of underground roadways, which administers services such as logistics, energy, water, laundry, and garbage. These services are automated using robots and managed by A.I. and humans. This section of the design incorporates the interaction between robotic automation and human interpretation. To sum up the entire service system, think of it as a wending machine that responds to the requirements of the site's occupants. This is planned with the installation of a shaft network connecting residential (receivers) to commercial, and service plots (providers). The shafts are laid out in a grid pattern to allow robots to forecast and interpret data more accurately. Figure 7 demonstrates on site services situated underground.

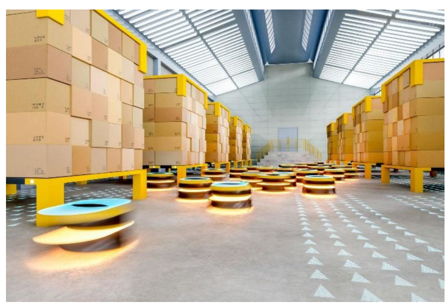
Figure 7: Kalamassery site services.



Source: Author

Implementation of AI and Automation to the residents

The residential and commercial plots are designed to engage relation with robots and A.I in the daily living of Kalamassery residents. The shaft system provides services like Laundry, logistic and merchandise and garbage management through automated robots. Figure 8 demonstrates a prototype of Hydro-gen service system providers.



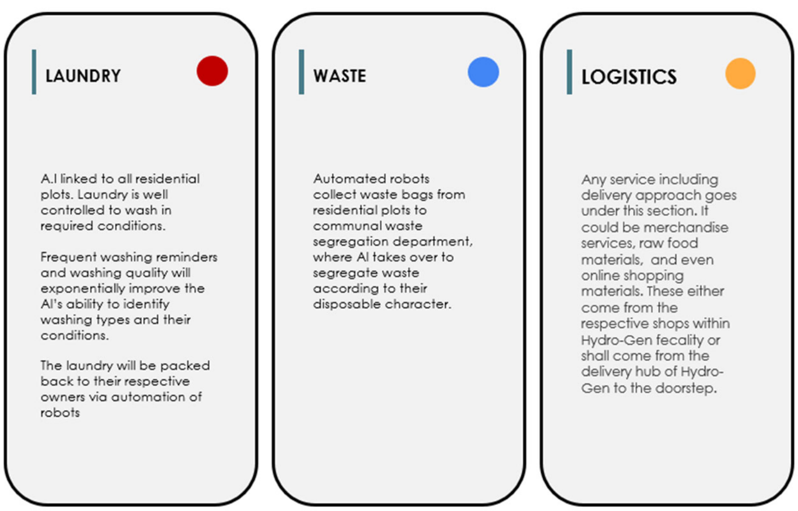


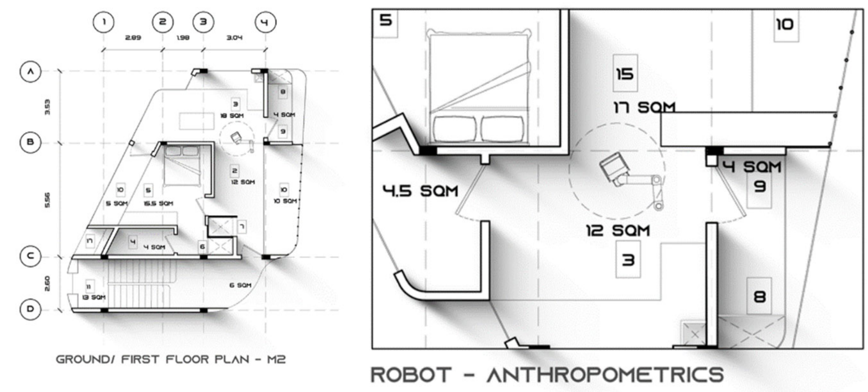
Figure 9: *Automation services on site.*

Source: Author

The service systems are assigned to different robots classified by color. These robots perform the job of collecting and transferring the goods and services as per Figure 9.

Residential typologies

In accommodating a high-density module, a fractal-based concept for housing served the inhabitants of Hydro-Gen. This fractal pattern is demonstrated in the site plan of Kalamassery in Figure 6. The residential typologies come with intervention of spaces with both Human and robotic anthropometrics [Figure 10]. The typologies vary from 1BHK to 2BHK housing flats in one plot. Figure 10 shows the plan of 1BHK housing typology. The shafts in residential plots are conveniently placed at entrance for logistic and laundry services [no.7 in Figure 10]. While the garbage shaft is provided at the utility space [no.8 in Figure 10]



CONCLUSION

Hydro-Gen with its concept of involving the site according to transit-oriented development creates a transit loop with a feeder bus to enhance the use of available public transport. While managing transport, the land use of the project is enhanced with the capabilities of introducing commercial aspects to the site. This enabled Hydro-Gen to propose, a sustainable urban incubator in the setting. The proposal revolves around implementing green hydrogen in energy consumption as a primary resource, in addition, it is proposed to be regulated by artificial intelligence which helps interpretations and data predictions. All these concepts are integrated with transit-oriented development.

Hydro-Gen is prone to increase revenue for public transport networks for their immense use, and for the green energy production sector in increasing their demand in the present city. As a result of reduced traffic congestion, the environment gains advantages as well. Pedestrian and bicycle safety is increased by non-motorized infrastructure. Hydro-Gen's concept of involvement with urban development, urban planning, and urban living of a city is apt to decrease the carbon footprint and carbon emissions.

NOMENCLATURE

A.I – Artificial Intelligence

URDPFI – Urban, Rural Development Plan. Formulation and Implementation.

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STRATEGIES TO CALIBRATE AND REDUCE EMBODIED CARBON OF AN OFFICE BUILDING IN INDIA

Sukanya Uday [1], Eashita Saxena[2]

[1] Design Architect, SJ SMEC, Rmz Galleria Office, Ambedkar Colony, Yelahanka, Bengaluru, Karnataka, India, sukanya.uday@smec.com
[2] Design Architect, SJ SMEC, Rmz Galleria Office, Ambedkar Colony, Yelahanka, Bengaluru, Karnataka, India, Eashita.Saxena@smec.com

ABSTRACT

In the past 5 decades, both developing and developed countries of the world have been raising major concerns over the impact of construction industry on the global carbon emissions. Although, it is statistically evident that the building and construction sector accounts for nearly 39% of the global carbon emissions, it is often ignored that more than half of this percentage is related to material mismanagement that arises due to decisions regarding material selection, method of extraction, manufacturing, procurement, assembling and construction technology. Therefore, in the pursuit of attaining the overall sustainability goals, the focus should not only be on reducing the net energy consumption of the building when in use (operational carbon emissions) but should also focus on minimizing the carbon footprint during the construction stage of the building (embodied carbon emissions). This study presents a contextual investigation on the embodied carbon emissions of an office complex in Mumbai, a high-density metropolitan city in India.

This research paper aims to
Deliberate a holistic approach on the embodied carbon assessment which includes analysing and recognising low carbon materials.
To accurately calibrate and demonstrate differences in the embodied carbon emissions of a built structure by using different permutations and combinations of materials, compositions, and specifications through case studies.
To propose best practices, steps, strategies, and design policies that focus on incentivising low carbon solutions at the first few design stages of a building.
which will aid landowners, policymakers, architects, and other practitioners to make the right decisions on building materials and construction methodology, thus raising the bar of sustainability targets in the building industry to institute a greener future.

Keywords: Construction materials, embodied carbon, Life cycle assessment, Environmental product declarations, low carbon materials.

INTRODUCTION

The building and construction sector is known primarily for being one of the major contributors to the global anthropogenic GHG (global greenhouse gas) emissions with a whopping 39% [**1**] (Figure-1) and are responsible for 1/3 of GHG. Majority of emissions are from developed countries. Rapidly industrializing developing countries will surpass emission levels from buildings in developed countries. 68% of Global Emissions are produced by top 10 countries in the world and India is one of them [**2**].

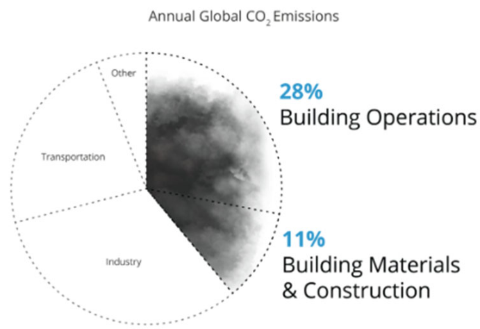

Figure-1: Breakdown of carbon emissions of main contributors
Source: Architecture 2030

To combat this and to optimise the reduction of GHG emissions from the building industry, many global and national environmental organisations were formed since 1992, which have brought about policies, strategies, and steps. Energy utilisation benchmarks were formulated, and incentives were given for projects that managed to increase energy conservation with these policies. But mostly the focus of these policies has been on the operational carbon, but much needed attention to the carbon emissions that are released during the construction and demolition stages were often overlooked and hence it was not well researched. Only in recent years, this potential was realised by certain organisations such as Architecture 2030, Structural Engineers 2050 Challenge, etc. which collaboratively work on reducing embodied carbon from the buildings by 2050.

Therefore, to ameliorate GHG emissions from the building sector, the focus needs to shift towards the reduction of the Whole life cycle carbon emissions i.e., carbon emitted throughout the life cycle of the building which involves four main stages – building construction, building utilisation, building maintenance, and building demolition processes. This requires intensive study and assessment of the whole life cycle of the building (Figure-2) [**3**], accurately calculating carbon emission in each step and stage to get a true picture of the overall carbon emissions and finding alternative architectural solutions to reduce the overall carbon footprint.

Figure 2: Stage of energy consumption and carbon emissions in buildings
Source**:** Carbon leadership forum Embodied carbon 101

There are various benefits of reducing embodied carbon of the building:
Environmental benefit **–**Building Sector is one of the largest contributors to the global GHG emissions in the world, but also has one of the largest potentials for its reduction. Recent reports suggest that **¼** of the emissions result from embodied carbon (figure 3) [**4**]. If the embodied carbon emissions are not addressed properly, they might end up taking ¾ of the total carbon emissions from buildings. Especially when, due to growth of cities, demand for more physical infrastructure, the number of buildings would be doubled by 2060.

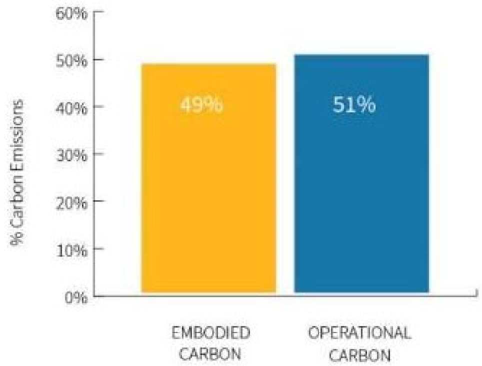

Figure 3: Total carbon emissions from new construction from 2020-2050
Source: Carbon cure, UN Environment Global Status report 2017

***Cost benefit* –** Current practices indicate that massive reductions can be achieved by specifying and substituting material alternatives with lower embodied carbon during design and specification process. As per RMI report [**5**] (Figure-4), embodied carbon saving of 19% - 45% at cost premiums of less than 1% can be achieved through proper design and construction interventions.

Figure 4: Top categories for reducing embodied carbon
Source: RMI – Reducing Embodied carbon in buildings- Low cost, High value opportunities

***Regulatory and social Benefit*s –**
Help developers to get benefits and incentives from government to address low carbon emissions.
Create new job opportunities in the sustainability sector.
Will help improve corporate social responsibility and branding.

SCOPE OF THIS RESEARCH

The category of life cycle assessment:
The whole life cycle of a building can be divided into 3 main stages (Figure-6) [**8**][**9**].
Cradle to site (during construction upfront carbon emissions), material extraction, transportation manufacturing and construction processes and technology
Cradle to service (operational carbon), maintenance and repair, Building usage, and
Cradle to grave (end of life carbon) demolition, disposal, and waste processing.

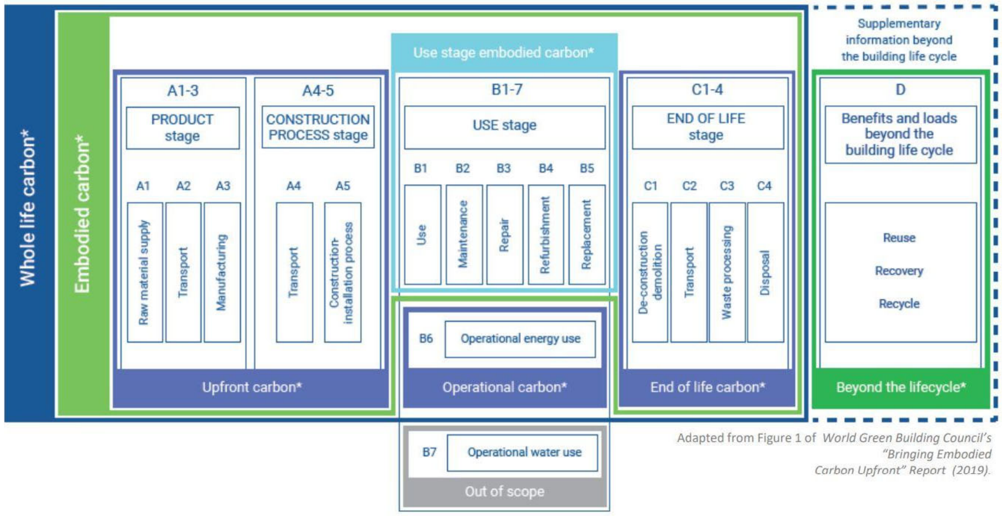

Figure 5: Top categories for reducing embodied carbon
Source: World Green Building Council: Bringing Embodied Carbon upfront Report 2019

In Figure 5, The processes in Life cycle of building and their stages
A1-A3 – **Cradle to gate** – Material processing stage
A4-A5 – **Gate to site** – Transportation and construction stage, A1-A5 - **Cradle to site**
A1-B5 – **Cradle to Service** – Maintenance and repair during the usage of building
A1-C4 – **Cradle to grave** – Demolition, Disposal, waste processing

The processes which lie majorly in the operational stage of the building are the major contributors to the release of carbon emissions (about 28%) [**10**]. These carbon emissions are released due to the energy lost in the use of HVAC, lighting, plug loads, MEP and other services required for optimizing user comfort and enabling functioning of the building. The processes which are associated with materials and construction process throughout the building life cycle fall under the Embodied carbon emissions.
This paper focuses on the embodied carbon emissions that occur due to the processes in the cradle to site stage as these processes contribute to approximately 11% of the total carbon emissions of a building throughout its lifecycle. Focusing on this stage at the very beginning of the project enables us to make smarter and more efficient decisions related to building materials and construction thus minimizing the embodied carbon emissions to the maximum possible extent.

A1-A3 –Material Selection:
The extraction process of each of the material components
The process and technology used for combining, manufacturing, and refining / polishing the materials
The by-products and wastes produced in the process.
Though the transportation of materials to the site and construction processes used are also significant contributors to the upfront carbon emissions; these categories have not been considered as they vary with site context.
Only stages A1-A3 has been considered for this study.

A4 – Transportation of Materials– Availability of material in the region, distance between component material extraction sites and their manufacturing, distance between manufacturing sites and the building site, the mode of transport, the carbon emission of the vehicle transporting the components and the material and the number of trips depending on the quantity of material required.
A5 – Construction Technology – If it is offsite or onsite. If it is precast or on-site construction, if labour is used or machines are used to assemble materials on site, if skilled labour is available for handling new material, if training can be provided to upskill them.

Case study Chosen:

India's total building floor area would be approximately 57.6 billion sqm by 2050, an increase of roughly 3.5% increase from 2015 [**11**][**12**]. Amount of office spaces across top 10 property markets of India has increased 18% from 2020, roughly 50 million sqft in 2021, making the total office stock in the country to cross 773 million sqft (CBRE Asia Report). This would lead for the demand of basic conventional construction materials like concrete, cement, steel, aluminum, bricks, glass, etc. Studies suggest that demand for cement and steel which are emissions intensive building materials in India would increase by 4% and 7% by 2050, in comparison to 2019, respectively. For Concrete, cement production creates approx. 7% of the world's CO2 emissions [**13**] is due to emissions released in its manufacturing process of cement which is the largest contributor of embodied carbon in the built environment.

Therefore, it is imperative to find alternate materials, suggest alternative strategies to reduce embodied carbon footprint at the very initial stages of building design. Appertaining to the above statistics and evidence, this research paper focuses on the embodied carbon emissions released in the cradle to site in a typical high rise in Mumbai, India.

Mumbai is chosen as context for the case study as it is the financial capital of India, has high density development and high working population.

Based on the following reasons, a typical high rise office building was considered for the analysis:

- One of the most high-density buildings
- High operational energy required to use and maintain (energy intensive building)
- High embodied carbon emissions due to usage of energy intensive materials (cement, steel, glass, aluminium, and insulation (sound and heat))
- Typical floorplate – offers ease of benchmarking and is easy to relate with quantification per floorplate, easy to establish embodied energy-based numbers and thumb rules.
- The following are the configuration of the case study considered:
- Building Structure – Flat slab structure without column capital (11m x 11 m grid)
- Built up area – 1,15,300 sqm
- Floorplate of each floor – 5240 sqm (85m x 60 m)
- Number of floors – G+19 +2 Basements = 22 floors in total
- Foundation / footing – Raft footing (2.5m depth below the basement)
- Glazing – Unitised
- Block work – concrete blocks
- Façade – aluminium cladding, unitised glazing
- Structural Materials - concrete and steel

To study a typical office building and to come up with solutions that could act as guidelines most typical building materials have been considered.

Cement and concrete – blockwork, foundation, framework (columns and beams)
Glass – façade, interiors
Aluminium – framing and Cladding
Steel – Structural stability (rods and reinforcement bars)
Aluminium – framing and Cladding
Steel – Structural stability (rods and reinforcement bars)

MATERIALS AND METHODOLOGY

This paper analyses embodied carbon impacts by conducting a life cycle analysis of a typical Greenfield office building based in Mumbai, India having 22 floors of 5240 sqm each, adding to a total of 1,15,300 sqm of Built-up area.

The three main methods of approach in addressing embodied carbon at the cradle to gate stage:
Whole-building Efficiency strategy – This involves adaptive reuse of an existing building, reducing the overall square footage of a project, improving efficiency of building construction techniques and structural systems with prefabricated systems or components, designing to minimize waste.
Material substitution- Replacing materials having high embodied carbon with those functional equivalents that have low embodied carbon footprint and lower GWP (global warming potential).
Specification – Designers can establish a desired value of GWP or Embodied carbon emission that will act as a benchmark for procuring. This will enable use of materials with less environmental impact and also, encourage vendors and manufacturers to come up with sustainable material options and to also establish EPDs (Environmental Product Declaration) in the market.

In this case study, the Specification strategy has been used to reduce the embodied carbon at the cradle to site stage.

Calibration of Embodied Carbon of Building Structure
Cradle to Gate – Material specific only

Requirements – Building basic design and the material specifications
Conventional Materials considered and their specifications

Table 1: Concrete used for various building works and its density in Kg/m3.

A1	Concrete Block work -200mm	2150
A2	Concrete wall work full	2300
A3	Concrete floor slab	2400
A4	Concrete Footing - Matt/ raft/ st	2400
A5	The drop - column capital below	2400
A6	Concrete work full	2300

Table 2: Steel used for various building works and its specification.

	Co- eff	Kg/Cum
Footing	0.1	75
Column	0.075	220
RW	0.0069	100
Beam	0.065	170
Slab	0.225	105
Drop	0.06	45
	0.531869	

Table 3: Aluminum used for various building works and its density in kg/m3

B1	Aluminium Cladding - 1220mm x 2440mm x4mm	1510
B2	Aluminium Framing for aluminium cladding - 170mm X 65 mm x 4mm	1510
B3	Aluminium Framing/ mullion for glazing - 170mm x 65mm x 4mm	1510

Table 4: Steel used for various building works and its density in kg/m3.

C1	Unitised GLAZING - 1120mm X 1625mmx 12mm	2500

STEP 1- Calculate the weight of the materials in Kg
Formula:
Volume(cu.m) = length(m) X breadth(m) X Thickness(m)X No. of materials
Weight (Kg) = Volume(cu.m) X density of material (Kg/cu.m)

STEP 2- Find the Embodied carbon of the specified material
Formula:
Embodied Carbon of Total Material (KgCO2e) = Weight (Kg) X Embodied Carbon Coefficients (Kg CO2e / Kg)

Table 5: Embodied Carbon of Building with Conventionally used materials

S.no	Material	Quantity in KG	TYPICAL	
			Embodied carbon factor (kgCO2e/ Kg)	Embodied carbon released (kg)
1	Steel obtained from oxygen furnace	71,55,737.50	1.55	1,10,91,393.13
2	Concrete - 14% cement, fine, coarse mix (M25)	8,26,69,065.40	0.17	1,40,53,741.12
3	Glass - regular	55,71,786.60	1.44	80,23,372.70
4	Aluminium - regular	5,21,188.56	8.9	46,38,578.21
	TOTAL	8,87,62,040.56		3,78,07,085.16

STEP 3- Find functional equivalents of these typical materials with lesser Embodied carbon and their Embodied carbon coefficients. Substitute them in the formula in STEP 2 and compare the results.

Table 6: Embodied Carbon of Building with Low embodied carbon materials

S.no	AFTER ALTERNATING MATERIALS		
	EM=mbodied carbon factor (kgCO2e/ Kg)	Embodied carbon released (kg)	Material
	0.73	52,23,688.38	Steel obtained from recycling
1	0.51	36,49,426.13	Steel obtained from electric furnace - renewable source
2	0.126	1,04,16,302.24	Concrete - mix- 30% flyash
3	1.2	66,86,143.92	Glass - low embodied carbon type
4	8.24	42,94,593.76	Aluminium - low embodied carbon type
		2,50,46,466.05	

Note – The embodied carbon coefficients of materials can be found in EPDs from vendors. The coefficients taken for this case study is from ICE (The Inventory of Carbon and Energy) and CLF (Carbon Leadership forum – Embodied Carbon 101 database)

Observations

About 33% of the upfront embodied carbon has reduced by adopting low embodied carbon materials in this case study.

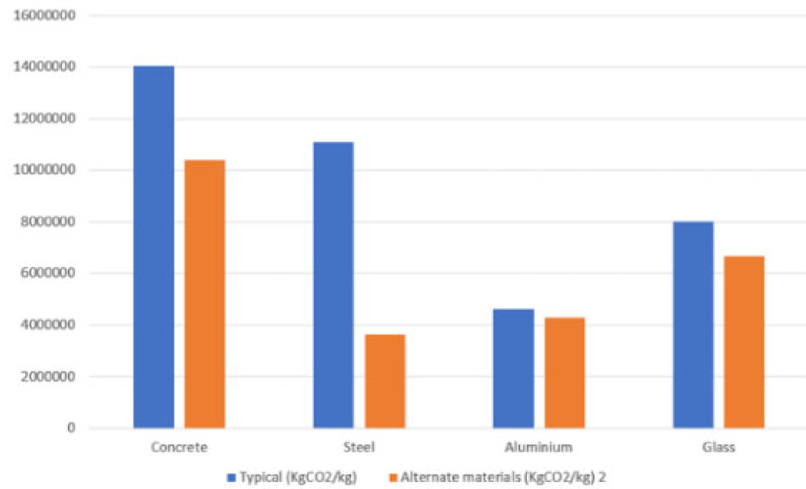

Figure 7: Results showing comparison between Typical materials and Low Embodied Carbon Materials

Other Strategies to Reduce Embodied carbon at the Cradle to Gate Stage

Concrete – the high embodied carbon content of concrete is mainly due to the carbon emissions due to the processing of Portland cement.

Use lesser cement by replacing a portion of the cement with supplementary cementitious materials (SCMs) such as fly ash and slag.

Use of organic materials as aggregates – strawcretes and hempcretes.

By electrification of cement production using biomass, hydropower, and other renewable sources instead of energy intensive clinker processing.

Use of carbon cured concrete – by introducing recycled CO2 into fresh concrete to reduce its carbon footprint. This stops the process of released CO2 into atmosphere thereby minimising emissions. The concrete produced contains lesser cement but provides same structural strength.

Use of carbon negative cements made from Magnesium silicates, geo polymer cements and calcined clay cements to reduce energy consumed in cement processing.

Steel

Recycling steel - produced from electric arc furnaces powered by solar, wind or hydroelectric power plants - that use scrap steel instead of using blast oxygen furnaces.

Use of timber produced with sustainable forestry management practices instead of steel for low rise to midrise structure (12 floors max)- if easily available.

Aluminium

30% of global aluminium demand can be satisfied by recycling scrap Aluminium.

That is obtained by smelting bauxite ore accounts for 5% global electricity demand which can be sourced by using renewable sources – solar and hydropower [**15**].

Glazing

Design building in such a way that passive strategies are used for lighting. This will reduce use of glass. Glass should be provided only wherever necessary.

Use shading devices instead of opting for double or triple glazing. The difference in R value is lesser but the embodied carbon margin increases drastically with each layer of glass added to the façade.

Certain types of Glass can also be recycled by 100%. [**16**] These can be processed further to achieve quality required for façade.

DISCUSSIONS AND LIMITATIONS OF STUDY

Though interior materials like gypsum boards, insulations, carpet tiles, paints and other interior finishes also add to the net embodied carbon of a building, the structural components contribute to 80% of embodied carbon and only these components have been addressed in this research paper.
Embodied carbon varies with different structural systems as the specification of materials required for the stability of that structure varies. This has not been addressed in this study.
Though the upfront Embodied carbon from cradle to site stage considers the processes of transportation of materials and method of construction, these have not been calibrated in this as the information is contextual and due to the inadequacy of benchmarking data base.

CONCLUSIONS

Decarbonization of building sector has a very crucial role to play in reducing global carbon emissions and overall global warming. A holistic approach that takes overall lifecycle assessment into consideration must be given its due significance. To do that, Embodied carbon can play a pivotal role in positively shaping the building industry, making it more sustainable, supporting circular economy. Firstly, at the top level, there needs to be more stringent policies. Initiatives by the central and local authorities that would ensure proper protocols are being following by the manufacturers of building materials, builders etc. To encourage developers, manufacturers and others who are a part of the building sector, government, local authorities need to incentivize use of low carbon innovations, technologies in the form of monetary support (grants), subsidies. This would encourage more people to want to adapt practices which ensures lower embodied carbon emission. It is suggested to use local materials to reduce the cost of transportation however it is not always possible in big cities such as Mumbai hence needs to look at newer materials that produce low carbon emissions or hybrid materials.
This is an opportunity to take inspiration from Vernacular Architecture as it offers many solutions that can be adapted in a modern case scenario. India has had a long history of building structures in a very sustainable way. It also becomes architects', engineers' etc. responsibility to be more mindful, and to be able to incorporate some inspirations from it. Such as: Energy efficiency in architecture and built environment is a concept that can be done by incorporating indigenous solutions. Shifting from using fossil fuels in production of materials such as cement will be very crucial. India has a very high potential to switch to lower carbon fuels. Due to the urgency of the challenge and the time it takes for technological systems to evolve, government will need to push the various stakeholders substantially to move towards low carbon technologies. Refurbishment of the buildings or reuse of material needs to be encouraged, this would massively help with reducing embodied carbon.

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SIMPLIFYING WATER MANAGEMENT – A NUMBERS BASED APPROACH

Akshay Tiwari

Head of Department, Interior Design, Certificate Courses, Hamstech College of creative education, Hyderabad, Telangana, India, ar.akshay.tiwari@gmail.com

ABSTRACT

As the effects of climate change come to the forefront and urbanization increases around the globe, it is observed that cities are becoming more and more dependent on groundwater. Additionally, the increase in population increases the demand for fresh water supply which remains the same, to address this it is important to understand what can be done at all levels. This research moves towards simplifying water management on a building level; the discussion revolves around understanding water requirements, sourcing, storage, usage, and disposal of water. Also, the research explores the ideas of reducing water usage, reusing water, and understanding the role of recharge of rainwater in the Indian context. Most of these problems have to be addressed in the pre-design stages where decisions must be made to help combat these issues. This study would like to take a calculation-based approach to understand the above-mentioned topics and also understand grey & black water treatment and the role they play in water management. The output of the research is to create tools that help calculate water requirements, potential savings, options of reuse, sizes of storage, and potential for rainwater Harvesting and recharge.

INTRODUCTION

Understanding water Management on a building level starts with an understanding of water sourcing, requirement, and Onsite storage and goes all the way to disposal methods. While this may seem like a difficult process it can be made simple by breaking it down into smaller portions and taking it one step at a time.
This paper explores:

- Source
- Requirement
- Reduction Strategies
- Waste Water Management
- Final calculation

Keeping this in mind the objective of this research is to generate a calculation tool that can help understand water requirements on a building level with ease. This tool can be used by architects, planners, interior designers, green building professionals, etc., and is intended to make the process of building water process simple and efficient. This research is limited to building water requirements and does not look into site water and rainwater calculations.

SOURCE

Water sources are divided into 2 major categories:
Surface Water is collected from the lake, rivers, glaciers, and ice caps. Water from these sources needs to be purified. As this is a large-scale process it is a government-controlled process. Metered water connections

are then provided to buildings based on their type. This system provides fresh water with a low bacterial and salt content.

The other source of fresh water is groundwater which is generally obtained on private sites. While community wells were popular until the last few decades, Bore wells have not taken over. The quality of water obtained from these wells differs in salinity and bacterial content on the basis of the catchment area of the aquifer and the type of soil in the region.

Understanding the source of water is important because water calculations are based on the source and any savings made need to reflect against the same source.

REQUIREMENT

Requirements for water are explained in detail in the National building code 2016 version. It details the requirement for all building types ranging from homes to airports. It also differentiates flushing requirements from daily use requirements. This simplifies the calculation process by providing the expected Grey and Black water discharge.

a) For communities with populations up to 20,000:

1)	Water supply through stand post :	40 lphd (Min)
2)	Water supply through house service: connection	70 to 100 lphd

b) For communities with : population 20,000 to 100,00 together with full flushing system — 100 to 135 lphd

c) For communities with population: above 100,000 together with full flushing system — 150 to 200 lphd

Note—The value of water supply given as 150 to 200 litre per head per day may be reduced to 135 litre per head per day for houses for Medium Income Group (MIG) and Lowe Income Groups (LIG) and Economically Weaker Section of Society (EWS), depending upon prevailing conditions and availability of water.
Out of the 150 to 200 litre per head per day, 45 litre per head per day may be taken for flushing requirements and the remaining quantity for other domestic purposes.

Figure 1: Water requirement for Residential Buildings
Source: NBC - 2016

Water Requirements for Buildings Other than Residences

Sl No.	Type of Building	Domestic litres per head/ day	Flushing Litres per head/ day	Total Consumption Litres per head/ day
1.	Factories including canteen where bath rooms are required to be provided	30	15	45
2.	Factories including canteen where no bath rooms are required to be provided	20	10	30
3.	Hospital (excluding laundry and kitchen):			
	a) Number of beds not exceeding 100	230	110	340
	b) Number of beds exceeding 100	300	150	450
	c) Out Patient Department (OPD)	10	5	15
4.	Nurses' homes and medical quarters	90	45	135
5.	Hostels	90	45	135
6.	Hotels (up to 3 star) excluding laundry, kitchen, staff and water bodies	120	60	180
7.	Hotels (4 star and above) excluding laundry, kitchen, staff and water bodies	260	60	320
8.	Offices (including canteen)	25	20	45
9.	Restaurants and food court including water requirement for kitchen:			
	a) Restaurants	55 per seat	15 per seat	70 per seat
	b) Food Court	25 per seat	10 per seat	35 per seat
10.	Clubhouse	25	20	45
11.	Stadiums	4	6	10
12.	Cinemas, concert halls and theatres and multiplex	5 per seat	10 per seat	15 per seat
13.	Schools/Educational institutions:			
	a) Without boarding facilities	25	20	45
	b) With boarding facilities	90	45	135

Figure 2: Water requirements for buildings other than residences
Source: NBC - 2016

Sl No.	Type of Building	Domestic Per Day	Flushing Per Day	Total Consumption Per Day
14.	Shopping and retail (mall) a) Staff	25	20	45
	b) Visitors	5	10	15
15.	Traffic Terminal stations a) Airports	40	30	70
	b) Railway stations (Junction) with bathing facility	40	30	70
	c) Railway stations (Junction) without bathing facility	30	15	45
	d) Railway stations (Intermediate) with bathing facility	25	20	45
	e) Railway stations (Intermediate) without bathing facility	15	10	25
	f) Interstate bus terminals	25	20	45
	g) Intrastate Bus Terminals/Metro Stations	10	5	15

Figure 3: Water requirement for buildings other than residences – 2
Source: NBC - 2016

EXAMPLES OF WATER REQUIREMENT

For this paper, the requirements of water will be calculated for a small-scale MIG community,

- No of residents: 1000
- Flushing requirement: 45l/head
- Domestic requirement: 115l/head
- Daily Water requirement per head: 160l

Table 1: Water requirement of MIG building Housing 1000 residents (Landscape not included)

Water requirement

Building type	Residential (Middle Income Group – Small scale)	Units
Per capita Daily flushing requirement as per NBC 2016 in liters	45	liters
Per capita Daily Domestic requirement as per NBC 2016 in liters	115	liters
Total requirement per capita	160	liters
No of occupants	1000	
Total Flushing requirement per day in liters (Black Water)	**45000**	liters

Total Domestic requirement per day in liters (Grey water)	**115000**	liters
No of blocks	1	
Total requirement per Day	**160000**	liters

ONSITE STORAGE

Onsite tanks have to be provided as most areas do not receive a 24-hour water supply. This is especially true in the case of residential buildings. The minimum tank size provided on-site should accommodate 1 day worth of water. While that may be the case the standard size is 1.5 days and the ideal would be 2 days' worth of water. In case the building seeks points for resilient design it needs to provide 3 days' worth of storage space for its water. This calculation is determined using the following formula:

Size of the tank in cubic meters = volume of water in litres / 1000

STORAGE TANK CALCULATION

Table 2: Total storage capacity for building requirements

Storage Tank sizes		
Total Tank size for 1 Day (Minimum)	160	CuM
Total Tank size for 1.5 Day (Standard)	240	CuM
Total Tank size for 2 Day (Ideal)	320	CuM
Total Tank size for 3 Day (Resilient Building)	480	CuM

REDUCTION STRATEGIES

Numerous products and methodologies are available today that help reduce the amount of water discharged. Some of these fixtures are efficient taps and showers. Many brands claim to reduce the water required to do any task by increasing the pressure and decreasing the discharge of water per minute. This helps reduce the water required for activities like hand wash and showers. However, is observed that domestic activities like cooking and cleaning still require the same amount of water. Additionally, water efficiency cannot be obtained unless water-efficient water purifiers, dishwashers, and washing machines are used (these fixtures are 2-5 times more expensive than regular fixtures available in the market).
Efficient flush systems are known to have a minimum of 40% efficiency in both single and double flush varieties. A standard single flush system requires 10 litres of water per flush. Whereas an efficient fixture has a double slush more with a 6l/4l flush capacity, this gives a straight 40% saving in the amount of water required for flushing.
Based on the above data the building water requirements are updated as mentioned below.
Assumptions: Flushing water reduction: 40%, Grey water reduction 10%

REDUCED WATER CALCULATION

Table 3: Updated Daily usage post implementation of reduction strategies

Updated Requirement		
Calculated / Proposed percentage of Flushing Water Saved	40	%
Water saved with efficient flushing systems	18000	liters
Reduced Flushing requirement	**27000**	liters
Calculated / Proposed percentage of Domestic Water Saved	10	%

Water saved with efficient taps and Showers	11500	liters
Reduced Domestic requirement	**103500**	liters
Reduced Daily requirement	130500	liters
Daily Water saved per block	**29500**	liters
Percentage of water saved	18.44	%

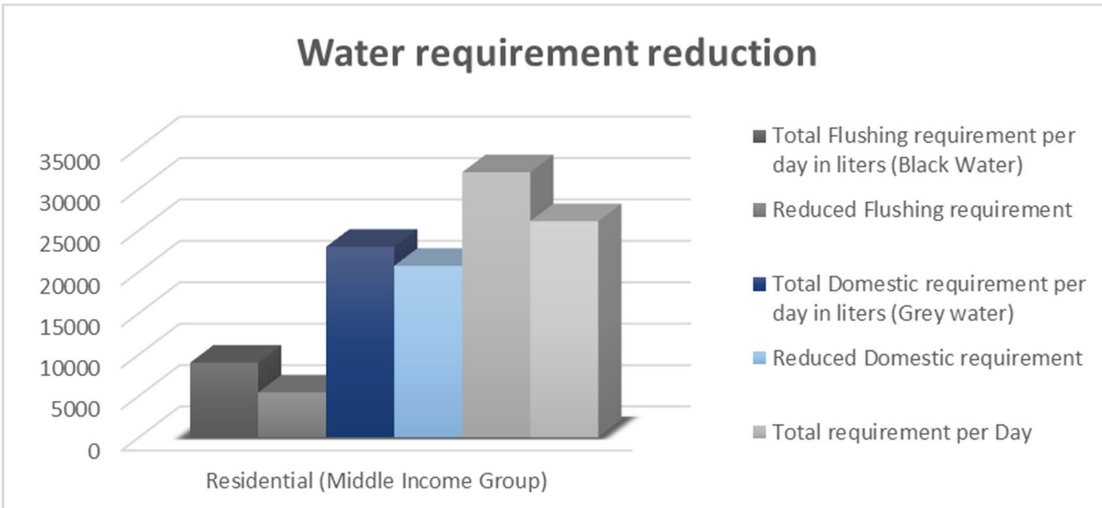

Figure 4: Water requirement and reduction graph

GREY & BLACK WATER MANAGEMENT

Reuse of water that had been obtained is the next big step to managing water. Multiple natural and artificial strategies are available that help in the reuse of wastewater. Some of these strategies and their respective characteristics are mentioned in the list below. These technologies are implemented and researched across the country and can be implemented individually or as a set. The tool intends to give data for both cases and allow the user to make decisions based on available data.

- Grey water treatment technologies
    - Phytoremediation
        - Natural Methodology
        - 75% - 80% Efficiency
        - Gives a high microbial result
        - Suitable for Landscape
    - Membrane bioreactor (MBR) technology
        - Artificial Methodology
        - Up to 90% efficiency
        - Consumes electricity
        - Kills microbes like E.coli
        - Suitable for Landscaping, Cleaning, and Flushing
- Black water treatment technologies
    - Indra
        - Artificial Methodology
        - Up to 95% efficiency
        - Consumes electricity
        - Kills microbes like E.coli
        - Suitable for Landscaping, Cleaning, and Flushing

Additional Requirements for these systems include Extra storage, Generator rooms, Double stack dispersion systems, Additional water tanks, and Additional supply systems and pumps.

Table 4: Potential of water recovered post management system use

Purification Systems and their Impact		
Efficiency of Black water filtration system	95	%
Black water recovered	25650	liters
Efficiency of Grey water filtration system	80	%
Grey water recovered	82800	liters

COMBINED CALCULATION FOR MIG

The tool was made using the tool MS excel and requires entry of a minimum no of variables (specifically: water requirement obtained from, no of occupants and percentages of water saved, and efficiency of technologies)

Table 5: Consolidated table showing total savings on building level

Water requirement

Building type	Residential (Middle Income Group)	Units
Per capita Daily flushing requirement as per NBC 2016 in liters	45	liters
Per capita Daily Domestic requirement as per NBC 2016 in liters	115	liters
Total requirement per capita	160	liters
No of occupants	1000	
Total Flushing requirement per day in liters (Black Water)	**45000**	liters
Total Domestic requirement per day in liters (Grey water)	**115000**	liters
No of blocks	1	
Total requirement per Day	**160000**	liters

Storage Tank sizes

Total Tank size for 1 Day (Minimum)	160	CuM
Total Tank size for 1.5 Day (Stadard)	240	CuM
Total Tank size for 2 Day (Ideal)	320	CuM
Total Tank size for 3 Day (Resilient Building)	480	CuM

Updated Requirement

Calculated / Proposed percentage of Flushing Water Saved	40	%
Water saved with efficient flushing systems	18000	liters
Reduced Flushing requirement	**27000**	liters
Calculated / Proposed percentage of Domestic Water Saved	10	%
Water saved with efficient taps and Showers	11500	liters

Reduced Domestic requirement	**103500**	liters
Reduced Daily requirement	130500	liters
Daily Water saved per block	**29500**	liters
Percentage of water saved	18.44	%

Purification Systems and their Impact

Efficiency of Black water filtration system	95	%
Black water recovered	25650	liters
Efficiency of Grey water filtration system	80	%
Grey water recovered	82800	liters

Table 6: Colour coding used in all tables.

(yellow)	Input Value
(peach)	Initial Requirement
(light green)	Reduced Requirement
(dark green)	Water available for reuse

CONCLUSION

The tool developed during the course helps reduce the time required to calculate the entire building water cycle in a few simple steps. It also helps understand the savings made using various techniques and helps make decisions accordingly. It helps simplify a process that is otherwise considered difficult and reduces the time and manpower spent on calculation. Additionally, it gives the percentage of water saved on a daily basis, sizes of water tanks required for storage, and the possible water available post purification in case of grey and black water systems. The research can further integrate site water requirements and rainwater calculations, this will give a holistic approach to the process of water management and will turn into an end-to-end decision-making tool within the scope of site water requirements.

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STRUCTURAL PERFORMANCE OF LIGHWEIGHT GEOPOLYMER CONCRETE IN THE UAE HOT CLIMATE

Mahmoud Haggag[1], Rahma Hagi Adan[2], Wedad Alyammahi[3], Amal Al Askari[4], Sheikha Alshehhi[5],

[1] Associate Prof., UAEU, Al Ain, UAE, mhaggag@uaeu.ac.ae
[2] Lecturer, UAEU, Al Ain, UAE, r-hassan@uaeu.ac.ae
[3] Student, UAEU, Al Ain, UAE, 201904178@uaeu.ac.ae
[4]Student, UAEU, Al Ain, UAE, 201850021@uaeu.ac.ae
[5] Student, UAEU, Al Ain, UAE, 201812747@uaeu.ac.ae

ABSTRACT

Thermal lag of building materials is the ability delay heat transfer into occupied spaces. Using thermal mass appropriately can improve the building thermal performance and thus reduce cooling load, energy consumption, and carbon footprints. In the UAE climate, where daytime and nighttime temperatures range reasonably, high thermal mass is beneficial. Conventional building construction methods rely on heavy masonry with limited heat transfer delay due to the nature and the sensible heating of the material its selves. Heat transfer into occupied spaces can either be eliminated or substantially delayed by the use of lightweight geopolymer concrete (GPC). Studies in GPC have increased due to its durability and lower environmental impact. This research project investigates the performance of lightweight geopolymer concrete (GPC) cladding panels containing micropores benchmarked with a comparative set up of expanded polystyrene foam (EPS) containing GPC. Through, identifying most suitable EPS bead size, which show better bonding with the concrete compositions to achieve higher thermal energy absorption and structural stability. However, this paper focuses on the investigating the compressive strength of GPC with EPS beads. The constituents of the GPC were dune sand and industrial waste materials. Three samples produced as control samples, the remaining nine samples, 45% of the GPC volume is substituted with different sizes of expanded polystyrene foam (EPS) beads. The GPC samples tested structurally at 28 days, the compressive strength of control samples presented an average of 77.1 MPa, while samples with EPS beads showed 19.5 MPa for EPS beads size 2mm, 22.3 MPa for EPS beads size 0.5 -0.2 mm, and 27.8 MPa for EPS beads size 0.2 – 0.05 mm sample. The results of compressive strength complied with the non-loadbearing building components such as partitioning outer walls, and façade tiles.

Keywords: geopolymer mortar; expanded polystyrene foam; façade tiles; compressive strength

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INTRODUCTION

The rapid development of urban communities is resulting in increasing demand for energy at an excessive rate. Due to the depletion of conventional energy sources, sustainable management of energy becomes increasingly important (IEA, 2021). Buildings consume 60% of the total energy consumption. Air conditioning consumes nearly 50 % of the building energy consumption. Therefore, air conditioning is a major consumer of energy in UAE and leads to very high levels of CO2 emissions (United Nations Environment Program, 2021). This can be avoided by adopting passive approaches to avoid overheating of the buildings during summer thus reducing active air conditioning system size. Replacing Portland cement (OPC) with geopolymer concrete (GPC) can lead to 80% reduction in embodied carbon and reduce energy consumption in buildings. (Turner et al, 2013). Several studies of comprehensive life cycle assessment of GPC indicated the positive impact in term of sustainability and CO2 emission reduction (Tayeh et al, 2021). In comparison with a traditional brick and cement building wall, Lightweight Geopolymer Concrete is highly demanded to alterative the conventional materials due to its low density, high strength and heat transfer coefficient. Tong, in his study (2020) concluded that, as industrial wastes, Fly Ash (FA), and

Ground Granulated Blast Furnace Slag (LGBS) can be used as raw materials in Lightweight Geopolymer Concrete Panel (LGCP). Such building wall panel leads to 48% CO2 emission reduction, up to 17 times energy consumption, and much cost effective compared to the conventional bricks (Tong, 2020). In Madrid and Oslo, a study investigated GPC walls containing microencapsulated phase change material (MPCM) in buildings. The resulted reported substantial reduction of annual power consumption for air conditioning in both cities (Cao et al, 2019). Geopolymer concrete used more in precast application, which attributable to the requirement of controlled parameters of curing environment specially the temperature. For that reason, geopolymers employed in my types of structures such railway sleepers, tunnel segments and structural elements such as columns and beams. (Almutairi et al, 2021). Moreover, Dawczynski et al reported that using GPC in concrete steel reinforcements application, as an alternative to portland cement concrete. The research found that GPC characteristics of enduring harsh environments such as sulphate soils, classify GPC as sustainable construction material for robust structure applications (Dawczynski et al, 2017).

A study investigated the mechanical performance of reinforced geopolymer concrete (CCG) in Brazil, and compared mechanical behavior of the CCG with reinforced Portland cement concrete (CCP). The results showed that CCG have similar mechanical characteristics to CCP and exceed it in some areas such as consistency (slump), and the ultimate load carrying capacity (Pires et al, 2019).

Another study compared the thermal physical behavior and mechanical characteristics of geopolymer concrete (GPC) and ordinary Portland cement (OPC), in term of fire-resistant properties after exposing the samples to 1200 °C according to the RATB fire curve. Different analysis conducted on the samples, and the results showed that GPC sample exhibited better bond behavior and compressive strength compared to OPC samples. Moreover, data from this study suggested that GPC material is a viable alternative to OPC in fire resistant building applications (Jiang et al, 2020).

Zou et al. investigated the optimized process conditions for a novel building insulation material used geopolymers as bonding material and sawdust wastes as aggregates. Three main variables were studied to optimize material's components proportion through testing thermal and mechanical properties, water resistance and microstructure. The results of the analysis suggested new biomass-based insulation material with good thermal and physical performance (Zou et al, 2020).

Azevedo et al. studied the use of geopolymer materials as roof tiles for building, by using clay bricks waste named chamotte as substitute precursor. The chemical and mineralogical analysis found that chamotte waste has characteristics to act as a raw material for procurement of ceramic roof tiles by means of geopolymeric reactions. These characteristics are that, chamotte is rich in silica and alumina which are essential for geopolymers synthesis, and it has fine particles with high pozzolanic reactivity (Azevedo et al, 2020).

RESEARCH PROBLEM

Portland Cement is responsible for 10% of CO2 emissions worldwide (Assi et al, 2017). Portland Cement demand in many countries has increased rapidly due to booming in the construction industry. Cement production consumes nearly 30-40% of the total industrial energy consumption (Ige et al, 2022). The energy required to produce Portland cement ranged from 3–6 MJ/kg clinker (Nath et al, 2015). Using geopolymer concrete, as sustainable alternative to Portland cement concrete, can be a solution not only for sustainable building construction but also for green infrastructure and road transportation. It can reduce the greenhouse gas emissions and prevent negative impact on the environment. Geopolymer concrete utilizes waste materials such as fly ash, ground granulated blast furnace slag, and dune sand. The current study is part of research project aim to produce light geopolymer concrete cladding panels with high thermal energy performance while retaining minimum structural strength. In this study, air-cured GPC composition samples are employed to investigate the compressive strength of GPC with different sizes of EPS beads.

MATERIALS AND METHODS

This section covers the material used in the experiments and specimen preparation. The elements of the dry mix were ground granulated blast furnace slag (GGBS), fly ash (FA), and dune sand (DS). As an alkaline solution, a sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) were used to stimulate the bonding reaction (geo-polymerization). Photographs of the development process of the samples and raw materials are shown in Figure 1, and the material information in Table 1.

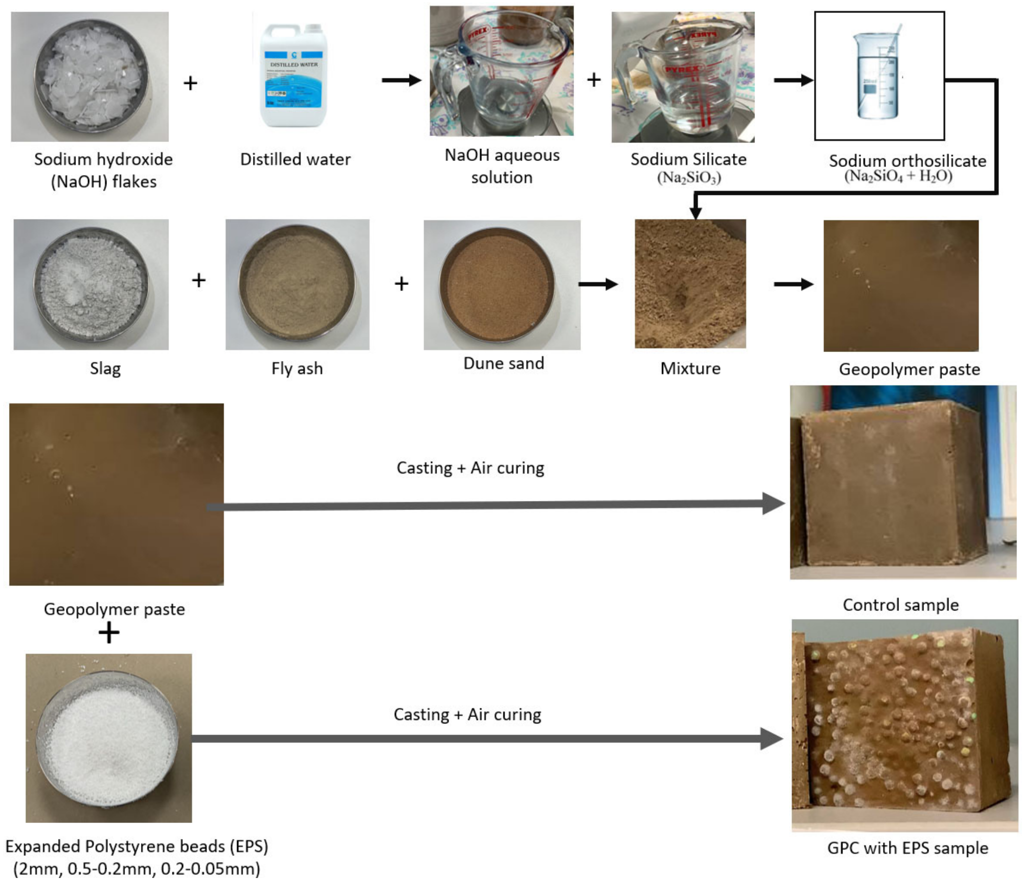

Figure 1: Photographs of the process of development of the samples and raw materials

Table 1: Material information, (Qadir et al, 2021)

Materials	Main Components	Proportions	Density (Kg/m3)
Dune Sand (DS)	SiO2, CaO, Al2O3	63.9%, 14.1%, 3%	1693
Fly Ash (FA)	SiO2, Al2O3, Fe2O3, CaO	48%, 23.1%, 12.5%, 3.3%	1262
Ground granulated blast furnace slag (GGBS)	CaO, SiO2, Al2O3, MgO	42%, 34.7%, 14.4%, 6.9%	1236
Sodium silicate solution	---	---	---
Sodium hydroxide	---	---	---

General process conditions were kept constant following previous studies (Rashid et al, 2019) (Ismail, N.; El-Hassan, 2019) as follows: The solid ratio of the GGBS, FA, and DS was kept constant at 1:3:6, the NaOH solution (18 M) and mass proportions of NaOH to Na2SiO3 were kept constant as 1:2.5, and the mass ratio of the alkaline solution to the dry mix was 1:3.

The first step in the process was to mix GGBS, FA, and DS until homogeneity was achieved. The mixed components were then combined with NaOH and Na2SiO3 in separate proportions so that both solid and liquid constituents could be mixed slowly while stirring until a homogeneous paste was achieved. This mixture was cast into steel molds (50 mm × 50 mm × 50 mm) by proper compaction to avoid entrapment of air bubbles and these samples called the control samples. A study investigated different percentage (15%, 30%, 45%) of geopolymer volume substitution, and the results showed that, 45% porous GP sample has the maximum reduction of heat transmission (Qadir et al, 2021). For that reason, in the other samples, 45% of geopolymer volume were replaced with expanded polystyrene foam (EPS) beads with three different sizes, 2mm, 0.5-0.2mm, and 0.2-0.05mm.

After the samples were cast into the molds, they were kept in the molds for 24 hours. During this time, all samples were kept at 25 °C to avoid any possible effect of external factors. After 24 hours had passed, the samples were unmolded, and all samples were stored in one laboratory to share similar thermal condition for further aging until structural and thermal testing.

After testing 12 samples, three were tested per case. These samples were tested after 28 days, using A 2000 kN universal testing machine to test the compressive strengths for all samples. The strain endpoint and test point values were 0.8 mm/min and 1.00 mm/min, respectively. The average values were used for the compressive strength calculations.

RESULTS AND DISCUSSION

Figure 2 shows the compressive strength of the samples at 28 days, resulting in a decrement in compressive strength from 77.1 MPa for the control sample to 19.5 MPa for EPS beads size 2mm, 22.3 MPa for EPS beads size 0.5 -0.2 mm, and 27.8 MPa for EPS beads size 0.2 – 0.05 mm sample. The results imply, that the size of the EPS beads affected the compressive strength of the GPC, the smaller the EPS bead size the more compressive strength, in inverse coloration pattern. In another study, the same composition was tested with heat curing of the samples, resulting a porosity of the samples with different porosity percentage. At 28 days, the strength was 26.4 MPa, 22.1 MPa, and 15.8 MPa for the porosity of 15%, 30%, and 45%, respectively (Qadir et al, 2021). Comparing the sample of porosity of 45% strength (15.8 MPa) with the result of this study, all the GPC samples with different EPS bead sizes have higher strength result from the porous GPC sample, and the reason for this strength reduction is due to an inconsistent solid structure throughout the bulk, with air voids as porosity (Qadir et al, 2021). The further investigation for this study will be testing the comprehensive strength of GPC with different EPS beads sizes after heat curing and creating GPC porous. The experimental results of GPC with different EPS beads sizes demonstrate compressive strength that comply with the international standard ASTM C129-17, and can be used for non-load bearing building components, including outer partitioning walls and façade tiles.

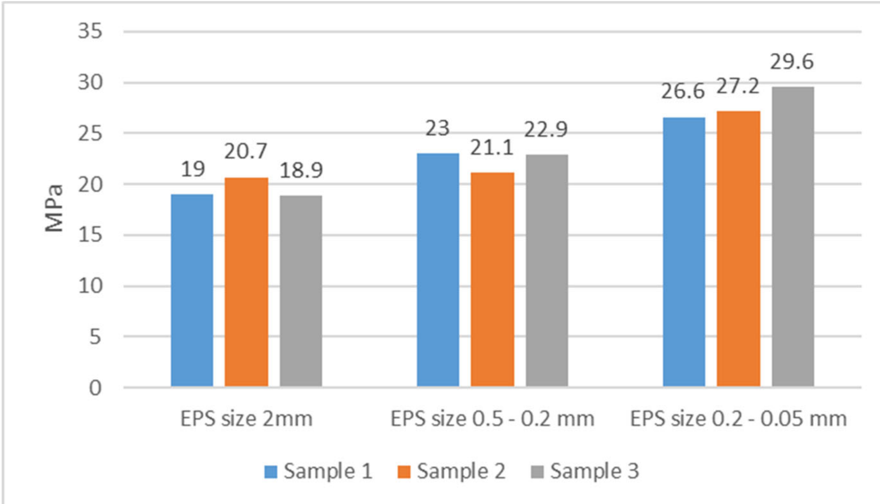

Figure 2: Comparison of compressive strength for the GPC samples

CONCULSION

In this study, geopolymer concrete (GPC) is produced and tested experimentally. Expanded polystyrene beads with different sizes (2mm, 0.5 – 0.2mm, 0.2 – 0.05mm) were added into the GPC mix by 45% by volume substitution and subsequently cured by air. Samples were tested for compressive strength, and it was found that the strength of the samples increased with the smaller EPS bead size. However, the strength of all samples is capable of complying with the non-loadbearing building components such as partitioning outer walls, and cladding. Further research is underway to optimize mechanical and thermal properties of GPC.

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ENERGY PERFORMANCE & THERMAL COMFORT IN OFFICE BUILDINGS IN RUSSIA

Danny Tran[1], Arman Hashemi[1*], Alex Scott-Whitby[1], Guy Eames[2], Svetlana Alekseyevna Zabelina[3], Kirill Borisovich Zubkov[3], Narguess Khatami[4]

[1] University of East London, School of Architecture, Commuting and Engineering, London, UK
[2] Planet 2030 Ltd., Peterborough, UK
[3] MASI University, Moscow, Russia
[4] Mott McDonald, London, UK
[*] Correspondence: a.hashemi@uel.ac.uk

ABSTRACT

The global aim of the building sustainability is to reduce carbon emissions and achieve zero emission buildings. Building Research Establishment Energy Assessment Methods (BREEAM) are effective tools to assess, improve and provide energy performance certificates for new and existing buildings. This paper assesses energy performance and thermal comfort in a BREEAM certified case study building in Russia, comparatively analysing results through changing the building fabric parameters. The case study is the top floor of an office building in Moscow, where internal conditions, and various parameters were accounted into the simulations in IES (VE). By testing the combinations of each parameter, scenarios with improved energy performance and thermal comfort were found. The results suggest the ideal configuration of parameters for Russia's harsh climate would be to use most optimal U-values and triple paned glazing, implementing a night purging strategy and 1.5m overhang louvres as the solar shading strategies to ensure the building remains thermally comfortable and avoid overheating during summer. It is recommended to reduce excessive glazing to mitigate the impact of heat loss during winter while strengthening the airtightness of the building, though the annual ranges suggest that it may not be enough against Russia's climate throughout the year; particularly in winter, PMV ranging from -2.17 in January to 0.81 in July representing a thermally uncomfortable situation both in summer and winter.

Keywords: BREEAM, Retrofit, Commercial Buildings, Energy Performance, Thermal Comfort.

INTRODUCTION

The last decades have seen rapid development in the field of building sustainability, where there is a global collaboration to improve energy efficiency and mitigate contribution to climate change. One such example is Russia, as buildings use more energy in order to stay operational against its climate, contributing to the intensive energy use, which is the 4th largest energy consuming country in 2020, consuming 28.31 Exajoules (N.Sönnichsen, 2021).

Russia's first regional code was developed in 1994, and starting 2000s, a new set of regulations was made to provide 'a 40% energy reduction for heating' (Y. Matrosov et al, 2007), where building envelope had to improve their performance by 2.5-3 times to do so. This in order resulted in building design to implement better energy efficient materials, and HVAC strategies across the sector to meet energy passport and audit requirements. Russia's construction industry faced many challenges, as a study by S. Anu et al (2015) states the percentage of unfinished construction annually is high, from 2005 to 2011, 10-16 non-residential buildings were completed each year, due to high construction costs and insufficient investments causing in critical delays, on top of the ongoing recession. Demand in the sector rises to meet the growth, increasing energy intensity, despite the target decrease of 56% by 2030.

Matrosov (2007) and Anu (2015) presents a common theme in Russia's ambitious goals, both instances pointing out the large reduction goal, from 40% at the start of the 2000s and to 56% for 2030. However, both studies state that improving code and standards and improving material efficiency, are the main method to achieve this. Though not incorrect, it could suggest a performance gap between the energy target and methods used to improve the building efficiency as target reduction remains high.
In recent years, organisations such as the Building Research Establishment (BRE) and Russian Green Building Council (RuGBC) are working collaboratively to promote green standards in Russian building. Translating and localising schemes from BREEAM including BREEAM international, new construction and in use, to be implemented in Russian regulation, with 60 BREEAM certified buildings as of 2018. Also working with local universities and aims to implement the practice into education, allowing graduates to attain accredited recognition (Telichenko et al, 2018), BRE acts as the overseer while RuGBC assists in the localisation process, but also in codes and regulations.

A recent comparative analysis discusses international green building certification in Russia, comparing different systems such as BREEAM, LEED, STO NOSTROY and others, the author asserts their view in the same vein as the aforementioned theme, stating that 'many requirements for Russian designers are inappropriate or often too high to be implemented' (A. Shvets, 2021). Giving an example of how some systems exclude the use of a few structural materials, that's prevalent in Russian works, further showing the complications of integrating international standards into Russia's code compliance. In terms of thermal comfort, it is well known that the climate in Russia continues to be an obstacle in green building development, within winter, the whole of Russia experiences high cold stress and often even reaching extreme cold stress. While in summer, mid-southern Russia reaching high heat stress (Varentsov M., 2020). This trend is reflected in thermal simulations of buildings in Russia's climate, as research which revolved around the correlation between energy efficiency and ventilation carried out by D. Baranova et al (2017), modelled a single residential unit comparing the impact of a 'never open' and 'always open' ventilation scenario, Both results show a trend in operative temperatures of two separate areas in the unit, with 'never open' using a natural ventilation system while 'always open' adds mechanic mechanical cooling to combat the overheating, which may be caused by trapped internal heat and solar gain with no extraction from mechanical or natural ventilation. These results imply that during summer, 'never open' exceeds 25 C on a monthly average while 'always open' remains under, while December, both temperatures could reach below 20 or 18 C. Though this is in the context of a residential unit, an assumption could be made that the climate will affect commercial buildings in a similar way. The climate, and operative temperature are both important aspects to consider when designing for thermal comfort, which is defined as 'the state of mind that expresses satisfaction with the surrounding environment' according to the Chartered Institute of Building Service Engineers (CIBSE), (Dabner J. et al, 2017). Thermal comfort is normally measured through Predicted Mean Votes (PMV), an index that aims to estimate the average value of votes for a group of users on a thermal sensation scale (Guenther S., 2021). Where the scale has 7 increments, going from cold to hot, these increments are assigned a score from -3 to +3, as seen in table 1, showing the metrics of the thermal sensation from ASHRAE (American society of heating, refrigerating and air conditioning engineers).

Table 1: PMV Thermal Comfort Scale;
Source: (Dabner J. et al, 2017)

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot

Previous research on how building parameters such as shading or glazing impact indoor thermal comfort has established that shading devices can be used in cold climates to improve thermal conditions, yet to a varying degree. This is seen in a two-part study performed on a case study building in Montreal, the first performs an experimental simulation analysis, using roller shades and venetian blinds (at different angles) in winter conditions, then comparing the results, where both data sets are similar in values and patterns. The findings show roller shades would work best on clear conditions, while venetian blinds are only efficient at 45 degrees. Where part two, combines the first part with the thermal transient model, to investigate impacts of varying external conditions, glazing, shading properties against thermal comfort and heating demands. With the outcoming data suggesting certain glazing elements and properties, there will be 'a trade-off between energy, thermal comfort and lighting needs.' (A. Tzempelikos, 2010) where for one trait to be more efficient, another trait may become compromised. This study may relate to the current project, Montreal may be similar in climate and temperature with Moscow, as seen in figure 1, graphs from the National Oceanic & Atmospheric Administration shows that the only average difference is around 2-3 degrees. The premise may also relate as both revolves around investigating how different building elements affects thermal comfort and heating demands with alternative methods.

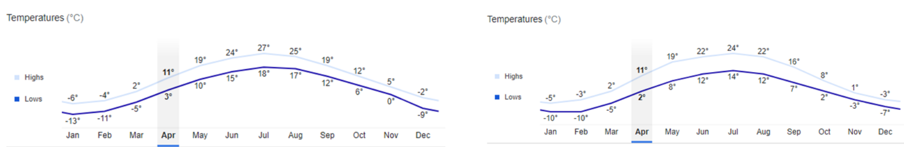


Figure 1: Average high & Low temperature in Montreal, Q.C., Canada (Left) & Moscow, Russia (Right)
Source: NOAA (2022)

To date, there's little quantitative analysis on Russian commercial building energy performances, though past studies has been executed on residential properties and of office buildings in similar climate, conveying a deficiency of research on Russian office building performances. The research aims to contribute to the body of knowledge by assessing energy performance and thermal comfort, by developing on how improvements through building parameters such as fabric U-value, internal heat gains, schedules and solar shading may affect it. This may be achieved by parametrically comparing combinations of parameters, using a case study floor in Moscow and use an energy modelling software to run simulations and generate data on energy performance and thermal comfort for each. Allowing an assessment and analysis on how energy efficient the case study to be made. The findings should be able to draw conclusions as to how Russian office building's energy efficiency can be better optimised.

METHODOLOGY

Case Study

The research uses the top floor of a Moscow office building for modelling and simulations, which is around 12 storeys high. The building consists of a concrete structure, along with a curtain wall façade and has already been certified by BREEAM, with a rough score for new construction at 40%, and for BREEAM in use part 1 & part 2 both scoring around 57%, though factors included scored high, such as 72% in Health and wellbeing as well as 88% in transport.

In order for the simulation to be accurate, the floor plan of the 12th floor as well as the floor below was modelled in detail, while the rest of the building is only the envelope. Ensuring that the simulation is replicating the same elevation and conditions as reality, for example, the total heat gain and glazing from the floor below may affect the 12th floor, while elevation is important as it factors into the climate condition. The geometry of the model used for the simulation can be seen in figure 2, with the 11th and 12th floor shown in more detail, the building envelope measures to 72m x 48m though the 12th floor perimeter spans around 72m x 18m. The floor plan in figure 6 further shows the different types of areas on the 12th level, most occupied spaces include executive offices, conference rooms and open workstations.

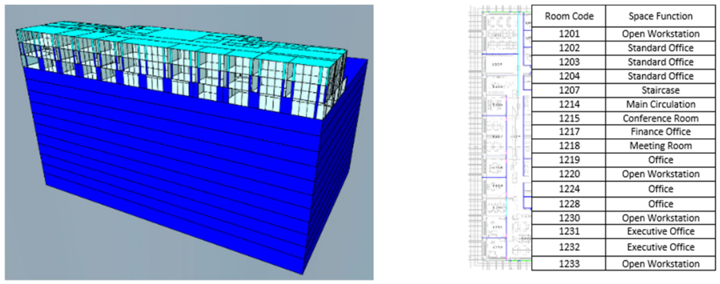


Figure 2: Simulation model and Room schedule

Parameters

The research compares the case study performance under 3 sets of U-Values and under 3 shading scenarios, while comparing results with and without night cooling, alongside other static parameters that may affect simulations, where the findings produce an optimal configuration could be found. From the paper authored by Matrosov (2007), a range of thermal resistance standards can be seen in Europe, where Russia's values can then be inversed to show the U-Value range as shown in table 2:

Table 2: U-Value Standards (W/m^{2}K)

Building Fabric	Poor	Medium	Optimised
Roof	0.340	0.230	0.120
Wall	0.530	0.355	0.180
Intermediate Floor	1.100		
Window	3.800	1.250	1.250

The building operates from, 9am-5pm, staff entering as early as 8pm, and leaving 6pm at the latest through the weekdays. During the occupancy of the building, several equipment, employees, and lighting create internal heat gains, which contributes to the resulting data. Using the number of occupants and schedules, table 3 shows the internal heat gain factors for each occupied space.

Alongside the three U-value scenarios, the research also has each simulations go through with horizontal overhang louvres and vertical fins, with 1m and 1.5m variants and comparing it to a model with no shades. This is to determine how much solar gain affects the energy performance and PMV in the internal space, as well as how the shading type changes the amount of solar gain entering the windows. Mechanical heating and cooling are set to 6:30am-6pm to make a suitable work environment for the employees during occupied hours on a daily basis, using a heating setpoint of 22 C and cooling setpoint of 24 C (Fergus N. et al, 2013) to achieve neutral temperature range from 22-24 C to ensure that the environment is comfortable. Though operative temperature rises in summer causing PMV to spike and overheat the building. To combat this, a Night Purging Strategy (NPS) could be implemented only during summer, which may allow internal space to cool before use, achieving thermal comfortable values in summer. The NPS used has 20% of the overall glazing of the walls openable, using top hung windows operating from 22:00 to 06:00 and opening threshold set to 25 C or higher, pre-cooling the building before it would be used the next day.

Table 3: Internal Heat Gain for each occupied space

Occupied Space	Sensible Gain (W/m²)		
	No. of Occupants	Lighting	Equipment
1201.Open Workstation	22	10	15
1202.Standard Office	1	10	5
1203.Standard Office	1	10	5
1204.Standard Office	1	10	5
1207.Staircase	X	5	X
1214.Main Circulation	X	10	X
1215.Conference Room	8	10	5
1217.Finance Office	6	10	15
1218.Meeting Room	8	10	5
1219.Office	2	10	5
1220.Open Workstation	24	10	15
1224.Office	3	10	5
1228.Office	1	10	5
1230.Open Workstation	6	10	15
1231.Executive Office	1	10	5
1232.Executive Office	1	10	5
1233.Open Workstation	18	10	15

RESULTS & DISCUSSION

Energy Consumption

To first analyse the energy performance results, an understanding of the current benchmark or amount of energy being used is needed, where energy consumption is typically measured in Kilowatt hours per square meters, being the total amount of energy used per hour, such as lighting, heating and equipment in a given square meter. Conferring to Europa statistics (2013), the average annual kilowatt hours per square metre for European countries stands approximately 250 kWh/m2, though countries closer to Moscow, nearer to Russia's border such as Finland, Estonia, and Latvia ranges from 292.58 to 403.08 kWh/m2 as shown in figure 3, which may suggest that the Western region of Russia encompassing Moscow, may also have an approximate average of 300 kWh/m2. However, the simulation results considers the entire building's envelope of 72x48m, as well as its 12-13 floors, therefore, energy consumption for the building measures up to over 250 Megawatt hours a month.

The simulations shows that there are no significant differences in trends between scenarios, as seen in figure 4 & 5, where figure 4 shows the 1.5m vertical fin, which has the poorest results while figure 5 shows 1m overhang with the most optimal results. Where the only factor that could be seen to cause a change is the standard of U-values. All configurations share a similar trend, starting at the peak in January, using 352.73-472.95 Mwh (352,730-472,950 KWh), though it begins a steep decrease until June, where energy use is at its lowest range from 261.35-263.94 Mwh (261,350-263,940 KWh) where the summer heat could provide natural heating during occupied hours reducing need for mechanical heating until the end of august, where energy consumption increases until December, which uses 349.17-465.96 Mwh (349,170-465,960 KWh) looping back to January.

The annual pattern can be logical, as through the colder months, the building relies on mechanical HVAC to create an artificial micro-climate in order to ensure the building remains operational at an acceptable threshold of thermal comfort. Though transitioning from winter to summer, it allows more reliance on solar gain and natural heating in instead with summers reaching as high or higher than 24 C, reducing the overall use of energy from June to August.

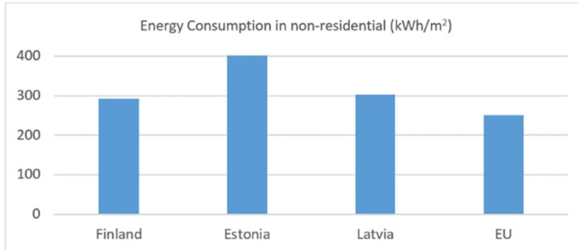
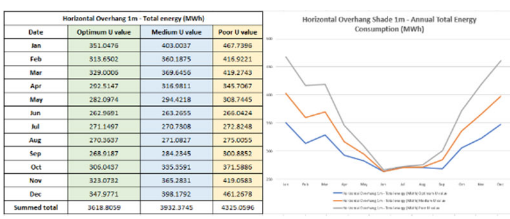
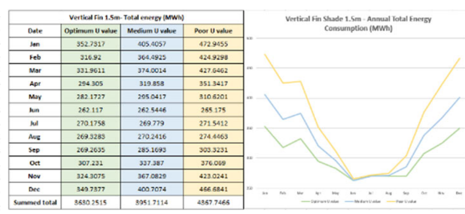


Figure 3. Average energy consumption per m^2 in European countries near Moscow;
Source: (EU Commission)

Improvement in energy consumption may be possible, when using the optimum U-values and comparing it to the poor standard, efficiency improves by 16.6%; however, when compared to the medium values, efficiency is around 7.97% improved. This may suggest that though improvement may be substantial, it raises the question of whether the improvement in efficiency is worth optimising the U-values, as improving the poor U-Values may be justifiable but to improve the medium values which has under 10% improvement may not prove to be enough, following the same trend in efficiency as the glazing type for each standard where there's a larger gap between single glaze and double glaze and a smaller gap between double and triple. While also mentioning that the type or length of shading has little effect on energy performance, with differences between all combinations as well as no shading only varying a +/-12Mwh at most.



Horizontal Overhang 1m - Total energy (MWh)			
Date	Optimum U value	Medium U value	Poor U value
Jan	351.0476	403.0037	467.7396
Feb	313.6502	360.1875	416.9221
Mar	329.0006	369.6456	419.2743
Apr	292.5147	316.9811	345.7067
May	282.0974	294.4218	308.7445
Jun	262.9691	263.2655	266.0424
Jul	271.1497	270.7308	272.8248
Aug	270.3637	271.0827	275.0055
Sep	268.9187	284.2345	300.8852
Oct	306.0437	335.3591	371.5886
Nov	323.0732	365.2831	419.0583
Dec	347.9771	398.1792	461.2678
Summed total	3618.8059	3932.3745	4325.0596

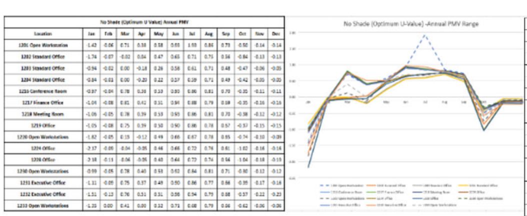


Vertical Fin 1.5m- Total energy (MWh)			
Date	Optimum U value	Medium U value	Poor U value
Jan	352.7317	405.4057	472.9455
Feb	316.92	364.4925	424.9298
Mar	331.9611	374.0014	427.6462
Apr	294.305	319.858	351.3417
May	282.1727	295.0417	310.6201
Jun	262.117	262.5446	265.175
Jul	270.1758	269.779	271.5412
Aug	269.3283	270.2416	274.4463
Sep	269.2635	285.1693	303.3231
Oct	307.231	337.387	376.069
Nov	324.3075	367.0829	423.0241
Dec	349.7377	400.7074	466.6841
Summed total	3630.2515	3951.7114	4367.7466

Figure 4: 1.5m Fin shading -Annual Energy Use **Figure 5:** 1m Overhang Shade-Annual Energy Use

Annual PMV Results

Using the no shade scenario as a baseline pattern, allowing a comparison between the baseline and the various shading scenarios to be carried out in order to evaluate the significance between shading. With no shading, U-values play a similar role as it did with energy consumption, which decreasing the overall range from -3 to +2.29 at a poor level to the range of -1.74 to +1.93 when optimised standard seen in figure 6. Though with NPS, the summer peak from figure 6 reduces from +1.93 to +1.55, due to additional cooling out of occupied hours,



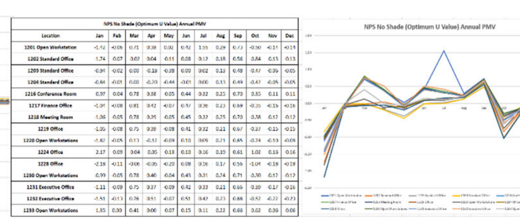
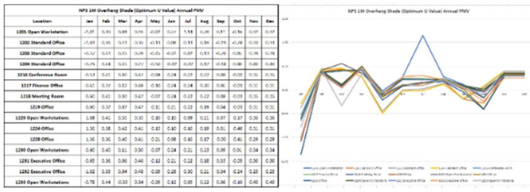


Figure 6: No Shading (Opt.) Annual PMV **Figure 7:** No Shading (Opt) Annual PMV with NPS

When comparing overhanging shading to the baseline, the peak of 2.29 has reduced to 1.19 when using 1m overhang while the 1.5m overhang will decrease the peak further to 1.02, reducing over half the original value. While, if the situation were to be optimised U-values with NPS such as the baseline 1.55, figure 8 shows an improvement of 1.14. deducting 0.41 from the baseline value, while figure 9 achieves a score of 0.81, almost halving the original score, improving by 0.74. A possible reason for this outcome would be due to the increase in length, the louvres would block out overhead direct sunlight against the curtain wall, while having a larger shadow range throughout the day.



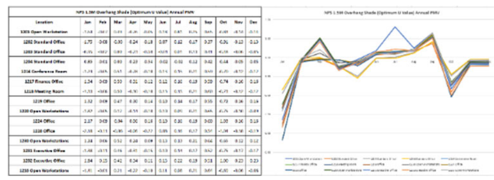
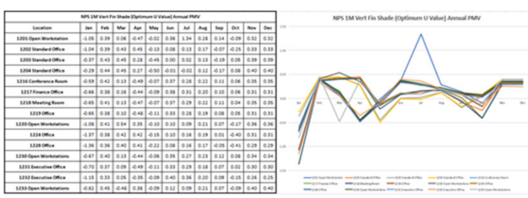


Figure 8: 1M Overhang (Opt.) Annual PMV NPS **Figure 9:** 1.5M Overhang (Opt.) Annual PMV NPS

However, using the vertical fin in the poor U-Value scenario, the peak value score around 1.71 when using 1m vertical louvre fins, while 1.5m louvre fins has a peak of 1.59. Whereas at top U-values, figure 11 is able to achieve 1.29, while figure 10 follows up with 1.34. Though it is somewhat surprising that the medium was able to achieve 1.27 without the need of a NPS, utilising 1m length louvres together with average U-value standard in current day, although it is not as impressive as the improvement made in overhang shading, the result is still able to reach just under half of the original baseline, going from 2.29 to 1.27.Although, vertical fin louvres do provide a substantial development when compared to the no shade baseline alone, ultimately, the results do not reach the extent of the improvements made by the overhang shading, while also not requiring compromising insulation during winter. Therefore, in an annual perspective, use of 1m or 1.5m overhang using an optimised set of U-values and integrated NPS would be the most efficient, however the research requires further in detail analyses, such as how effective PMV may be on a day-to-day basis.



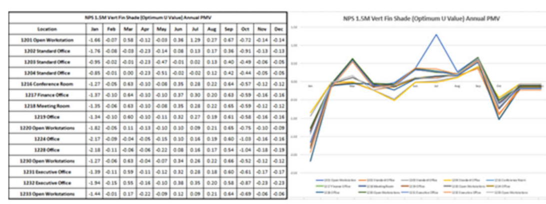
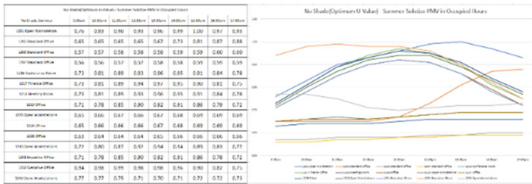


Figure 10: 1M fin (Opt.) Annual PMV with nps **Figure 11:** 1.5M fin (Opt.) Annual PMV with nps

Daily PMV Solstice

By analysing the data on a daily scale, rather than annually, it would allow a more thorough breakdown of the PMV and thermal comfort to be taken, where each room's performance can be individually assessed.

Firstly, the no shaded baseline during summer seems reliant on the sun's path, this could be evident by the curving patterns throughout all or most of the rooms throughout figure 12, the southern rooms follow a standard curve, starting around 0.75-0.78 at 9am, peaking around 12-13pm at 1.15-1.21, and ending at 5pm from 0.79-0.85. Though, other rooms may not follow this trend due to its location, therefore, those rooms may peak earlier or later, such as 1232/1233 peaking from 10-11am as they're situated on the east side, while 1201 and 1202 peaks from 15-17pm as they're on the west. However, there are also rooms not exposed directly to the solar gain, being the northern side, resulting in a flat line result with minor fluctuations of +/- 0.03 PMV.



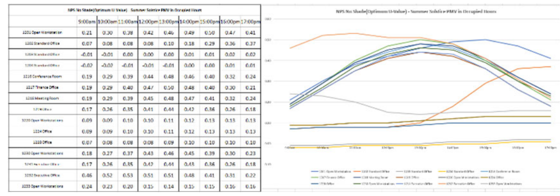
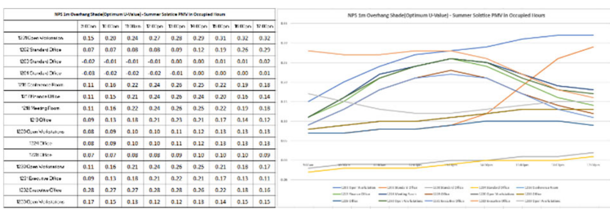


Figure 12: No Shading (Opt.) Summer PMV **Figure 13:** No Shading (Opt) Summer PMV nps

Secondly, the horizontal overhang model essentially produced the more optimal results, while the 1m variant within figure 14 shares a similar pattern to the no shading baseline, it is able to stay within the +/-0.5 PMV as the values ranges from -0.04 to +0.4. While the 1.5m overhang manages to produce a different pattern compared to the other scenarios during summer as shown in figure 15, the occupied spaces follow a shallow fluctuating curve through the day, though rooms on the west area such as 1201 and 1202, increases towards the evening, where other rooms follow a shallow curve peaking 0.68-0.7



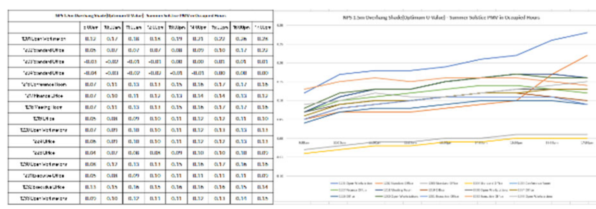
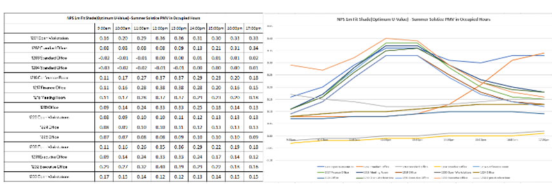


Figure 14: 1m Overhang (Opt.) Summer PMV nps Figure **15:** 1.5m Overhang (Opt) Summer PMV nps

Finally for the summer solstice, the vertical fin shares similar results to the baseline data, as the results within 16 and 17 conveys that most rooms generally having the same patterns in both summer when compared to the model with no shades. With the main difference being that instead peaking, the curve plateaus from 12-13pm, typically around the value of 1.01 - 1.03, this could be due to vertical fins casting a shadow and blocking direct sunlight from infiltrating the window head on, rather than overhead. Though, not impacting the results enough where it may differ from having no solar shades.



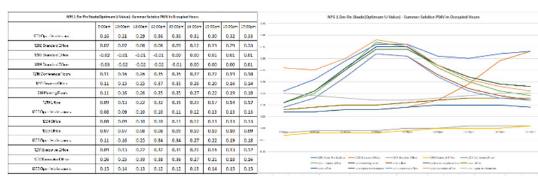


Figure 16: 1m fin (Opt.) Summer PMV nps **Figure 17:** 1.5m Overhang (Opt) Summer PMV nps

When incorporating NPS into the simulations, the patterns throughout any scenario is not affected significantly, though the main difference would be the change in the values. As an example, for no shading, the range was from 0.56 to 1.00, however with integrating the night purging strategy, the range narrows to -0.02 to 0.53, essentially, achieving thermal comfort. This process yields similar results for most scenarios except for the 1m overhang which has kept the original range of -0.03 - 0.32, with values decreasing slightly in between, as well as the 1m vertical fins which remains from -0.02 – 0.40. Although, the 1.5m configuration had a bigger improvement, going from 0.55-0.78 to -0.04-0.28, which allows the 1.5m overhang to remain neutral and balanced on the thermal comfort scale. While the 1.5m vertical fins had improved from 0.55-0.86 to -0.03 to 0.38.

These results convey a pattern, where 1m variants does not improve as much as the 1.5m counterparts, a possible explanation for this reaction may lie in the reason for incorporating NPS from the start. As NPS was integrated in order to keep the commercial building from overheating, however from the data stated earlier, both 1m optimised ranges falls within the +-0.5 PMV, therefore would not require any improvements as the NPS was set to activate when the temperature reaches 25 C or higher, to allow the windows to open in order to pre-cool the building before use, though if the 1m variants remains neutral, then that would suggest the operating temperature would be between 22-24 C in order to meet CIBSE Guide A's temperature comfort criteria.

Unlike the daily summer PMV, within winter, the solar path does not directly influence the PMV, with the main differences between the two results being the pattern, using the no shading 1217 as the baseline, during summer, the PMV would curve from 0.73 at 9am, where it continues to increase until 1pm peaking at 0.97, where it would then decrease until 5pm, ending around 0.73. However, during winter, 1217 would start at -0.18 and where it would peak in summer at 1pm, the score increases to -0.16 and would increase further to -0.15 until 3pm where it remains -0.16 up until 5pm. With the largest difference in PMV being 0.03, which would be unnoticeable in terms of thermal comfort. Overall having a shorter range than it would in summer, with a range of -0.25 to -0.03.

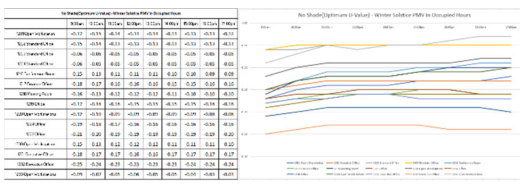


Figure 18: No Shading (Opt.) Winter PMV

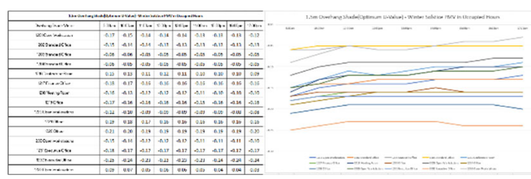


Figure 19: 1.5m Overhang (Opt) Winter PMV

Figure 18 and 19 compares the no shading to a 1.5m overhang, however as seen, the results are almost exact and highly similar. Due to the lack of influence from solar gain or external climate conditions, it seems possible that these results are created in a completely artificial environment, creating somewhat of an internal micro-climate where the temperature would be manipulated through mechanical heating, ventilation, and air conditioning (HVAC). However, if the solar gain has no effect on winter PMV, then it would also suggest that the shading could be redundant during winter.

As previously stated, during winter, the ranges in each scenario compresses, allowing some cases such as no shading to fit within the neutral threshold to succeed in thermal comfort. Similar results can be when using optimised values, whatever the range was before such as 1.5m fin's 0.55-0.86 or 1.5m overhang's 0.55-0.78, it will be fixed to -0.25 to -0.03, just as it was during no shades. This may be due to the autonomous nature of creating a thermally comfortable space solely using mechanical HVAC, creating a fixed range depending on the level of U-Value, as if a poor U-Value standard was used, the range would then be fixed to -0.69 to -0.08, though this is not to say that the shading results are identical to each other, as the values are varying within the fixed range. This may be advantageous as with an optimised U-Value, it would fix whatever configuration to become thermally comfortable. Where in stark contrast, during summer both the sun path and shading strategy can control when the highest and lowest point in each configuration, where in some cases both values tend to be too warm to classify as neutral.

Operative Temperature Results Ultimately, operative temperature results run parallel to PMV, meaning that trends and patterns will be highly similar to that of PMV's result, due to the fact that the operative temperature is a huge factor when calculating PMV, alongside internal and latent gains, clothing insulation and activity type among other properties. Therefore, instead of repeating patterns and re-establishing explanations discussed within PMV, there will be a focus on the analysis of the operative temperature, which will allow further insight in context to the PMV results as well as being able to assess internal temperature within the occupied spaces, for areas where a PMV scale may not prove to be enough.

Throughout most simulations beforehand, room 1201 seems to be the room that always peak in terms of warmth, this could be due to where the office is situated, allowing for more exposure to solar gain through the day by taking up 1/6 of the southern façade of the top floor, but also having a second curtain wall, meaning that two of the four walls are glazed, which could explain how the room is prone to overheating as well as heat loss. Using 1m Overhang as seen in figure 20 and 21, in July, 1201 may reach a range from 27.84-28.51 C, being the warmest room, with the second warmest office ranging 25.21-25.45 C, being 1232. Which is a similar case, with two sides being curtain wall, though the office may not be as large as the 1201 space, it may still be vulnerable to the same type of thermal bridging, both rooms score the lowest within January 1201 scoring -6.13 C while 1232 scores 6.1 C, additionally proving that most of the heat loss may be due to both occupied spaces. This would lead to suggest that rooms with 2 curtain wall elements are not as efficient and using more external wall elements would improve that room's performance.

Figure 18: 1m Overhang (Poor) Annual Temp.

Figure 19: 1m Overhang (Opt) Annual Temp.

CONCLUSION

To precis, the holistic aim of the paper was to assess and improve energy performance and thermal comfort in a Russian Office Building. Various combination scenarios including levels of U-values, types of shading and with and without night purging strategies were considered. The positive results of the research and simulations would sequentially combine to show how both energy performance and thermal comfort could be improved. This configuration uses the optimised set of U-values in order to increase airtightness and insulation, which would in turn keep the building warm and reduce energy consumption, using triple glazing with argon filled cavities for curtain walling and reduce heat losses, also requiring a reduction in wall to glazing ratio to reduce heat losses during winter. The application of overhung shading and night purge ventilation, to precool buildings, are also effective strategies to prevent overheating during summer.

ACKNOWLEDGEMENT

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ENHANCING THERMAL COMFORT IN CONVERTED DWELLINGS THROUGH PASSIVE DESIGN STRATEGIES.

Marius Rotaru[1], Arman Hashemi[1*], Ioana Madalina Predescu[1]

[1] University of East London, School of Architecture, Commuting and Engineering, London, UK
[*] Correspondence: a.hashemi@uel.ac.uk

ABSTRACT

Poorly ventilated dwellings, new winter-focused insulation standards, and the increasing global temperatures are factors that aggravate the overheating during hot spells. The number of dwellings that experience overheating are exponentially rising, and simultaneously are the number of deaths. Overheating is currently of a major concern for many UK dwellings particularly in urban areas. The projected alarming temperature rise of 4 °C in the next 50 years in addition to more frequent heatwaves also contributes to the need of urgency to address this issue. This paper investigates the effects of passive design strategies, including natural ventilation, solar shading, and optimised window sizes and openings, on thermal comfort in a case study residential building in London. Dynamic thermal simulation in IES(VE) was conducted and CIBSE TM59 was used for the assessments. The results show significant improvement in thermal comfort particularly when a combination of these strategies was considered.

Keywords: Overheating, Thermal Comfort, Passive Design.

INTRODUCTION

Overheating has become a major concern in dwellings as a result of climate change during the past two decades (ZCH, 2015). The UK Climate Change Projection (UKCP, 2009) has estimated that all the regions in the UK will manifest warmer summers, especially in the South of England where it is estimated that the temperature will rise by 4.2 degrees by the end of the century. The majority of the UK population lives in urban areas, where the outdoor temperatures are at its highest due to the effect of the Urban Heat Island (UBI) (Mavrogianni et. al.,2016). Moreover, according to the Building Research Establishment (BRE), apartments located within the urban boundary are most prone to overheating and thermal discomfort. The Energy Performance of Building Directive recommends using strategies such as solar shading and natural ventilation to reduce risks of overheating. A report from the UK Green Building Council (UKGBC, 2017), states that in the last 30 years, carbon emissions by the building sector have reduced (Table 1); however, data shows that domestic buildings still contribute to 30% of the total carbon emissions in the UK.

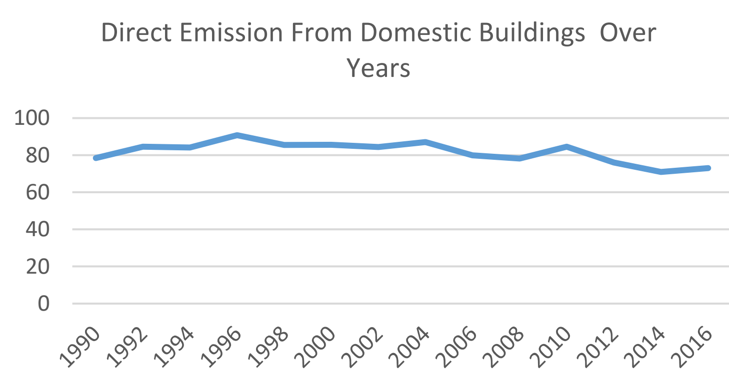

Figure 1: Direct emission from fuel use in domestic buildings (UKGBC,2017)

The Existing housing and Climate Change Report (2007) has set actions which will help to decrease carbon emissions. This can be achieved by refurbishing dwellings which present weak thermal insulation, improving cladding's thermal transmission, thermal bridge, and airtightness; assisting to reduce the carbon footprint by 60% by 2050. In addition, the Code for Sustainable Homes (CSH) in 2006, aimed at reducing the emission by creating more sustainable Zero Energy homes. The CSH has now been replaced with BREEAM, an assessment method that values the sustainable performance of buildings, starting from the choice of materials, the construction of the building and its environmental impact. The UK has currently no policies to reduce the effects of UHI on dwellings and nonetheless policies to help existing and new dwellings adapt to high temperatures (Committee on Climate Change, 2016).

A study by Wright et. al. (2005) aimed to explore the relation between the internal and external temperatures measured during the summertime and if the overheating risk is related to the type of construction and its thermal capacity, in four dwellings in Manchester and five dwellings in London, during a heatwave in August that lasted 9 days. In Manchester, the upper storey was more likely to be warmer than the lower storey, due to the structure and its thermal mass; however, in London, the indoor temperatures were much higher on both day- and night-time. The results of the above research coincide with the research by Beizaee et. al. 2013) in July-August 2007 to assess temperature ranges in bedrooms and living rooms in 207 dwellings in England. The findings showed that dwellings built before 1919, which present solid walls and high thermal mass, are notably cooler than dwellings built afterwards, which generally present cavity walls. It was argued that flats and dwellings positioned at higher storeys tend to have a warmer indoor temperature. The authors argued that relatively modern dwellings, built after 1990, are prone to higher risk of overheating as the amount of insulation used is mainly aimed at reducing energy consumption during winter, but does not take into consideration overheating during summer. Lomas and Porritt (2016), affirm that the urbanisation and the housing crisis led to an increase in high-rise buildings. Those dwellings, for most of the time, present prefabricated modules or thermally lightweight materials that may have a good insulating standard; however, they lack on thermal mass that is essential to absorb excessive heat and overcome overheating risk. Dengel and Swainson (2012) also assert that overheating risk is more likely to occur in new build dwellings and highly insulated houses in contrast with the general assumption where older buildings are at more risk due to their lack on insulation. Another study conducted by Lomas and Kane (2012) in 268 dwellings in Leicester during summer of 2009, concludes that dwellings with solid walls and especially those built before 1919 generally tend to have cooler indoor temperatures compared to dwellings that present a cavity wall; yet dwellings built after 1980s had a slightly warmer living rooms than bedrooms, and dwellings built before 80s present the opposite pattern. The authors justifies the outcomes by arguing the insulated roofs can decrease solar gains hence improving the conditions. Several studies other studies, including a report by Zero Carbon Hub (2015) and Building research Establishment (2014), state that even modern dwellings with high insulation and great airtightness are exposed to risk of overheating during the hot periods (Tink, Porritt, Allison and Loveday, 2018). Poorly ventilated dwellings, new insulation standards (imposed by the Building Regulations, which aim is to reduce heat loss during winter) and the increasing global temperatures are factors that aggravate the overheating during hot spells. The number of dwellings that experience overheating and disruption of thermal comfort are exponentially rising, and simultaneously the number of deaths. To this end, the aim of this research paper is to investigate suitable sustainable design strategies that can be applied to existing dwellings, further, to recommend and help occupants to improve the indoor thermal comfort by applying those strategies.

RESEARCH AIM AND METHODOLOGY

Case Study Building

The selected case study building is a typical naturally ventilated converted terrace house built in 1890s in London (Fig.2). The research was carried out on the top floor where occupants have experienced thermal discomfort during summertime. The building consists of solid walls made of red bricks; therefore, no cavity wall insulation is present; the roof however has been upgraded with a 300mm fibreglass insulation. The flat has an approximate floor area of 46 sqm with three different thermal zones: open plan kitchen and living room, bedroom 1 and Bedroom 2 (Fig.2). The flat has large, double-glazed windows, facing North, in bedroom 1 and in the living room, and rooflights (facing South) in the kitchen, bathroom and Bedroom 2. The large top hung window panels, facing North, cannot be fully opened due to safety reasons and noise pollution as a rail network runs very close to the building. This reduces the ability to enhance indoor natural ventilation. Table 1 shows the construction elements and U-values.

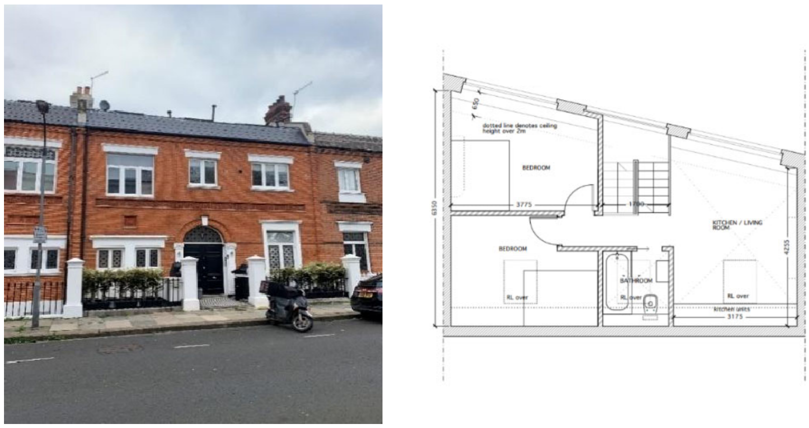

Figure 2: Front elevation of the case study building facing South (left); Floor plan of the case study building (right) (Hammersmith and Fulham Council)

Table 1: Summary of construction build up and approximate u-value.

Building Component	Construction Build Up	U-Value (W/m2K)
External Wall	X2 Brickwork 4mm Render 12.5mm posterboard	1.7
Party walls	X2 Brickwork 50mm Cavity	0.6
Internal Partitional Wall	Solid Brick covered with 12.5mm plasterboard	2.1
Roof	4mm Synthetic Slate tiles 6mm Vapour Barrier 300mm Fiberglass insulation	0.13
Windows	Double Glazed with uPVC frame	1.3
Roof Light	Double Glazed with uPVC frame	1.3
Intermediate Floor	Uninsulated suspended timber	0.84
Doors	Timber	1.3

Simulation Procedure

Simulations are conducted in IES(VE) aiming to assess compliance with CIBSE TM59 (CIBSE TM59, 2017) for thermal comfort. TM59, stats that when assessing overheating, Design Summer Years (DSY) should be used, therefore in the following simulations, as the case study is situated in London, the London DSY is used.

Table 2: Window and Doors Openings

Thermal Zone	*C. Degrees*	*Period*
Living Room & Kitchen	Exceeds 22C	Open between 9am- 22pm
Doors		
Internal Doors		Closed Between 22pm-9am
External Door		All Day Closed

Table 3: Occupancy profile and internal gains

Thermal Zone	*Period*	*Maximum*
Bedrooms	Occupied all day	22pm-9am
Living & Kitchen		9am-22pm

Internal gains such as lighting and equipment are following the TM59 guidelines and vary between thermal zone depending on the occupancy. Heating and cooling are set off continuously, throughout the whole simulation period 1 May-30 September. Conforming to TM59, dwellings that are primarily naturally ventilated, must satisfy the two criteria imposed, A and B.

Criterion A states that the number of hours, in bedrooms, lounges, living rooms and kitchens, which ΔT is greater than or equal to one degree shall not be more than 3% of occupied hours for the period between May and September (CIBSE TM59,2017). Criterion B is applied for bedrooms only and it state that the operative temperature of the room between the hours 22:00 and 07:00 must not exceed 26 °C for more than 1% of annual hours, which corresponds to 32 hours, 33 or more hours in exceedance will fail the simulation. This is to assure comfort during the sleeping schedule (CIBSE TM59,2017).

SIMULATION RESULTS AND DISCUSSION

The case study building has been simulated formulating different scenario alternatives (Table 4); follows, therefore, a discussion of the outcome of the simulation which will talk through the various data gathered.
Table 4: Summary of different scenario alternatives used in the simulation

Variables	Alternatives
Occupancy	Following TM59 standard (Living and Kitchen 09:00 to 22:00, Bedroom 24/7 with peak between 22:00 and 09:00).
Windows operation	Always open; Always closed; Open at night; TM59(when the temperature of the occupied room exceeds 22 °C)
Shading system	No shading; 500, 750, 1000mm
Openable windows	As built (9m2); Increased (12m2)

Simulation was conducted to assess the situation for the following as the base case scenario: windows and doors closed permanently, occupancy of 100%, and lastly no shading. The results (Table 5) show a very high risk of overheating. Despite extreme outcomes, this will be used to assess how the implementations of the various alternatives would affect comfort. The south facing zones including Bedroom 2 and Living room/Kitchen are more likely to experience overheating.

Table 5: Outcome of the worst-case scenario

Thermal Zone	Maximum Temperature	TM 59 Criteria A&B Pass/Fail
Bedroom 1	37	Fail
Bedroom 2	48	Fail
Living room and Kitchen	46	Fail

Additional simulation was conducted with the following criteria according to the TM59 occupancy and control profiles explained in Table 2 and Table 3. The results (Table 6) show a clear reduction of the overall temperatures, especially of Bedroom 1 where window is facing North, however Bedroom 2 fails TM59 criterion A, where the number of hours between 22:00 and 07:00 from May to September, ΔT exceeds 3% of the occupied hours; yet, both bedrooms fail to meet criterion B however the situation is significantly worse in Bedroom 2. The results suggest that natural could reduce the overheating risk, however excessive solar gain could deteriorate the conditions for the south facing rooms.

Table 6: Outcome of the simulation implementing TM59 criteria

Thermal Zone	Maximum Temperature	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours	TM59 Pass/fail
Bedroom 1	32	Pass	0.9	Fail	33	Fail
Bedroom 2	33	Fail	4.4	Fail	119	Fail
Living Room and Kitchen	30	Pass	0.4	--		Pass

Considering the above results, a 1000mm shading device was considered on the south facing windows. Windows were fully open during the whole day and the openable area increased from 9 sqm to 12 sqm to improve natural ventilation. The occupancy period was considered as set by the TM59. The results of the simulation show significant improvement with all three zones meeting both TM59 criteria. It should be noted that although increase openable area improves ventilation, it needs to be combined with solar shading to avoid excessive solar gain. Yet, more research is required to assess the effects of larger glazing on heat-losses during winter.

The effects of natural ventilation were further investigated by considering four different schedules: a) always open, b) always closed, c) TM59 schedule and lastly d) open at night (opened between 18:00 and 07:00 and closed between 07:00 and 18:00). Occupancy periods remained as defined by TM59. The results are summarised in Table 7. The results indicate that thermal comfort was achieved for the windows “always open” and” open at night”. For the “always open” scenario, the best outcome was achieved however this may not always be feasible due to noise, pollution or for security reasons especially for the flats on the ground floor.

Table 7: Effects of natural ventilation on thermal comfort

Thermal Zones	Maximum Temperature`	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours
Windows always open					
Bedroom 1	31	Pass	0.1	Pass	0
Bedroom 2	30	Pass	0.1	Pass	1
Living room and Kitchen	30	Pass	0.0	---	
Windows always closed					
Bedroom 1	31	Fail	5.0	Fail	87
Bedroom 2	30	Fail	16.9	Fail	264
Living room and Kitchen	32	Fail	13.0	---	

TM59 profile					
Bedroom 1	35	Pass	0.9	Fail	33
Bedroom 2	37	Fail	4.4	Fail	119
Living Room and Kitchen	36	Pass	0.4	--	
Windows open at night					
Bedroom 1	30	Pass	0.1	Pass	1
Bedroom 2	31	Pass	0.8	Pass	3
Living room and Kitchen	31	Pass	0.8	---	

The effects of solar shading were also investigated by considering 500mm, 750mm and 1000mm overhangs applied to south facing windows. As expected, the outcome of the simulation shows a clear reduction of annual solar heat gain by over 30% from 1.75 to 1.22 MWh for no shading scenario compared to 1000mm overhang, respectively. Table 8 summarises thermal comfort conditions when shading was applied. According to the results (table 8), all zones meet the requirements of Criterion A; however, Bedroom 2 does not mee the requirements set by Criterion B.

Table 8: Outcome of simulation for shading

Thermal Zone with 500mm shading	Maximum Temperature`	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours
Bedroom 1	31	Pass	0.2	Pass	10
Bedroom 2	32	Pass	0.9	Fail	50
Living room and Kitchen	29	Pass	0.0	---	
Thermal Zone with 750mm shading					
C	30	Pass	0.2	Pass	9
Bedroom 2	31	Pass	0.7	Fail	41
Living room and Kitchen	29	Pass	0.0	---	
Thermal Zone with 1000mm shading					
Bedroom 1	30	Pass	0.2	Pass	8
Bedroom 2	31	Pass	0.5	Fail	33
Living room and Kitchen	28	Pass	0.0	---	

Figures 3 and 4, extracted from IES(VE), also illustrate indoor conditions when opening areas increased from 9 m^2 to12 m^2. The red colour is the time when the temperature exceeded 26 C (considered as overheating) for the duration of simulations (May 1 to September 30) for all rooms. Comparing the results, it is evident that the number of hours when the temperature exceeds 26 C has significantly decreased in all rooms indicating reduced risk of overheating thanks to improved natural ventilation.

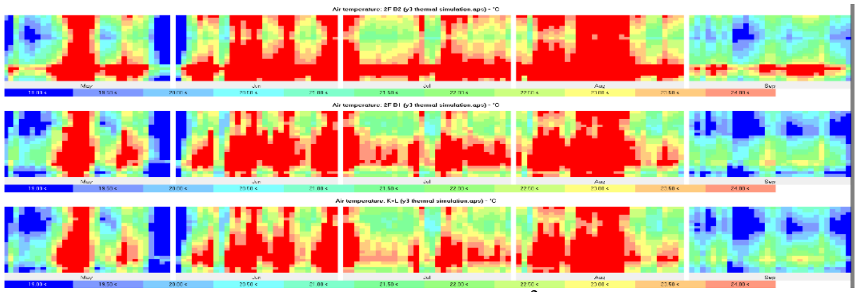

Figure 3: opening areas 9 m^2, “as built”

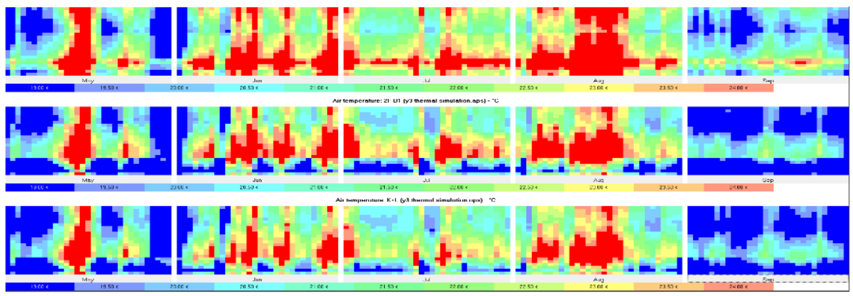

Figure 4: opening areas 12 m^2

Figure 4 shows the outcomes of the simulation for the combination of the most effective strategies, namely opening time and sizes combined with 1000mm solar shading. The results show a clear reduction of overheating (red colour) when temperature exceeds 26 C. The yellow and light green colours indicate temperatures between 20 and 23 C. All zones have passed both TM59 criteria (Table 8) indicating a significant reduction in risk of overheating in the flat during summer.

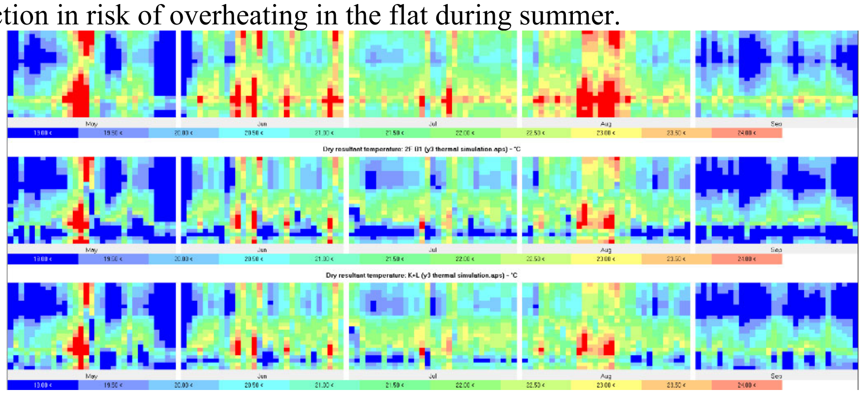

Figure 5: Outcome of the simulation with all strategies implemented

Table 9: Outcome of simulation with multiple strategies applied

Thermal Zone	Maximum Temperature`	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours
Bedroom 1	27	Pass	0.2	Pass	0
Bedroom 2	27	Pass	0.6	Pass	0
Living room and Kitchen	27	Pass	0.0	---	

CONCLUSION

The predicted rising temperature combined with heat weaves and acute weather events in the UK have raised the question as to whether the new and existing dwellings can adapt to the consequences of climate change including acute overheating. The aim of this research to investigate and enhance thermal comfort in a typical case study building by implementing sustainable passive strategies. The results show that such strategies could significantly improve the conditions. The implementation of a combination of passive design strategies, including natural ventilation, solar shading, and thermal mass, in early stages of design could effectively address these issues in buildings mitigating the risk of overheating and thermal discomfort for occupants of buildings. This would not only improve the health and wellbeing of the occupants but would also reduce the need for mechanical ventilation that could contribute to more energy consumption and CO2 emissions. This said, rising temperatures in moderate and cold climates may also reduce the need for heating during the wintertime. More investigation is required to understand the overall effects of global warming on the energy performance of residential building in such climatic conditions.

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ENERGY CONSUMPTION BEHAVIOUR IN HISTORICAL CHURCHES

Ionela Daniela Dragu[1], Arman Hashemi[1*], Robin Talbot[2], David Greenfield[3], Emma Arbuthnot[4], Philip Ashton[2], Marco Picco[2]

[1] University of East London, School of Architecture, Commuting and Engineering School of Architecture, Computing and Engineering, University of East London, London E16 2RD, UK.
[2] School of Architecture, Technology and Engineering, University of Brighton, Brighton BN2 4GJ, UK; University of Brighton, School of Architecture, Technology and Engineering.
[3] School of Applied Sciences, University of Brighton, Brighton BN2 4GJ, UK.
[4] Diocese of Chichester, Church of England, Church House, 211 New Church Road, Hove BN3 4ED, UK.
[*] Correspondence: a.hashemi@uel.ac.uk

ABSTRACT

The historical buildings are being categorized under low thermal comfort because of their primary construction materials and their architecture, requiring a large volume of air to heat/cool to achieve the human comfort levels required today. The existing problems within the historical churches are increasing, destroying not just the cultural heritage, but also affecting the health of people using them. This raises environmental concerns and questions as to how to preserve historic buildings, and artefacts, while providing acceptable indoor environments and thermal comfort for the users of these buildings. A case study church building was selected to be monitored. Data loggers were installed to measure/record temperature and relative humidity ranges. The results were analysed to assess thermal comfort according to CIBSE TM52 and CIBSE Guide A standards/guidelines. The results demonstrate that the indoor environments are, in majority of the times, cooler than the minimum acceptable standards, not achieving thermal comfort requirements for the occupants of the building.

INTRODUCTION

It is known that many of the historical churches survived hundreds of years with minimum maintenance and without any improvements in terms of comfort, due to the construction materials and technologies used in their period. The UK climate, that is cold/wet in winters and warm/wet in summers, may not provide suitable indoor environments in church buildings affecting users' health [21]. The structure and objects located in those churches may be at high risk of being damaged and even collapsing, resulting in reduced lifetime and value of buildings [1,13]. A general problem with historical churches is that due to the porous envelope proper ventilation is required to avoid the moisture being trapped in the materials resulting in further damages [31]. Detailed investigation on the building materials and construction methods is therefore a priority.

Historical churches

Of all the constructions, churches are one of the most globally important historical buildings, due to their cultural heritage which are defined as 'culture named and projected into the past, and simultaneously, the past congealed into culture' [20]. The UK climate conditions are found to be rather challenging being dominated by moisture with an external average relative humidity of 80% (Lawson-Smith, 1988). Due to the different performances of the wall materials, various micro-climates can be found on the historical buildings, [17]. Historical churches lean towards a range of common physical problems, that are mainly related to construction materials and insulation strategies, heating, ventilation as well as to weathering, chemicals and other environmental issues. Amongst all these problems, damp and condensation in the materials could be highlighted as most challenging issues. This problem arises as a result of the low temperatures on the surfaces, walls, glazing, floor or ceiling. The general combination of low temperatures with high air humidity is creating excessive moisture [18]. However, extreme changes in temperature can also expose timber furniture and structures to drying, expansion, shrinkage or deflection. A permanent water infiltration, which accumulates moisture, would create salt damage to walls and ceilings [18].

Constructed, in general over a floor level, without damp-proof membranes or vapour barriers, historical churches can retain a significant amount of water in the walls even with regular maintenance services in place. Additionally, defective ventilation and HVAC systems/strategies would affect both the building fabrics and people's health [3]. These are identified as the main cause of dampness and decay in most churches, as well as damage to vulnerable materials and contents [29].

One of the dominant factors of those problems in naturally ventilated churches is the high relative humidity which encourages the growth of mould and algae. The low temperatures in a cold climate and poor ventilation in warm/wet seasons are also contributing to the destruction of historic monumental and cultural heritage [15]. Those historical churches have been functioning for centuries in cold conditions without a central heating method in place; however, heating and thermal comfort become major issues when building occupants are brought into consideration [23,30].

Modern heating systems can be installed to improve thermal comfort in churches; however, without proper research, such systems may present risks in terms of preserving cultural heritage and result in irrevocable damage to building fabric, artefacts, organs, etc. [5,22].

Moreover, achieving and maintaining thermal comfort in churches is a major challenge due to the high energy due to large areas and heights. Space heating presents around 60% of the total energy consumption in the UK [14], while 80% of the energy used in the churches is for heating [6]. In many cases, inappropriate heating systems are damaging the building materials due to their installation processes. [24]. Yet, creating a balance between energy efficiency, thermal comfort and conservation is considered as a major challenge in historical churches. To this end, this research aims to evaluate the existing internal conditions in historical churches with the aim to improve the indoor environments, energy performance and thermal comfort.

RESEARCH METHODOLOGY

Case study – Church of Saint Mary de Haura, Shoreham-by-Sea, UK

The history of the church dates to the Norman period and was built at the end of 11th century by Phillip de Braose, son of William Braose which was fighting with William the Conqueror in 1066 at Hastings Battle. Throughout the medieval periods, Saint Mary de Haura was one of the largest and most important parish churches in Sussex [16]. The church is a listed Grade I building in rather poor conditions due to a slow decay [16].

The existing structure is half of the church (Figure 8), which was divided by large round columns. The space could hold hundreds of people, and it measured around 30 metres by 20 metres, with two wide side aisles, and later, a large south porch. Constructed over only one floor, the main structure of the church is made of Caen stone imported from Normandy and local flint, while for the interior structures used a less durable stone, the roof being covered in tiles manufactured in old Horsham (Figures 1,2,3). The actual stage of the church requires repairs to stone parts, roof and gutters [16]. Regarding the actual heating system used in St Mary's, this is provided through a central heating system with 21 radiators at floor level. Being only a part of the initial building, by curiosity, it was researched for the cause of collapsing the nave in the late 1600s, but the true reason is still a mystery [26].

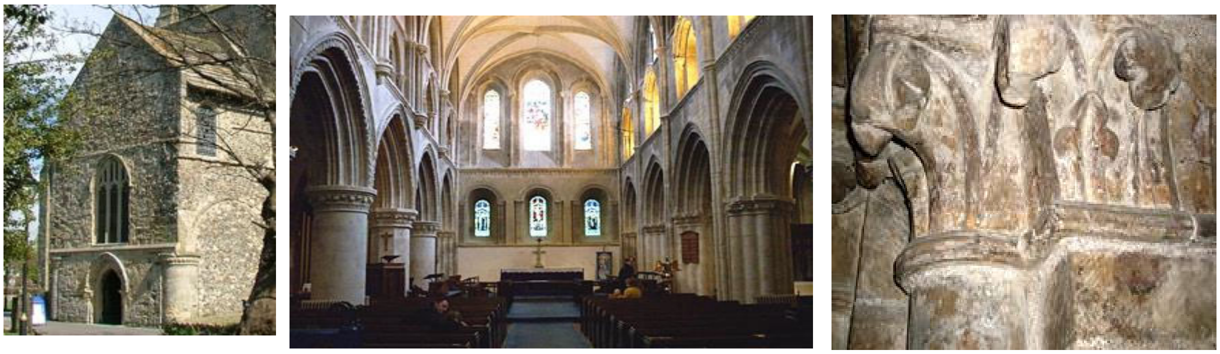

Figure 1: St Mary de Haura Church (left); Internal space of the church (middle); Column with old paint (right)

METHODOLOGY

Understanding the individual energy consumption behaviour, while having in mind that the energy performance targets were an exemption to the churches due to the missing of benchmarks on the energy efficiency of construction methods and materials used, will help on finding the best solution on improving the overall energy consumption [13]. The first part of the methodology is to analyse the energy performance of the building materials such as stone, limestone, brick and wood, picking up three thickness to consider for the walls of 800mm, 1000mm and 1200mm. The U-values shown in Table 1 have been achieved using the formula applied in the examples below:

Assuming that the walls are made of 0.8m limestone with thermal conductivity of limestone of 1.5 W/mK, the U-Value of 800mm is 1.5 x 1000/800 = 1.9 W/m^2K approximative. The same assumption with the walls of 0.8m stone with thermal conductivity of hard stone of 2.33 W/mK, the U-Value of 800mm is 2.33 x 1000/800 = 2.9 W/m^2K approximative.

The results show a high U-value for stone historical churches due to their high thermal conductivity, which means they have a low thermal resistance, following a high loss of heat through those walls. Resulting in a rise of the relative humidity due to the large thermal mass which keeps the church in a cool condition until summer.

Table 1: U-values calculated for diverse construction materials of the church

Material	Thermal Conductivity (W/mK)	U-Value of 800mm wall thickness (W/m^2K)	U-Value of 1000mm wall thickness (W/m^2K)	U-Value of 1200mm wall thickness (W/m^2K)
Limestone	1.50	1.9	1.5	1.25
Stone (basalt, granite)	2.33	2.9	2.33	1.94
Building brick	0.73	0.91	0.73	0.60
Wood (softwood/hardwood)	0.12/0.17	0.15/0.21	0.12/0.17	0.10/0.14

When it comes to thermal comfort, a ‘reasonable comfort’ can be considered only when at least 80% of occupants within that building are feeling comfortable from a temperature point of view and this comfortable level is varying due to the changes of outdoor temperatures and the adaptability of humans during the time to the new temperatures [23]. The control of thermal comfort within historical buildings, in particular, within a church is very challenging because it needs to be considered through many simultaneously aspects, such as the occupants’ thermal comfort and optimal interior environment suitable for preservation of the artwork and the fragile building components [28]. While humans can adapt their behaviour to deal with the thermal environment by adding or removing clothes or changing their position up to a certain temperature and a relative humidity level, this is not working the same way while about the materials. For example, to keep the wooden furniture safe and mould fungi away, an equilibrate moisture level should be considered between 30% and 80% with an environment relatively dry, this means a relative humidity (RH) below 76% [25].

In terms to delivering this research and proposing a solution, it is necessary to investigate the standards required for the indoor environment to compare further with the data collected. Having said that, the British Standards BS EN 15759-1:2011- Conservation of cultural property. Indoor climate Guidelines for heating churches, chapels and other places of worship [4], as well as CIBSE standards [10] will be used as guidelines for this study. According to BS EN 15759-1:2011, the relative humidity is representing a critical parameter from the preservation point of view [4]. The studies show that the historical churches achieve a relative humidity of 60%-80%, being already over the conservation tolerances [2]. Maintaining the relative humidity at 58% RH within churches requires a temperature of 30°C; this is while the indoor temperature should be limited to 22°C for preservation purposes [2]. On the other hand, the relative humidity is not a critical factor for the occupants, if ranging between 30% and 80%. The main issue seems to be the temperature that should range between 18°C and 22°C [12]. Despite all the above, Curteis [11] argues that many standards are not appropriate for the environment of historical churches because those are set mostly for stable conditions, while on historical churches does exist a multitude of different microclimates at the same time. However, the current sustainability requirements impose some efforts to be made, where possible, to diminish the need for energy and the resulting environmental impact [27].

Data collection & Adaptive Approach of TM52

The main methodology used to assess the thermal comfort in historical church buildings within this research is monitoring the environmental conditions of temperature and relative humidity in the case study building. Eltek data loggers and EmonTH and EmonPi sensors were installed in various locations in the church (see Figure 4) to collect the temperature and humidity data for the period between 27 November 2019 and 11 December 2020 inclusive. During this period, the dashboard data could be accessed online through a portal for visualization of the current environment in the church. Still, there are some missing data due to the overwriting of data, while some of the data was restricted by the limitation of batteries (due to Covid travel restriction to maintain data loggers), for a total of 41 full days in the periods between 09 May 2020 and 19 May 2020, 20 May 2020 and 6 June 2020, 17 June 2020 and 25 June 2020, 11 November 2020 and 15 November 2020. Apart from missing full days of data, there was also missing some data on other days for a few hours only. Luckily, this was not a major issue and all the information gathered was enough to support this investigation accordingly.

The method to be used is the adaptive approach of CIBSE TM52 [15] and the criterions 1,2 and 3 of the assessment [9]. The comfortable temperature (Tcomf) will be calculated based on the Running Mean of the daily mean outdoor temperature (Trm) for each hour of each day on which internal data has been collected by using the formula:

$$Tcomf = 0.33\ Trm + 18.8$$

Where Trm can be obtained using the external hourly temperatures calculated under the formula below using 30 days before of each day of analysis, which would be in this case the 28 October 2019 to 26 November 2019 inclusive, to obtain the Trm for our first day of investigation, 27 November 2019:

$Trm = (1- \alpha)(Tod\text{-}1 + \alpha Tod\text{-}2 + \alpha 2\ Tod\text{-}3 + \alpha 3\ Tod\text{-}4 + \alpha 4\ Tod\text{-}5 \ldots\ldots\ldots. + \alpha 29 Tod\text{-}30)$
Where α is equal to 0.8.

But, if Running Mean *(Trm) is lower than 10, then T(comf) = 0.09Trm+22.6*, *if Trm greater than 10 then T(comf) = (0.33 Trm) + 18.8*.

Applying the formulas from above to achieve Tcomf, in an excel spreadsheet, a minimum acceptable temperature (Tmin), a maximum acceptable temperature (Tmax) and an upper limit temperature (Tupp) would be achieved applying the formulas below:

$Tmin = 0.33\ Trm + 15.8$
$Tmax = 0.33\ Trm + 21.8$
$Tupp = 0.33\ Trm + 25.8$

Where Tmin will be 3° lower than Tcomf , Tmax will be 3° higher than Tcomf and Tupp will be 4° higher than Tmax. Following those, DeltaT (ΔT) will be obtained to can carry on the assessment via Criterion 1,2 and 3. DeltaT (ΔT) would be the result of:

$Top – Tmax = \Delta T$

Due to the missing radiant temperatures (Tr) in the collected data, to calculate the operating temperatures (Top), ΔT will use the internal hourly temperatures (Tin) instead of Top. The data temperatures will then be assessed via the Criterions 1, 2 and 3 to achieve a true result for this research regarding the risk of overheating or overcooling of the church. Criterion 1 will assess the number of hours when the indoor temperatures are higher than the maximum temperature with 0.5°C or more, using the DeltaT formula above. Criterion 2 assess the number of times this type of incident happens during every 24 hours. While under Criterion 3 will be assessed the number of hourly incidents when indoor temperatures reach or exceed the upper limit temperatures allowed [9].

DATA ANALYSIS AND DISCUSSIONS

For the purpose of collecting temperature and relative humidity, Eltek data loggers and EmonPi nodes sensors were installed within the church in various locations like choir room, by the entrance, altar area, by the organ, north wall, on pews area and boiler room, collecting quantitative data for each individual area to the online dashboard portal and from where it has been downloaded.

As stated above, the collected data was not complete for all the areas for the entire period between November 2019 and December 2020, and there is missing data on the north wall for April, May, June, October, November and December, while the other areas, apart from Pew 2 which is complete, has missing data in October, November and December. The data captured from the loggers and sensors installed in the church has been analysed and transformed in the table below (Table 2) of minimum and maximum temperatures and relative humidity for an initial understanding of the existing thermal situation each month. Those different zones are more or less heated and so, variations in temperatures from zone to zone were found.

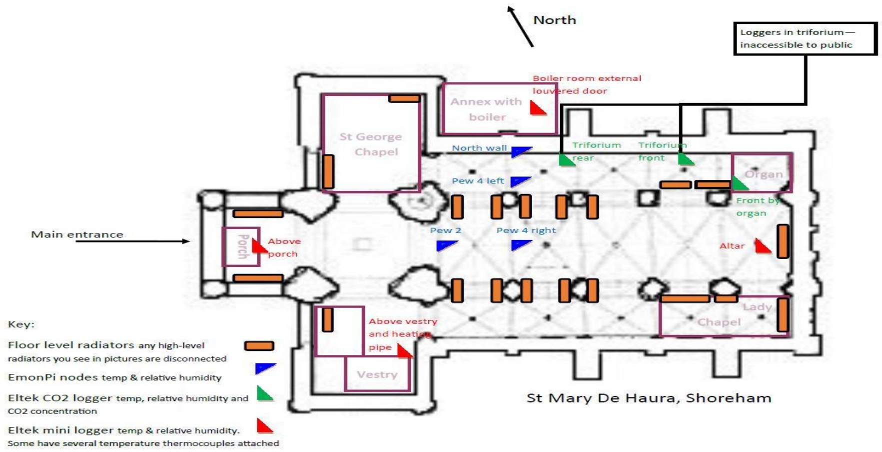

Figure 4 - The floor plan of the church showing the position of radiators, loggers and sensors installed

Table 2 : Minimum and maximum internal temperatures and relative humidity in the church

Area	Nov 19	Dec 19	Jan 20	Feb 20	Mar 20	Apr 20	May 20	Jun 20	Jul 20	Aug 20	Sept 20	Oct 20	Nov 20	Dec 20
Choir Room	13.5°C-15.7°C	12.5°C - 17.5°C	11.6°C-15.8°C	11.6°C-15.2°C	11.4°C-15.1°C	11.4°C-14°C	13.3°C-15.6°C	15.8°C-18.1°C	17.5°C-24.6°C	18.5°C-25°C	18°C-23.7°C	-	-	-
North Wall RH	64%RH-75.4% RH	59.1% RH - 71.6 %RH	62.3% RH -79.4 %RH	68.3% RH -85.6% RH	64.5% RH -75.1% RH	-	-	-	69.2% RH - 86.5% RH	73.3% RH - 87.1% RH	71% RH - 89.4% RH	-	-	-
North Wall Temp	13.1°C-16.1°C	13°C-18.6°C	10.8°C-15.9°C	11.2°C-14.6°C	11.8°C-15°C	-	-	-	17.6°C-19.7°C	18°C-22.5°C	17.8°C-18.8°C	-	-	-
Pew 2 RH	63.2% RH - 74.9% RH	47.2% RH - 72.1% RH	53.5% RH -80.5% RH	64.9% RH -86.6% RH	59.2% RH -79.2% RH	64.9% RH - 75.8% RH	68.4% RH - 74.5% RH	65.1% RH - 80.6% RH	65% RH - 83.7% RH	59.3% RH - 84% RH	65% RH - 80.6% RH	70.7% RH -87.7% RH	67.8% RH -87.9% RH	73.6% RH - 83.6% RH
Pew 2 Temp	12°C-18.2°C	11.7°C - 22.2°C	10.2°C-17°C	10.1°C-17°C	10.2°C-19.9°C	10.4°C-14.9°C	13.2°C-16.5°C	16.2°C-19.8°C	17.3°C-20.3°C	17.2°C-23.4°C	16.8°C-19.9°C	12.9°C-17.9°C	11.4°C-18.4°C	8.5°C-12.5°C
Pew 4 left RH	61.4% RH - 71.1% RH	48.1% RH - 81.2% RH	56.5% RH -71.1% RH	63.2% RH -71.1% RH	55.9% RH -71.1% RH	61% RH - 71.1% RH	64.1% RH - 74% RH	64.5% RH - 81.5% RH	69.8% RH - 82.1% RH	69.9% RH - 85.4% RH	67.8% RH - 82.1% RH	-	-	-
Pew 4 left Temp	12.4°C-17.3°C	12.1°C - 20.6°C	11.2°C-17.6°C	10.7°C-16.6°C	10.4°C-17.9°C	10.5°C-17.6°C	13.1°C-15.9°C	13.5°C-18.1°C	17°C-19.6°C	18.4°C-22°C	17.5°C-19.5°C	-	-	-
Pew 4 RH	58.1% RH - 71.1% RH	50.7% RH - 64.7% RH	60.7% RH -75.9% RH	65.3% RH -81.6% RH	55.9% RH -69.4% RH	61.2% RH - 75.2% RH	68.2% RH - 74% RH	68.8% RH - 81.5% RH	72.5% RH - 82.2% RH	68.9% RH - 84.8% RH	67.8% RH - 82.1% RH	-	--	-
Pew 4 Temp	12°C-18.6°C	11.7°C - 20.2°C	10.5°C-15.9°C	11°C-15.2°C	10.9°C-18.2°C	-	13.1°C-16°C	15.9°C-18.4°C	16.9°C-19.3°C	18.1°C-22.3°C	16.9°C-19.1°C	-	-	-

Figure 4 shows the position of data loggers and sensors: two of the EmonPi nodes were positioned in the middle of the church with a distance of about 2-3 meters between them and another one been installed on the north wall as considered to be the coldest part within the church due to the sun position on the south and to detect the differences in temperatures between the sitting area with radiators nearby and the coldest wall surface. The Eltek base station is positioned on the bookshelf of the choir room while the EmonPi base station on the floor of the choir room. The sensors nodes were placed on the walls and under the pew fourth at the rear and front, and an Eltek logger placed under the front altar. Two other loggers placed in triforium (north side) are allowing an analysis of any vertical differences in humidity, while other four loggers placed at the entrance, boiler room, altar/organ area and vestry room are allowing for monitoring the relative humidity on all ends of the church.

Temperatures within the church

The principal factor for the thermal stress in buildings is related to inappropriate internal temperatures. Such internal temperatures are being influenced by the external weather that also affect other internal environments.

Other factors influencing the comfort levels include the clothing and types/levels, air movement and quality, radiant heat and the number of occupants [8]. According to CIBSE Guide A, the indoor temperature, at a comfort level within churches, should be between 19°C and 21°C in the winter months [7]. For the temperatures below 19°C, the occupants are feeling cold and are forced to wear more clothes which may makes them uncomfortable. Above 21°C, occupants may start feeling too warm, and if even higher, they will start sweating and creates discomfort [7]. For the historical artefacts and artwork, temperatures between 16°C and 20°C would be optimal. It is considered that even going down to 10°C, is not harmful to objects, but anything below 10°C will increase the risk of condensation, which should be avoided in historical buildings/churches [19].

Table 2 above, shows that the observed temperatures are not within the ranges recommended by CIBSE. The church registers even lower temperatures in the winter period and, as well in the summer, which result is the thermal discomfort. High temperatures are also observed in some winter months in Pew areas 2 and 4, comparing to the other areas in the church that may be due to the radiant heat coming from the radiators in the close vicinity. Generally, the internal temperatures in the church during winter is not exceeding 18.5°C and temperature ranges vary from an area to another and also influenced by the external temperatures. The average temperatures during winter, when the heating system is off, is between 8.5°C and 14.5°C maximum. The registered higher temperatures in winter months around some afternoon hours, is assumed to be due to the people occupying the church while heating system was on.

The observations show that the choir room, in the coldest months, register the lowest temperatures than any other areas. The north wall also registered low temperatures during winter similar to the choir room. On the other hands, during summertime, according to CIBSE Guide A, the internal environment within churches should be able to achieve a range between 22°C and 25 °C [7]. Analysing the data obtained, the conclusion drawn is that only in August the temperatures in the church were in between parameters suggested by CIBSE Guide A during daytime. Due to the lack of insulation, and south facing orientation, the choir room shows higher temperatures than the rest of the church during July, August, and September. During summer, the choir room (a low ceiling wooden freestanding construction built within the church) can be easily overheated, while the other areas in the church can be still within the range if the external temperature increase. It should be noted that, due to its characteristics, the choir room performance may be significantly different in comparison with the other areas in the church.

Relative humidity within the church

In general terms, a relative humidity below 25% can cause skin dryness and shocks due to static electricity, while in opposite direction, a relative humidity over 80% can make feel skin sticky and uncomfortable, leading to condensation and mould growth on surfaces and creating difficulties in breathing. The optimal recommendations for relative humidity within churches in the UK is between 40% and 70%, according to CIBSE Guide A [7]. From the historical artwork and artefacts point of view, the humidity must be carefully monitored for displayed artwork, as well as the ones in the storage and not exceeding the range of 40% - 70%. If below 40%, the artefacts and materials will be at risk of drying out. If above 70%, the growth of mould, pest and fungal infestation would be major risks. Rapid fluctuation od relative humidity may also increase the risk of condensation [19].

Keeping the relative humidity at a recommended level will assure the conservation of the building and wellbeing of occupants. When observing the RH% at St Mary's church, in the majority of months, the relative humidity was exceeding 70%. The coldest months are showing a relative humidity slightly over the limit of 70% but not lower than 50.7%. On the positive side, the materials and artefacts are not at risk of drying out and people can feel just about comfortable from this point of view.

The summer data shows a really massive increase in the humidity within the church due to the higher temperatures registered in the interior. The inappropriate ventilation in warmer period is representing a factor for the higher humidity and an issue for the church. All the areas with loggers installed are significantly affected by high humidity rates, the worst of all being the north wall.

The consistency of relative humidity in those months is between 59.3% and 89.4% which is representing a propitious environment for the growth of mould and fungal. Furthermore, these are affecting the building materials by producing condensation at surfaces level and conduct to slow decay while people may feel uncomfortable with difficulties in breathing, sticky wet skin, and an increased risk of pulmonary disease, asthma or allergies.

Thermal comfort assessment – Adaptive approach of CIBSE TM52

The adaptive approach of the TM52 method used to assess thermal comfort conditions. Because it was no possible to collect the operating temperatures from the church, the internal temperatures collected from Pew 2 were used instead, because there were no missing data and due to its position in the middle of the church. The results show that the church is reaching very low temperatures during winter and temperatures raised only when the heating was on or when the external temperate raised.

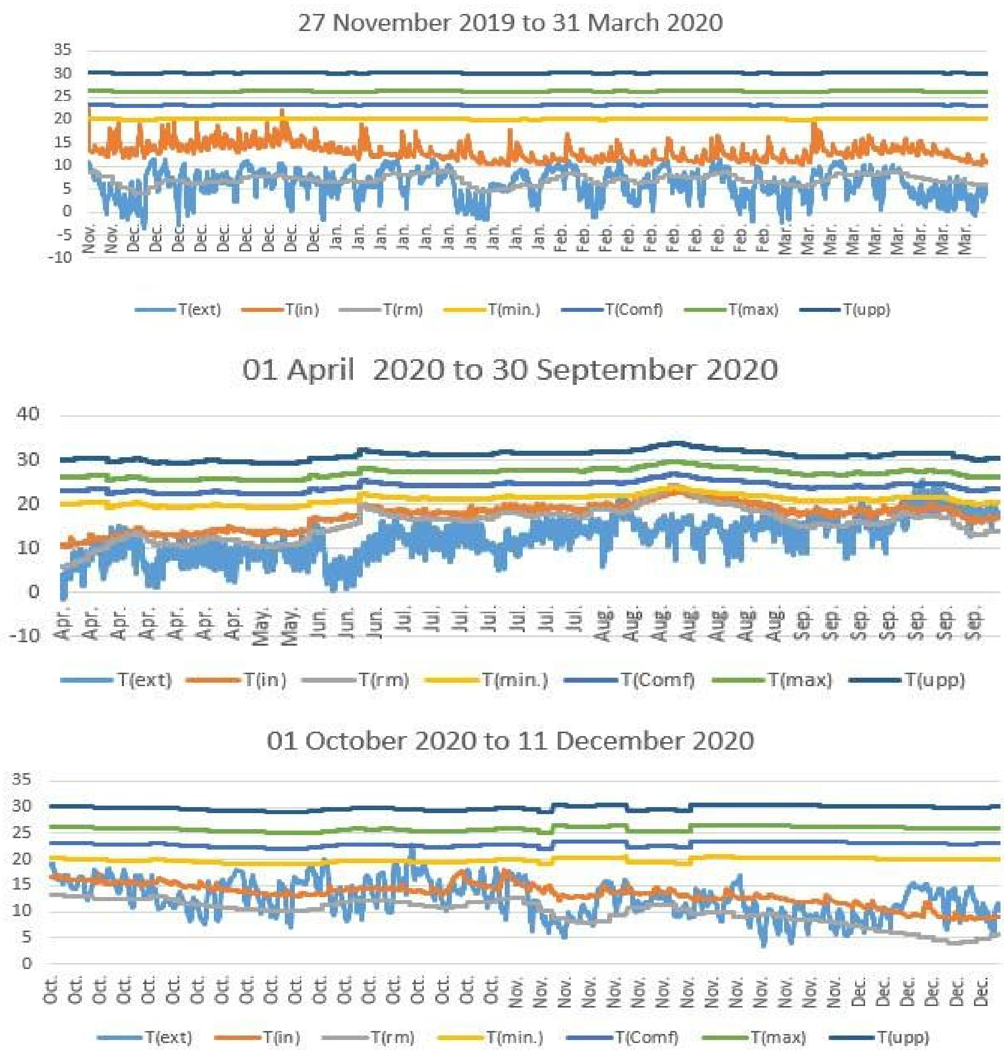

Figure 5:

The reason of assuming that heating was on is given by the radical fluctuations of temperatures when the external temperatures go in opposite directions to internal ones. For example, looking to January 2020 it can be observed the external temperature T(ext) showing temperatures dropping under 5°C up to -5°C, while the indoor temperatures T(in) in those periods shows a raise which occasionally, meets the minimum thermal requirements and close to meet the comfortable level. The same conclusion can be drawn for December 2019, February 2020, March 2020, when the external temperatures were rather low and heating was necessary. However, for the external temperature over 5°C, the indoor temperatures were influenced only by the external environment while the heating was not on keeping the internal temperatures between 10°C and 18°C. The results show that despite the warmer days in the winter months, heating is necessary to meet thermal comfort requirements.

Summer months registered a lower level of variations on indoor temperatures, keeping the indoor environment steadier between 14°C and 20°C during May, June, July, August, while the external temperatures fluctuated between 5°C and 20°C.

During April, September, October, November and December 2020, the external temperatures show a high rise, while the internal temperatures show more constant temperatures between 10°C and 15°C in December and up to 18.5°C in November 2020. In many cases the external temperatures during those months are warmer than the indoor ones, those variation being still high, between the lowest of -3°C in April up to the highest temperature registered of 27°C in September. This is assumed to be due to the high thermal mass of the church.

When assessing according to TM 52 assessment Criteria 1, 2 and 3, all temperatures are below the upper limit and maximum limit temperatures. As the assessment under the assessment criteria had the results equal to zero (pass) for each individual hour monitored in 381 days of monitoring, the conclusion was that the church is never at risk of overheating, but at high risk of overcooling.

CONCLUSION

The results of this research reveal that the indoor environments in historic churches may not be acceptable neither in terms of preserving artefacts nor in terms of thermal comfort for the occupants. Improvements are therefore required to make a balance between the requirements for the preservation of building materials and artefacts with thermal comfort and energy efficiency. Creating a balance between these factors can be a challenging task that required further research and investigation into the types and performances of various heating systems/strategies in historic churches. This may also depend on the priorities within each individual church depending on its use and historic values, artefacts, construction methods and materials. Although challenging, based on the results of this study, it could be argued that preserving valuable historic buildings while providing thermal comfort for the occupants is achievable.

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EFFECT OF BUILDING HEIGHT AND ORIENTATION ON INDOOR AIR TEMPERATURE FOR RESIDENTIAL BUILDING IN HOT AND HUMID CLIMATE

Naja Aqilah [1], Sheikh Ahmad Zaki [2], Hom Bahadur Rijal [3]

[1] PhD student, Tokyo City University, Yokohama, Japan, najaaqilah16@gmail.com
[2] Assoc. Prof, University Technology Malaysia, Kuala Lumpur, Malaysia, sheikh.kl@utm.my
[3] Professor, Tokyo City University, Yokohama, Japan, rijal@tcu.ac.jp

ABSTRACT

Residential thermal comfort and energy efficiency are becoming highly relevant in hot and humid climate condition due to the increasing usage of air-conditioning and global warming. As we spent around two third of our time at homes, thermal discomfort experience in residential building is the cause for the concern because of the significant effect of indoor air environment to the well-being of a person. Building height and orientation are two crucial elements that do have an impact on the indoor air temperature. Thus, 19 targeted houses from apartment buildings in Kuala Lumpur, Malaysia were chosen as the location for the field measurement and survey for this study. The objective is to identify the effect of building height and orientation on residential indoor air temperature. Within five-minute intervals, the indoor thermal environment for each room were observed and recorded. The rooms were also sorted based on block and building orientation as the targeted houses were not in the same block and varied in building orientation. The findings show the building height has a significant impact on indoor air temperature. For the bedroom of the south-west, the house at the third level (L3) has an indoor temperature of 30.2°C which is 2.3°C higher than in the house at the 13th level (L13) with indoor temperature of 27.9°C. In addition, the indoor temperature differences between the lowest and highest floors for different orientation directions are 0.8°C, 0.6°C, and 2.8°C. The results also show that the indoor air temperature of the living room in the house oriented in the north-west direction can be reduced up to 0.9°C on the higher floor. These findings can be helpful for preliminary understanding of detailed characteristics for residential indoor air temperature in relationship with building's height and orientation.

INTRODUCTION

Within the last few years, the energy use in the building sector has been increasing as a result from the global climate change and continuous demand building services and occupant's comfort levels. Perini et al. (2014) stated in their study that high indoor air temperatures have been increasing in Europe by using cooling systems. In Malaysia, Kubota et al. (2011) concluded that air-conditioners (AC) are the biggest contributor with the highest energy consumption of 1,167 kWh per year. Over the next three decades, the rising use of AC is expected to be one of the primary sources of global electricity demand over the next three decades (Khoshbakht et al., 2019). In residential buildings, peak demand of AC use was higher during night-time due to sleeping purposes (Kubota et al., 2011, Ranjbar et al., 2017). Thus, it is important to investigate what factors can influence the indoor air temperature in order to more practically use natural ventilation instead of mechanical ventilation (air-conditioners) to maintain comfort and health.

As mentioned by Yin et al. (2018), building height and orientation are two of the parameters that have been considered to manage the urban geometry. The result from Wong et al. (2007) shows that when the building orientation changed to north-south, the energy consumption by air-conditioners can be reduced up to 11.5%. Other than that, a study from Karimimoshaver and Shahrak (2022) determined that when the ratio of height to street width (H/W = 1.5) with the angle 135◦ from the north in summer and winter is more ideal and suitable. Wong et al. (2002) obtained a result at which the temperature between upper and lower floor has a difference of 2°C and above. This was because of the high wind velocity at upper floors and the tolerance temperature difference caused by living habits as mentioned by Yao et al. (2018). Previous studies focused on innovative techniques to determine the effects on indoor ventilation, however nowadays there is only a little research that focused more on the ventilation efficiency in tropical climates (Aflaki et al., 2014). Therefore, the objective of this research is to identify the impact of height and orientation of the residential buildings on the indoor air temperature.

METHODOLOGY

The Measurement of Outdoor Thermal Environment

In this study, the data for the outdoor air temperature and relative humidity were measured in 10-min intervals. Then, the data would be stored in the data logger at weather station located in Malaysia-Japan International Institute of Technology (MJIIT) building (Figure 1). The station was installed at approximately 68 m of height at the rooftop. The accuracy for the air temperature variables is ± 0.3°C and for relative humidity is ± 4.0%. The locations where the field measurement was conducted, Desa Rejang is located at 4.7 km away from MJIIT weather station.

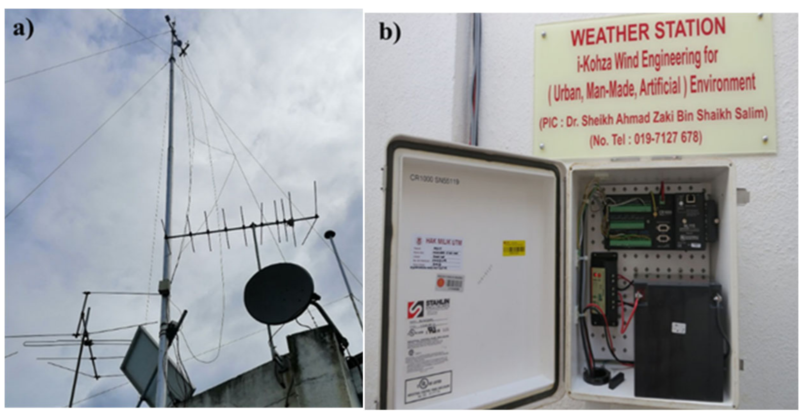


Figure 1. Weather station a) installed sensors and b) data logger at the rooftop of the MJIIT building.

Targeted Building

Research by Abdul Ghani et al. (2015) stated that urban communities in Malaysia mostly choose to have a lifestyle in a tall multistory apartment building. From this perspectives, 19 targeted houses of low-cost apartment in Desa Rejang were chosen as the site for the field measurement. This research was considered as a long-term field measurement with 5- minutes interval of data collection. The low-cost apartment was fully built in March 2005. It is a 19-storey building with 12 blocks which can accommodate 2791 housing units. However, only seven blocks were investigated for the field measurement. Figure 2 shows the location for this study. The front views and schematic plan layout of the low-cost apartment is shown in Figure 3.

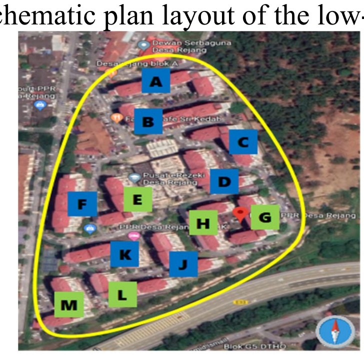


Figure 2. The location of targeted houses at Apartment Desa Rejang. The selected and remaining blocks are indicated by blue and green boxes respectively.

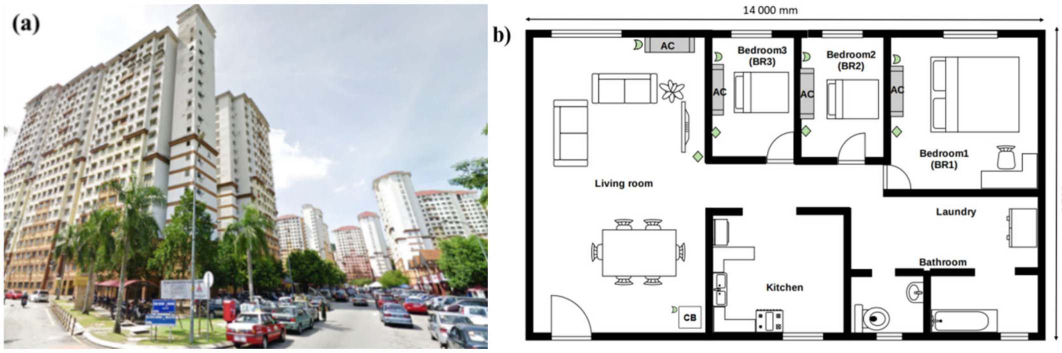


Figure 3. (a) Front view and (b) Plan views (schematic layout)

The Measurement of Indoor Thermal Environment

In order to measure the indoor temperature with relative humidity at 5-min interval, a thermo recorder (T&D Corporation, TR-77Ui) was used as the instrument for a period from March 2016 to August 2017. It was installed in each measured room (Figure 4). The targeted houses would be visited on a weekly basis for data collection process. The indoor thermal environment of each room was successfully recorded from 52 to 386 days at most. The number of measurement days was not consistent among the houses as some occupants refused to continue the measurement because of privacy issues.

Figure 4. The installation of thermo recorder in each room.

Table 1 list the information of all targeted houses such as floor, orientation of the main facade, block, duration of stay (years), number of occupants, and measured room. It can be seen from the table that the lowest floor of the targeted apartment building is level 3 (L3) and the highest is level 18 (L18). The information about the duration of stay or the number of years that the residents have lived in their respective house was collected from each house's occupant. The measured room are represented by the living room (LR), bedroom 1 (BR1), bedroom 2 (BR2), and bedroom 3 (BR3). The blocks selected in this study were oriented in the south-west, north-west, south-east, north-east, and west. More information regarding the data collection, building selection and specification of instrument used was described in previous study (Aqilah et al., 2021).

Table 1: Information of all targeted houses

ID	Floor	Orientation of the main facade	Block	Years of stay	Number of occupants	Measured room
1	L6	North-East	C	8	7	LR
2	L18	North-West	K	9	6	BR1, BR3
3	L6	North-East	C	9	3	BR1
4	L18	North-East	C	8	3	BR1, BR2
5	L3	North-West	A	12	5	LR

6	L9	North-West	A	11	4	LR
7	L10	North-West	A	10	8	BR1
8	L3	South-West	D	10	7	BR1, BR2
9	L8	South-West	D	8	6	LR, BR1
10	L13	South-West	D	9	9	BR3
11	L2	South-East	B	11	3	BR1
12	L9	South-East	B	11	3	LR, BR2, BR3
13	L10	North-West	A	3 months	2	BR3
14	L16	North-West	A	9	6	LR, BR1
15	L14	North-West	K	11	6	BR1
16	L9	West	F	10	4	BR1
17	L18	North-West	K	4	2	LR, BR3
18	L17	North-East	C	10	4	BR1
19	L8	South-West	J	10	6	BR1

RESULTS AND DISCUSSION

Patterns of Outdoor Thermal Environment

To better understand the outdoor thermal environment, the collected data of outdoor air temperature and relative humidity were observed and analysed. The annual monthly variation was observed from March 2016 until August 2017 as shown in Figure 5. The average monthly outdoor air temperature was ranging between 27 to 30°C along with the average relative humidity which ranging between 59 to 85%. In overall average, the outdoor temperature was observed as 28°C and for relative humidity, it was recorded as 79%.

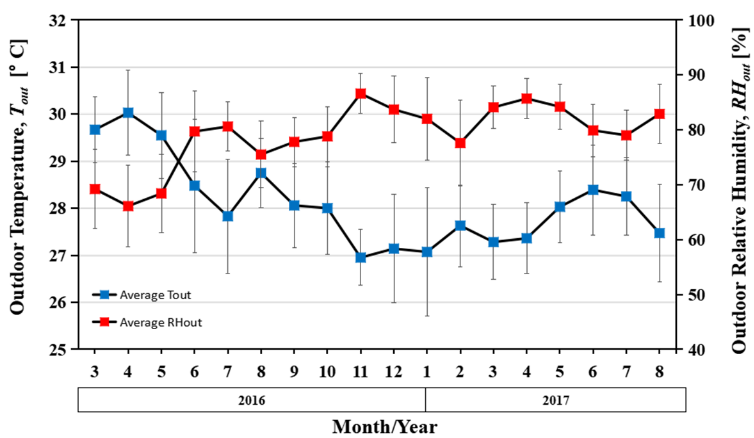


Figure 5. Monthly outdoor temperature and relative humidity. The error bar represented the standard deviation.

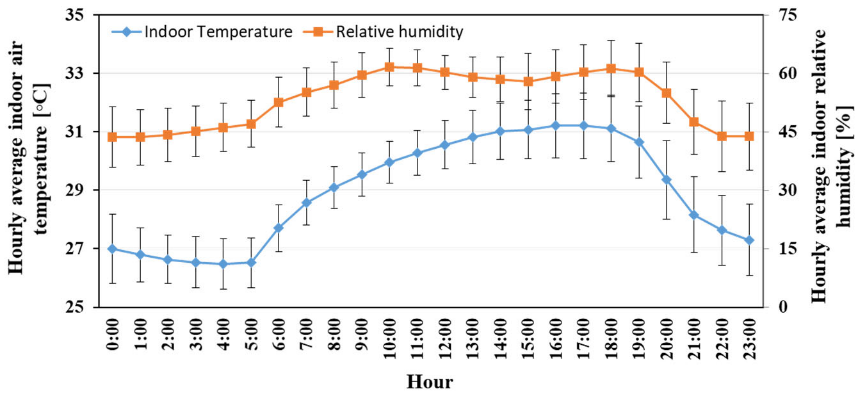
Patterns of Indoor Thermal Environment

To clarify the indoor thermal environment of targeted houses, the indoor thermal environment was analyzed. Generally, the comfortable indoor air temperature is ranged from 23°C to 26°C. The range of comfortable relative humidity is 40% to 70% (Malaysia Standard MS1525). The daily and hourly on a specific date of indoor temperature and relative humidity were selected to analyze the patterns of indoor thermal environment. The results from the representatives of lower and upper level for all houses which are apartment ID2 (L18-upper) and ID8 (L3-lower) were explained in detail. Moreover, the pattern of daily indoor thermal environment in LR and BR also are included. Lastly, the effect of building height and orientation of the house on indoor air temperature was explained. The variation in the temperature with respect to the number of occupants were neglected as most of the occupant as it is not much different.

Hourly Indoor Thermal Environment

Figure 6 shows the hourly indoor air temperature on a daily basis for house ID2 and ID8 which were measured for 89 and 101 days. The indoor air temperatures of 31.2°C was recorded as the highest temperature at 16:00 and 17:00 for ID2 and 30.8°C at 16:00 for ID8. The lowest indoor temperature of ID8 was 29.0°C at 7:00, and the average was 29.8°C. The indoor air temperature remained constant until midnight and decreased at 2:00. For house ID2, the lowest indoor air temperature was 26.5°C at 04:00 and the average was 28.9°C. The indoor air temperature from 0:00 until 5:00 remained at the lowest point and started to rise at 6:00. The relative humidity in houses ID2 and ID8 were in the comfortable range with an hourly average of 54% and 57% respectively. The minimum relative humidity level for ID2 was 44% at 01:00 and 53% at 16:00 for ID8.

(a)



(b)

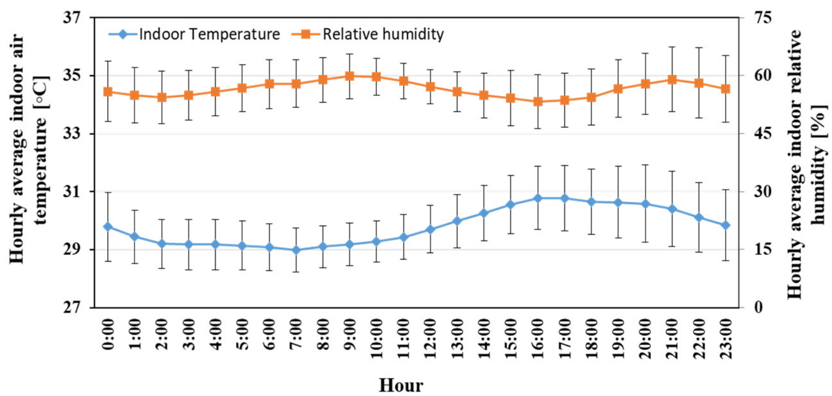


Figure 6. Hourly average indoor thermal environment for house (a) ID2 and (b) ID8. The standard deviation was represented by the error bar.

Next, Figure 7 shows the histograms of hourly indoor air temperature and relative humidity of all 19 investigated houses. The average hourly indoor temperature and relative humidity are 28.0°C and 58%, respectively. The range for minimum and maximum daily indoor air temperatures were recorded as 16.4°C and 32.0°C, respectively. Meanwhile, the minimum indoor relative humidity was recorded as 34% and the maximum was at 70%.

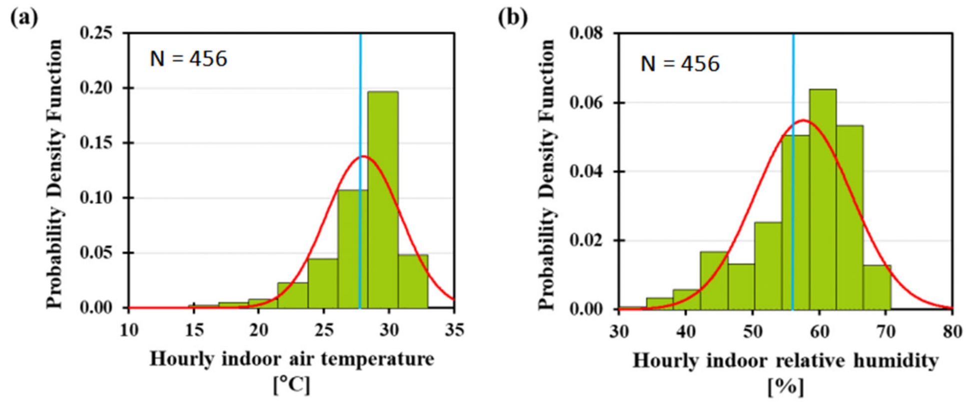


Figure 7. Histograms of hourly (a) indoor air temperature and (b) indoor relative humidity. N is the number of samples, and the blue line indicates the average value.

Daily Indoor Thermal Environment

The histograms of daily indoor air temperature and relative humidity of all 19 investigated houses are shown in Figure 8. The average daily indoor temperature was 29.5°C while the average daily relative humidity was 62%. The minimum and maximum daily indoor air temperatures were 24.0°C and 33.6°C, respectively. For indoor relative humidity, the minimum and maximum values were 41% and 79%, respectively.

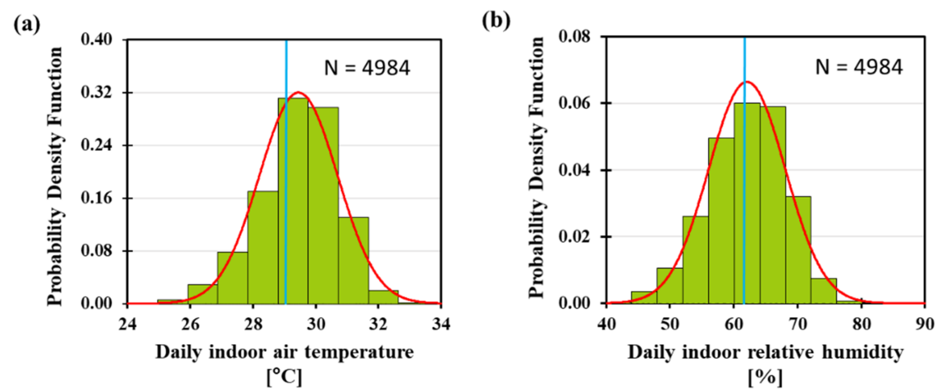
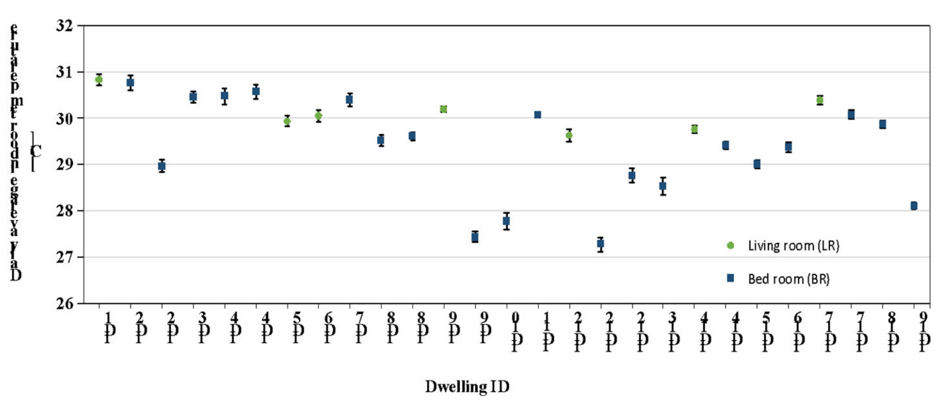


Figure 8. Histograms of daily data for (a) indoor air temperature and (b) indoor relative humidity. N is the number of samples, and the blue line indicates the average value.

(a)



(b)

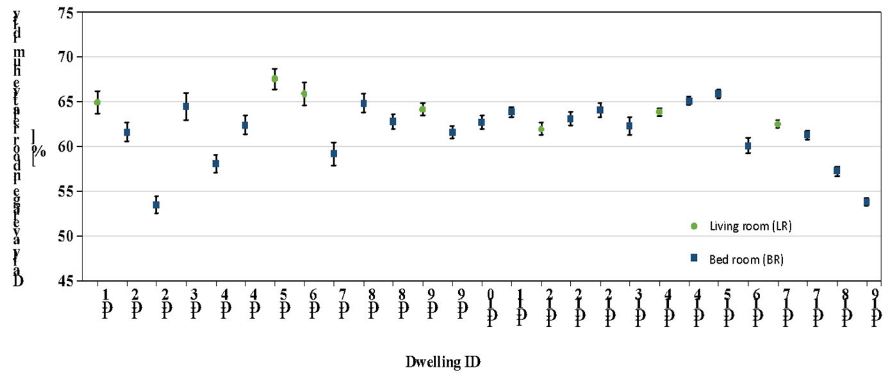


Figure 9. Daily average (a) indoor air temperature and (b) relative humidity for LR and BR in each targeted house with 95% confidence interval (mean ± 2 S.E.)

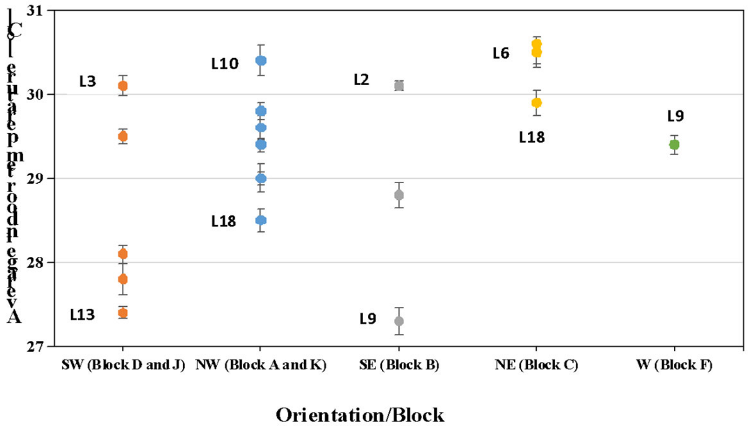
The daily average indoor air temperature and relative humidity with 95% confidence interval in LR and BR of each targeted house are displayed in Figure 9. In LR, the daily indoor air temperature was ranging between 27.5°C and 31.8°C. The average value is 30.1°C. Meanwhile, the daily average in BR was 29.3°C and ranged from 26.9°C to 31.6°C. It is noticeable from Figure 9a that a higher indoor air temperature in LR was recorded compared to in BR for houses ID9, ID12, ID14, and ID17. This might be due to the open space of LR which requires extra energy to maintain the temperature and the habitual of occupant which mainly used the AC in the bedroom during sleeping time (Zaki et al., 2018). For example, in house ID12, the indoor air temperature in LR was 29.6°C which is 2.3°C higher than that in BR. However, there is no consistent pattern that can be detected from the level of indoor relative humidity in both LR and BR. It can be seen from Figure 9b that house ID2 has the lowest level of indoor relative humidity in BR (54%) rather than in house ID5 for LR (67%).

Building Height and Orientation Effect on Indoor Air Temperature

Based on Aflaki et al. (2014), the building height has an impact on indoor air temperature. A higher floor can reduce around 1.2°C of the indoor air temperature especially in LR. Therefore, the indoor temperatures in BR and LR were sorted based on their floor level from lower to higher to examine any significant effect on the indoor air temperature. We sorted the rooms based on block and building orientation as the targeted houses were not in the same block and varied in building orientation. The study by Al-Tamimi et al. (2011) also confirmed that building orientation affects the indoor air temperature.

Figure 10 shows the indoor air temperatures of BR and LR at lower and upper floors of all targeted houses. The average indoor temperature of each targeted house in BR and LR was indicated as *y*-axis and the orientation and block of the house was indicated as the *x*-axis. The results reveal the effective role of building height on indoor air temperature. For the BR of the south-west, the house at the third level (L3) has an indoor temperature of 30.2°C which is 2.3°C higher than in the house at the 13th level (L13) with indoor temperature of 27.9°C. This might be due to the wind velocity in the room. A result from Aflaki et al. (2014) concluded that the wind velocity in the living room for a house which in the upper floor is four times higher than in the same room for more lower floor. In addition, the differences in the indoor temperature between the lowest and highest floors for the houses oriented in the north-west, south-east, and north-east directions are 0.8°C, 2.8°C, and 0.6°C, respectively. The results also showed that the indoor air temperature of the LR in the house oriented in the north-west direction can be reduced up to 0.9°C on the higher floor.

(a)



(b)

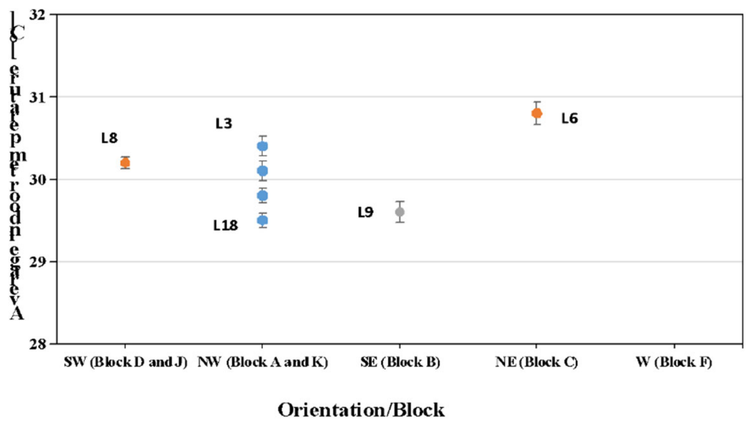


Figure 10. Indoor air temperature in a) BR and b) LR at lower and upper floors with 95% confidence interval (mean ± 2 S.E). (L: level of the floor; SW: south-west; NW: north-west; SE: south-east; NE: north-east; W: west)

CONCLUSIONS

This research also aims to identify the effect of height and orientation of the residential building on indoor air temperature. Therefore, a field measurement was conducted in 19 houses to measure the indoor air temperature and relative humidity. The main findings can be concluded as below:

- The results from the representatives of lower (ID8) and upper level (ID2) for all houses shows that average hourly indoor air temperature has 1°C difference.
- The average daily indoor air temperature in the living and bedrooms are 30.1°C and 29.3°C.
- Building height and orientation influences the indoor air temperature. The air temperature in a house at lower floor is higher than the house at upper floor. For the BR in the south-west orientation, house located on L3 has a 2.3°C higher indoor temperature than of the house located on L13. Other than that, the differences of the indoor air temperatures between the houses located on the lowest and highest floor levels are shown by those in the north-west (0.8°C), south-east (2.8°C) and north-east (0.6°C) orientation. The results also showed that the indoor air temperature in LR of the house in the north-west orientation can be reduced up to 0.9 °C on the higher floor.

These results are relevant in preliminary understanding of detailed characteristics for residential indoor air temperature in relationship with building's height and orientation. However, this research has neglected the variation in temperature with respect to number of occupants mainly due to the low number of samples.

Thus, more monitoring data and long-term field measurement can benefit a more comprehensive understanding of occupant thermal comfort.

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EXPLORATION THE SUSTAINABLE DESIGN STRATEGIES OF MASS CUSTOMISED SOCIAL HOUSING FOR SAVING ENERGY WITH THE EXAMPLE OF PHOENIX RESPONSE HOUSE PROJECT IN GEELONG AUSTRALIA

Jinxi Wei[1], Hongxian Li[2], Masa Noguchi[3], James Doerfler[4], Abdul-Manan Sadick[5]

[1] PhD Student, School of Architecture and Built Environment, Faculty of Science Engineering & Built Environment, Deakin University, VIC, AU, weijin@deakin.edu.au
[2] Senior lecturer, School of Architecture and Built Environment, Faculty of Science Engineering & Built Environment, Deakin University, VIC, AU, hong.li@deakin.edu.au
[3]Associate Professor, Environmental Design Faculty of Architecture, Building and Planning, University of Melbourne, VIC, AU, masa.noguchi@unimelb.edu.au
[4]Chair in Architecture, School of Architecture and Built Environment, Faculty of Science Engineering & Built Environment, Deakin University, VIC, AU, james.doerfler@deakin.edu.au
[5] Lecturer, School of Architecture and Built Environment, Faculty of Science Engineering & Built Environment, Deakin University, VIC, AU, s.sadick@deakin.edu.au

ABSTRACT

Social housing as humanitarian building which guarantees the basic survival requirements of low-income people and vulnerable groups has been aroused extensive attention from our society. Due to the impact of frequent natural hazards and long-term covid-19, more and more people has suffered unemployment and fundamental source of livelihood, even lost their homes. As a result, this made the demand for social housing greatly increased. Therefore, mass customisation of social housing design as an economy, agility and fast construction strategy has aroused wide public concern by governments and organizations around the world. However, there is insufficient theoretical or practical research on mass customisation social housing design based on concerning energy consumption analysis. The higher energy consumption of social housing means more economic spending and environmental burdens, which are directly impact the occupants' living experiences and well-being. However, there is insufficient exploration and research in retrofitting prefabricated social housing based on considering building energy performance under human centred design. Therefore, this paper will aim to propose a research road map of human centred prefab social housing design based on simulated building performance result and evaluating with the example of a prefabricated social housing project Phoenix Response house in Geelong of Australia to explore the impact of energy consumption to social housing design strategies.

INTRODUCTION

House has been seen as one of the crucial space which directly impact the quality of human life. It not only be deemed to the haven of life, but an important guarantee for maintaining social order (HBettaieb, D.M. and Alsabban, R. 2021). From 2020 till now, pandemic sweeping the world and triggered uncountable defects both in economical development and people's normal life. Based on the recent social and economy report " Scarring effects of the pandemic economy" from ACU, Australia's recovery has not been the rising tide that lifts all boats. Though the government has promulgated a series of related policies to stimulate economy recovery like Job Keeper and Food Cost Cashback which had cushioned the worst conditions in individual and retail economic lost, it failed to eradicate the financial pressure and long-backlogged unemployment issues (Tom Barnes, Scott Doidge. 2022). Indeed, the number of families and individuals who have lost their source of livelihood has surged, which makes the development and construction of social housing more urgent.

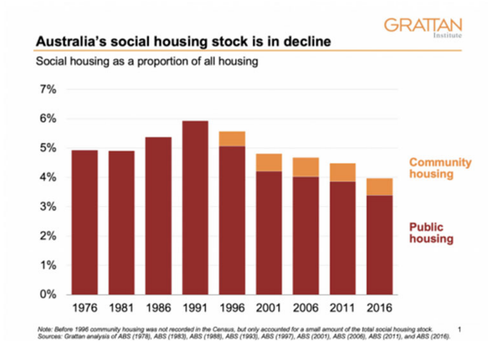
In building market, mass customization achieves a higher margin and is more advantageous for its mode of "one for all" in prefabricated building components to delivery products for a large amount of clients in agility, flexibility with lower unit cost. It became a trend with the aim of economic and environment in modern architecture development (Wei, J, Noguchi, M. & Li, H. 2022) . Mass customised prefabrication has its value in friendly environmental housing construction for its advantages of affordable and energy cost reduction. Both of these are necessary for the condition of social housing building requirements, and further, it is possible to consider mass customised prefabrication into social housing design strategies. However, only considering for building economical or fast construction is not sufficient for the whole need of social housing design. When considering the occupants' well-being for long-term living, a human centered design based on personalised need and demand should be explored (Masa Noguchi, Victor Bunster, 2016). Furthermore, human centered design not only focus on the multi-functional needs for occupants, but concentrate on combining exterior and interior natural conditions by using sustainable design strategies to improve human comfort and reducing energy consumption. This is also the aim of this paper to explore the appropriate strategic framework both hoisting energy efficiency and human living experiences by the case study and energy analysis of the project Phoenix Response House in Geelong of Australia.

LITERATURE REVIEW

Condition of social housing development in Australia

Due to under-investment of federal government of Australia, the development of social housing and affordable housing have faced increasingly growing crisis in recent years. Based on the statistics from Australian government, there are more than 116,000 people who need the support of social and affordable housing for basic living requirements around the whole country. The amount of victims are still increasing in the slow economic recovery after pandemic. The definition of affordable rental in Australia means less than 30% of total income of an individual or housing occupants from National Rental Affordability Scheme (NRAS). At present, while the government has invested in social housing project and in support of homeless, it is still more people under needs than the real exist homes. The increase of social housing stock is keeping in a slowly rate in the recent 20 years showed in figure-1(a). While the population grow up in a quickly way during these years, which means that there's a huge demand for social housing that needs to be filled. However, the federal government has allocated even smaller allocations to low-cost housing and it exacerbates the issue of social housing allocation. Under this condition, more and more organizations and groups of Australia begin to focus on social housing related projects and agree with that the governments should join forces to invest more social public housing and community.

In addition, under the normative system of NRAS, more non-governmental organizations, like Launch Housing, also began to spontaneously organize donations and financing to manage the projects of social housing and community development. The figure-1(b) shows the social housing community construction in Victoria, Australia. This is a new trail for social housing development that local councils prepare to merge social housing and affordable housing as part of new building development which invested by developers introduced in the broad areas of Victoria. Based on this proposal, it makes possibilities for a higher quality social housing with the aim of homelessness wellness that could be achieved.



(**a**)

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Figure 1. Conditions of social housing development in Australia. (a) Australia's social housing stock in decline from 1991-2016.; (b)The new trail of social housing community plan in Victoria of Australia, photographed by Paul Rovere.
Source: The diagram made by Grattan Institute https://grattan.edu.au/news/a-place-to-call-home-its-time-for-a-social-housing-future-fund.

Energy consumption and efficiency for social housing

The aim of social housing is service for vulnerable people who just experienced homeless, low-income or even family violence for short-term to long-term living. Hence, the occupants' living experience includes financial affordable should be considered by the providers (mostly local government and non-profit organizations). Due to the requirement to ensure that rents are kept at a low level for social housing occupants, many institutions and developers have to balance construction budgets with rental income. However, tenants in social housing or communities have their own special needs for living experiences. The energy cost is one of the key expenditure which directly affect their living qualities. In specific, with the impact of pandemic, people has been People have become accustomed to living at home and working from home, which has led to a significant increase in the proportion of time people spend at home. Correspondingly, the use of energy consumption will also greatly increase. Though energy subsides by government may mitigate the problem to some extend, it still increased the financial pressure for social housing occupants. Plus, with the mentioned above, social housing design and construction always considered in the lowest cost without any post operation cost. The building performance like heating and cooling insulation, radiation shading or natural lighting and ventilation which are highly related to human living experience and energy consumption, may not considered at the beginning design or building process. Therefore, a human-centered design combining with energy consumption reduction or energy efficiency improvement should be considered as building retrofitting strategies into social housing design with the aim of improving occupants' living experience.

Based on the statistic research from Sustainability Department of Victoria Government, the condition of energy using proportion and the comparison of different type of energy consumption has been clearly show in figure-2(a) that the energy for heating could be seen as the most extremely serious among all the using types. Indeed, especially considering the impact of severe climate change in recent years, extremely heating and cooling in summer or winter has greatly infected residents' thermal comfort to say nothing of the poor building performance with social housing. The figure-2(b) listed residents for overheating and cooling problems in the home investigation. According to the diagram, it shows more than half interviewee were unsatisfied with their thermal experience, and even, over 45% have to leave their home with the issue of overheating and cooling. Hence, the thermal insulation should be considered as one of the key design aspect in the further design or retrofitting strategies. Furthermore, a series of sustainable design strategies should be applied with the aim of build a human comfort and environmental friendly social housing with less energy consumption and economic costs of long-term operation.

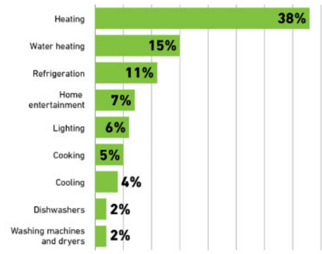

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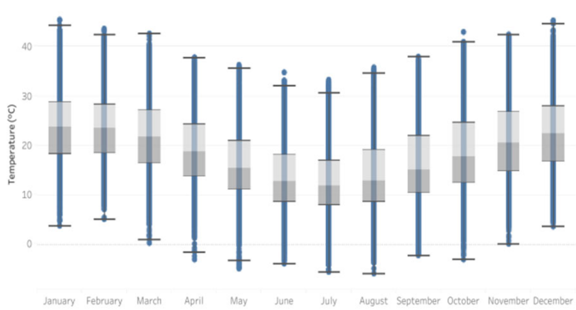
Figure 2. Data statistics of the condition of energy use for public housing from Sustainability Victoria. (a) Types of family energy use proportion from Residential Baseline Study.; (b)Survey of thermal comfort condition of public housing occupants in Victoria of Australia 2020.

Source: https://www.sustainability.vic.gov.au/news/news-articles/better-social-housing-protects-the-vulnerable-and-the-environment.

CASE STUDY

The building explored and evaluated in case study is the project of Phoenix Response housing in Geelong of Australia, which situated in between 37.4 and 38.9 degree South latitude. The site is experiencing mild temperate climate with low temperature range near coast to high range, and it can exceed human comfort zone both in summer higher temperature and winter cold temperature. Building insulation for both heat and cold isolation strategies should be considered within the climate conditions. In addition, based on the Beau of Statistic of Australia, the range of temperature and wind directions could be showed in below charts figure-1(a) and (b). According to the statistic of yearly weather data, the temperature is above or below the comfort range of human body (between 20~24 ℃). The building thermal insulation and cold wind isolation strategies will be considered in this climate zone. The project Phoenix Response house is an assembled micro home designed for vulnerable people as social housing and post-disaster housing with the aim of building a comfort space for impacted occupants' living in figure-2(a). The modal size is 29.25 sqm with one bedroom, one living room with opened kitchen and a bathroom at inner area (showed in figure-2(b). One of the advantages is that the unit space could be folded and unfolded in multiple functional use and the flexible space is available be assembled with prefabricated technologies which can simply build with lower economic cost in the long run. In another way, the prefabricated modular components shows its advantages in agility transportation, construction convenience and fast building, which are meet the basic requirements of housing mass customisation, a new trend for mass building construction with lower financial budget and less carbon emission in modern building development (Mass Noguchi, 2016). Except for the environmental construction strategies, this building adopt a series of passive and active design strategies to improve energy performance.



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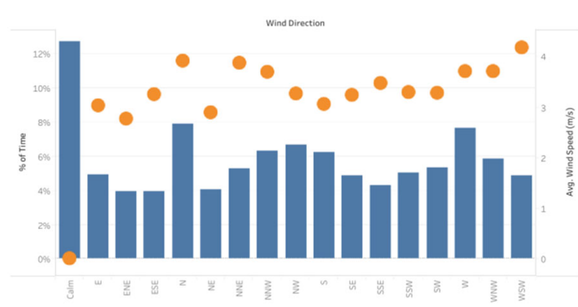
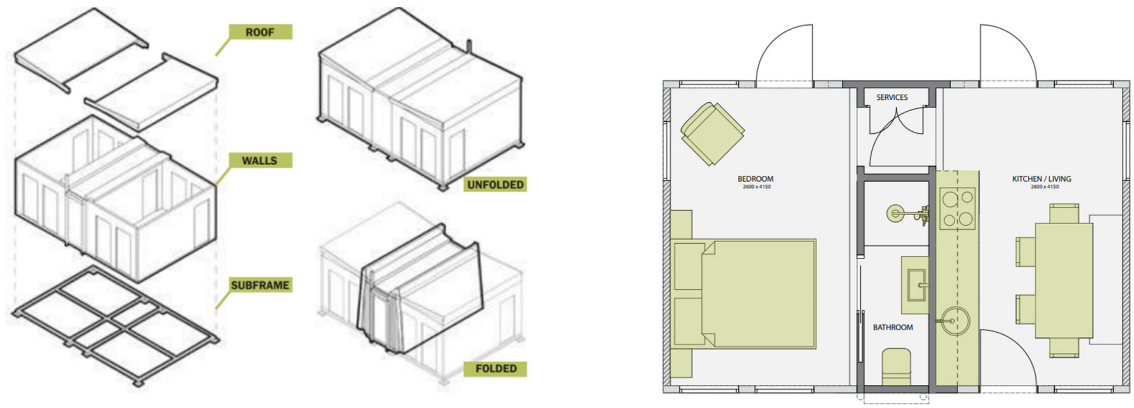


(**b**)

Figure 3. Data statistics of Climate zone map Nationwide House Energy Rating Scheme. (a) yearly average temperature by month in Geelong area.; (b) Survey of yearly average wind directions in winter of Geelong area.

Source: prefab21, a project by deakin architecture & formflow the phoenix response house.



(**a**) (**b**)

Figure 4. Design analysis diagram of Phoenix Response house of Geelong. (Drew by Formflow Workshop and Deakin University's School of Architecture and Built Environment) (a) Designed diagram of folding and unfolded space type; (b) Building plan of Phoenix Response house design
Source: PREFAB21, a project by deakin architecture & formflow the phoenix response house.

Energy saving strategy

The building envelope has adopted heating and cooling insulation material to reduce indoor temperature difference which means reducing the power needed for conditioning the space greatly, despite using electric hot water instead of gas. The outer material of building envelope was using steel cladding with steel frame with 100% of recyclable to reduce life cycle cost. However, the steel frame could be seen as thermal bridge which is not friendly with insulation. Hence, the inner layer material was considered by using Earthwool insulation to improve the insulating ability for building envelope. Earthwood material was manufactured from recycled natural raw materials like glass bottle or sand to long-fibre soft and pillowy products which has a higher thermal insulating performance with the U-Value range from 2.5 to 6.0. It is popular in construction market for it's environmental value, high recycling efficiency and lower cost of production. Then, it adopting plywood material as the inner wall layer which can further strengthen the insulating performance. The window was adopting single-layer glass material which is not in a higher thermal performance and might be retrofitted for the further energy reduction. The list of total material productive ranges has been listed below in figure-5. Based on the chose material and adopted prefabricated technologies for construction, the total carbon emission was greatly reduced when comparing with other steel frame housing in Victoria. The calculated data of carbon emission could be showed in the below figure-6 chart (a) and (b).

Renewable resource application

Renewable resources application is one of the key strategies to solve off grid electrical issues.Under this condition, solar power is regarded as the optimal solution. For a 29m² unit with single living or two person, the average daily energy consumption for lighting and other using equipment will be around 9kW. According to this amount, 8 solar panels will fit on the roof, which can generate around 3kw in ideal conditions. If the building is connected to the grid, solar power can be stored for any power emergency. In specific, power is stored in a large battery, which allows for 2 days of zero power generation if conditions are poor. Although solar power can achieve 100% sustainable energy use, its high cost, especially for the installation and maintenance of large batteries, also prevents the widespread use of solar power systems. Therefore, the project uses a hybrid mode to balance the limitations of a single power supply to make economic benefits and environmental sustainability to achieve maximum win-win situation. Furthermore, the project adopted power wall to enrich the maximum of solar power usage. The Powerwall has a 14kw capacity and allows for 2 days of no solar charging. Having a solar battery also enables the buyer to be subsidized for government rebates (up to 20%). Its rechargeable lithium ion battery pack provides energy storage for solar, self consumption, time based control and backup.

In terms of energy use of water resources, the project also set up a transportable water tank with capacity of 1000 Liter that efficiently store water under the housing space. This is a wise way to incorporate a high literage storage unit without sacrificing usable space. Moreover, the house also adopted a sewerage systems collect domestic waste water and use it for other purposes.

METHODS

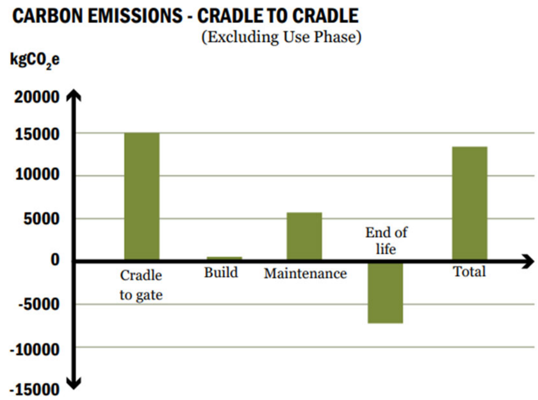
In order to evaluate the energy performance and other conditions of passive design with natural lighting or radiation, a building simulation strategy will be considered as testing system to run. Based on the simulation result, a clear data collection of energy performance or sunlight conditions will be gathered to evaluate the design outcomes as authentic as possible. In regard to this need, this paper will explore a digital simulation strategy by using Ladybug and Honeybee as plugin software in Grasshopper of Rhino to combine Diva and EnergyPlus simulating lighting, solar radiations and building energy performance.

For the first step, the digital designed modal could be built in Rhino, and this made the further simulation possible by input it into Grasshopper, a platform for plug-in software run with integrated battery components. Then, the weather data file from EnergyPlus with local weather information can be inputted via Ladybug, and all the further simulation process will set and run under the weather file background. In the third step, according to calculating the modal condition integrated with data weather file, the sunlight illumination analysis and solar radiation analysis accompany with sun path diagram could be simulated. At last, based on the simulation results, the natural lighting design and shading design of the building will be analyzed and evaluated, and further suggestions for improvement will be put forward.

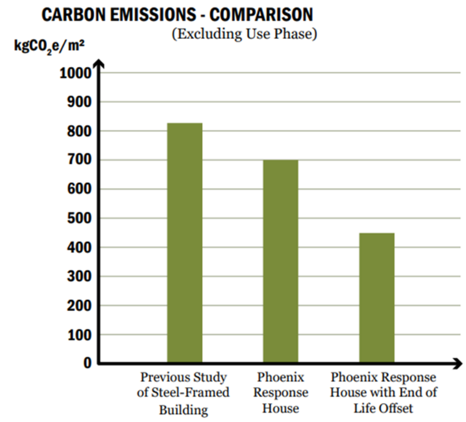
Moreover, in this simulation, LadyBug and Honeybee were combined to simulate the building thermal performance (process of simulation will be showed in appendix). The approximate energy consumption was calculated based on the input of parameters of existing building envelope materials integrate scheduled human using behaviour. The energy consumption simulation can also be used to predict the energy consumption during future use to determine the carbon emission of the building.

	Steel clading	Earthwood insulation	Plywood	Single glazing glass panel
Building envelpope elements and thickness	Outer material of building envelope, roof and floor was using steel cladding，0.42MBT	the insulation material of building envelope, roof and floor was using earthwood insulation, 90mm	Inner layer material of building envelope, roof and floor was using Plywood panel，12mm	Window material was adopted single glass panel, 4mm
R-Values (W/(m²·K)	0.09	2.5	1.25	0.2
U-Values (W/(m²·K)	11.2	0.4	0.8	5
Thermal Conductivity (W/ m·K)	45.28	0.036	0.11	0.2

Figure 5. Characterization table of the thermal envelope
Source: the table of thermal envelope material was made by author.



(a)



(b)

Figure 6. Calculated data chart of condition in carbon emission with Phoenix Response House. (a) Carbon emission condition data chart with different stage of Phoenix Response House; (b) The carbon emission condition of Phoenix Response House comparing with previous study of Steel Framed Building and it's end of life offset.

Source: PREFAB21, a project by deakin architecture & formflow the phoenix response house.

RESULTS DISCUSSION

Based on the simulation analysis and building design evaluation for energy performance and human comfort. There's a series of results to discuss, and then, some advantages and potential design problems would be realized with retrofitting suggestions for further design. At first, based on the the setting process of simulation software system by Ladybug and Honeybee, a weather file setting of introducing local weather data to system. According to the data collection, the sun path accompany with solar radiation condition could be simulated. The site is experiencing a large amount of solar heat and radiation from northwest and west area of the building which means too much heat gains. A shading system around the windows or wall of west side should be applied especially in summer. In addition, considering the building layout with the site is another way to weak the west heat by using its shape for shading solar radiation. Second, with the building illumination analysis, the natural light condition of inner space is good, but still can be further improved by natural lighting introducing strategies. Based on the figure diagram above, it shows the building have a great illumination condition near the window area at north and west side of the building. It is comfort to layout a active space like study or working functional spaces at these areas, and bedroom at south area without too much sunlight in summer. However, it would be cold and dark without any warm sunlight at south inner area in winter. In regard with this condition, opening a certain area of skylight in the roof can solve the problem of dim light in the southern part of the room to some extent. At the same time, the orientation of the house is also worth to consider with solar radiation and natural lighting. Third, based on the energy simulation with building envelope and human behaviour schedule input, a estimated energy consumption diagram could be simulated and evaluated. According to the energy performance evaluation of the house, it revealed noteworthy energy loss in winter, due to infiltration issue and the poor glazing materials' insulating performance, while the main heating gains were due to thermal bridge transmission by openings and infiltration which were showed in figure (9). Hence, windows play an essential importance role in thermal performance as it controls the main solar radiations, natural lighting and ventilation.

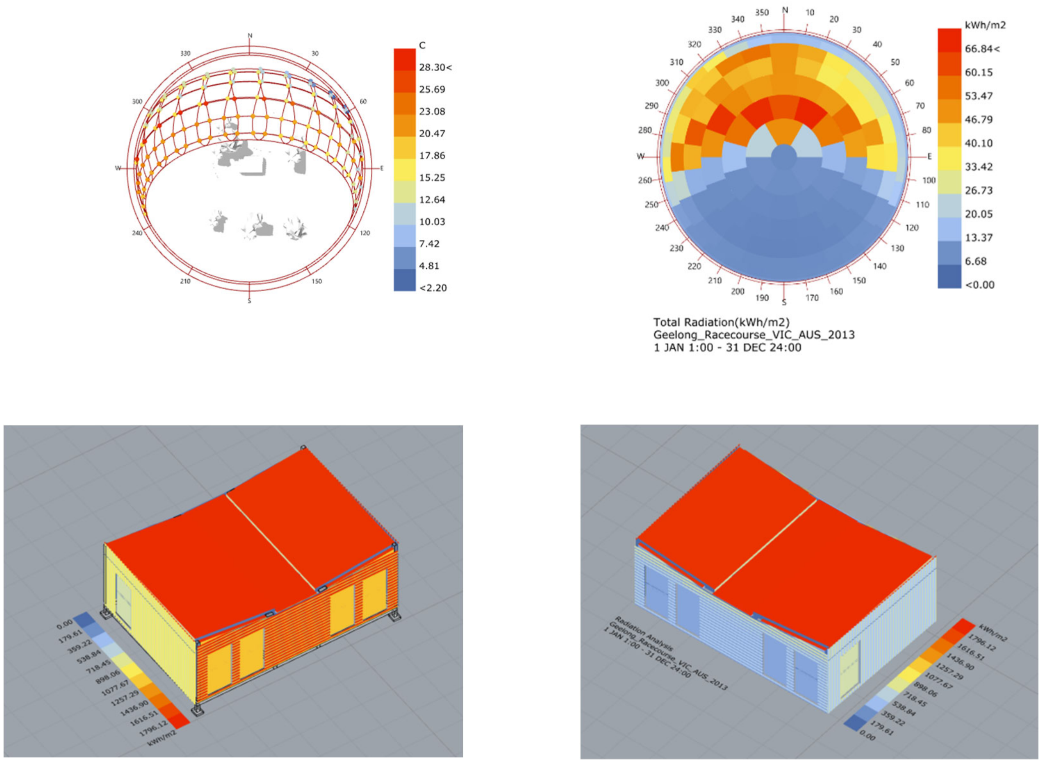


Figure 7. Simulation results of site solar radiation and the condition of building heat gain by ladybug plug-in software of Grasshopper in Rhino.
Source: J.Wei

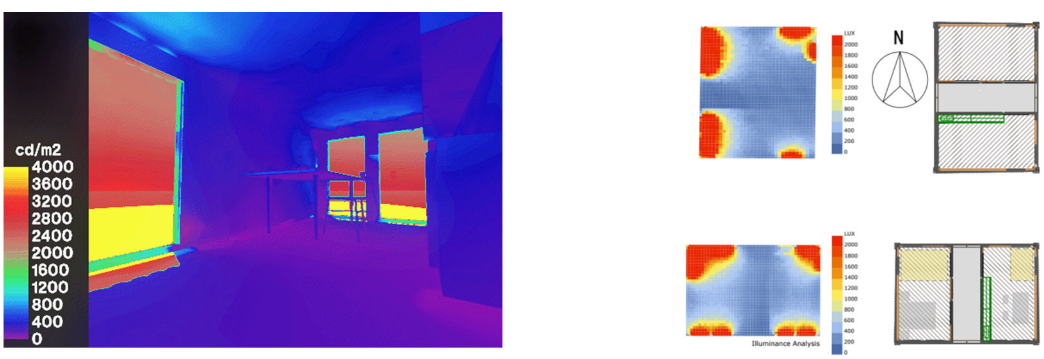


Figure 8. simulation results of sunlight illumination condition at inner space.
Source: picture and drawings are made by author, J.Wei

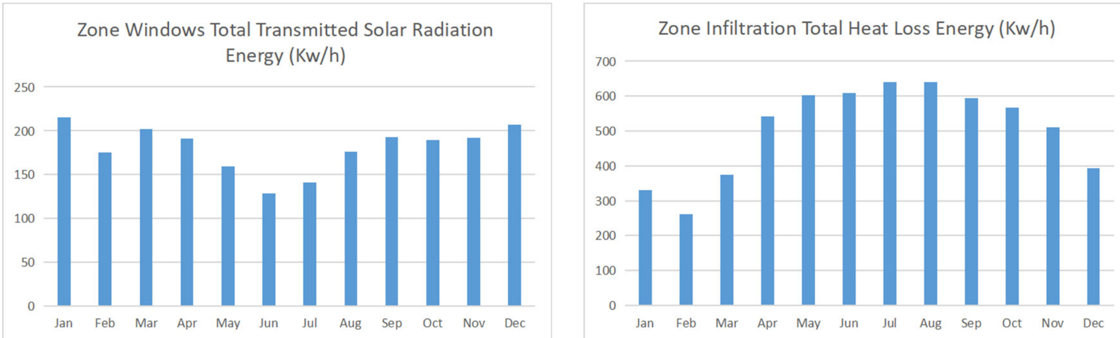
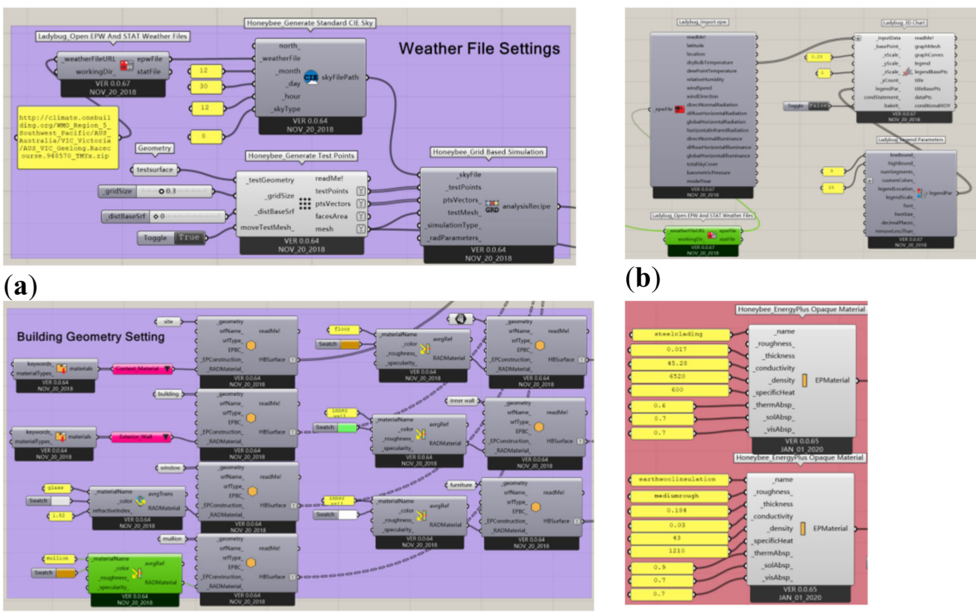


Figure 9. simulation results of transmitted solar radiation and infiltration heat loss.
Source: picture and drawings are made by author, J.Wei



(a) (b) (c) (d)

Figure 10. the setting process of simulation software system by Ladybug and Honeybee. **(a)** weather file settings of introducing local weather data to system. **(b)** wind direction, dry bulb temperature and sun path analysis setting. **(c)** building geometry setting. **(d)** building envelope materials setting.
Source: picture and drawings are made by author, J.Wei

CONCLUSIONS

According to the project analysis and evaluation of Phoenix Response House with the aim of exploring a design road map based on energy consumption and building performance, there's a clear design strategy road map could be identified and summarized. At first, retrofitting using passive design strategies is an effective way with considerable capacity to improve energy performance and reducing carbon emission for residential building especially for social housing mass customisation. Then, the material of building envelope retrofitting as an active technology application strategy can significantly promote building thermal performance, which is highly related to human living experience. The insulation layer appliance for roof, facade and floor in contact with lower thermal exchange between indoor and outdoor space through thermal mass condition improvement. As for simulation system, Ladybug and Honeybee as plug-in software of grasshopper has its advantages to integrate 3D digital modal with outside climate conditions, which are not available only by using EnergyPlus. Based on the parameter setting and input, a series of detailed output and result could be showed visualized as colorful diagrams with figurative building modal. Furthermore, this paper also proves the superiority and feasibility of this simulation method as building energy consumption simulation testing system through project simulation analysis. This set of analysis framework is also worthy of further application in other project analysis studies.

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THE USE OF PHASE CHANGE MATERIAL TO REDUCE PEAK AIR-CONDITIONING LOAD IN HOT CLIMATE OF UAE

Mahmoud Haggag[1], Ahmed Hassan[2], Usman Masood[3]

[1] Associate Prof., UAEU, Al Ain, UAE, mhaggag@uaeu.ac.ae
[2] Associate Prof., UAEU, Al Ain, UAE, ahmed.hassan@uaeu.ac.ae
[3] Research Assistant, UAEU, Al Ain, UAE, usman.m@uaeu.ac.ae

ABSTRACT

District cooling systems are increasingly being deployed in hot climates, which constitute around 50% of energy consumption. A considerable improvement in the district cooling system (DCS) performance can create a substantial impact on the energy consumption and capacity installation through storage by reducing the air conditioning peak load. Using a phase change material (PCM) to absorb and release heat offers latent heating and cooling for the environment. This study aims to incorporate a thermal energy storage system (TES) containing PCM that can store cooling contained in chilled water during off peak time and release the same at the peak time to reduce the peak cooling load. A preliminary study was carried out by the authors on involving paraffin based PCM with melting range of 30–33°C in a thermal energy storage unit. The purpose of this research is to determine the feasibility of a PCM-based air pre-cooling approach that can reduce the peak cooling demand by 20% by storing ambient cooling from the previous night and releasing it to the fresh air supply stream throughout the following day. The PCM containers are positioned towards the hot air as the pre-cooling unit is installed in a standard AC duct, which allows hot air to reach the test chamber at a specific velocity. The study concluded that PCM enhanced the pre-cooling performance and reduced the outlet air temperature. A drop of 5.5°C occur in case velocity of 1 m/s. Air conditioning system reduced capacity reached by 28%. The optimum use of PCM by incorporating chilled water-cooling is under investigation as the district cooling system delivers chilled water to buildings during day and night. However, most of the night times, buildings are not in use thus storing night time chilled water cooling through the PCM and releasing the same during day time is expected to substantially drop the cooling load.

Keywords: Phase change material, Energy efficiency, District Cooling, Thermal energy storage, Latent heat storage.

INTRODUCTION

Energy consumption has risen dramatically in tandem with global economic and demographic expansion. The reliance on fossil fuels to satisfy everyday energy need is causing environmental damage. Globalization and the usage of nonrenewable energy sources have been identified as the primary drivers of carbon emissions. Using renewable energy, on the other hand, has been shown to lower carbon emissions (Wang & Zhang, 2021). Over the last 20 years, the rise in primary energy output and carbon dioxide emissions has been 49% and 43% respectively (Li, Enhua, Xu, & Musah, 2021). Buildings account for 25% to 30% of all energy use, making it one of the most energy-intensive industries. As a result, its contribution to carbon emissions is significant (Li, Wang, Lin, & Chen, 2021). Considering the next three decades, buildings are predicted to consume 50% more energy, highlighting the necessity of increasing the energy efficiency of buildings (Narbuts, Vanaga, Freimanis, & and Blumberga, 2021). According to the findings space heating and cooling demand accounts for approximately 75% of all energy utilized in single and multifamily homes (Patel, J, Qureshi, M, & and Darji, 2018). The massive contribution of cities to CO2 emissions, which is 70%, and their production 80% of global gross domestic product (GDP). It is regarded to be the beginning of the environmental disaster. According to the growing demand curve, space cooling demands in buildings will increase threefold over the next three decades (Choblet, Gicquel, alexander Schmitz, & Fang, 2007).

Urbanization linked cooling demand is expected to increase rapidly according to IEA elaborated on Fig 1 (Souayfane, Fardoun, and Biwole, & H, 2016).

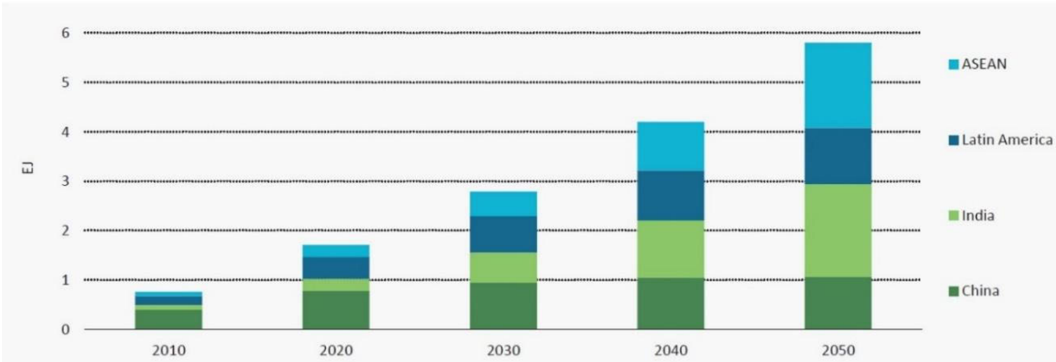

Figure 1 : Cooling demand prediction in four regions (exa-joul)

Many solutions have been proposed by researchers to deal with peak demand, carbon emissions, and fossil fuel dependency. Renewable energy sources and electrical energy storage are popular solutions; by improving the efficiencies of existing systems, we can avoid environmental disaster (Aljehani, Razack, Nitsche, & and Al-Hallaj, 2018). Connecting the heat and cooling needs of several customers to existing sources is one strategy for conserving resources (Werner, 2013). District cooling are said to provide energy security because they are more flexible in terms of energy use than individual air conditioning units (Spurr, 2001). Heating and cooling resources can come from both renewable and nonrenewable energy sources. The main feature of TES integration with DCS is to minimize energy consumption during the high wet bulb temperature by lowering the peak thermal load on chillers. A PCM-based thermal energy storage system might offer more degrees of freedom to the DCS.

The utilization of thermal energy storage (TES) is among the most promising strategies to optimize energy consumption. Perceptible heat, latent heat, and chemical reactions are all possible ways for TES materials to store energy. In recent decades, latent heat thermal energy storage (LHTES) has gotten a lot of attention as a promising technology for heating and cooling buildings. A number of studies have indicated that employing thermal mass in well-insulated residential buildings may save between 5% and 30% on cooling and heating energy (Kuznik, Virgone, & and Noel, 2008). PCM has gained a lot of attention in the previous four decades and has become a hot topic of research (Shakibi, Afzal, Shokri, & and Sobhani, 2022). The capacity of PCMs to retain latent heat thermal energy allows them to absorb surplus energy in buildings and maintain a comfortable temperature (Ge, Li, Li, & and Liu, 2022).

Commercial phase change materials (PCMs) operate between -30°C and 850°C, making them useful in a broad range of contexts as a thermal energy batter (Atkins, et al., 2022). Different integrating procedures encompass a wide range of encapsulation that has impact on heat transfer. At this time, micro-encapsulation allows PCM slurries to be used in a number of applications at a range of temperatures (Jacob & and Bruno, 2015).

In this paper, a review about DCS how to be used to its full potential while minimizing operating and overall capital expenses by reducing capacity of the chiller plant, and operational cost have been elaborated using PCM. Also, PCMs have been discussed for thermal energy storage. A study has been presented on air pre-cooling using paraffin as TES. Section 2 provides an overview PCM as thermal energy storage. Section 3 reviews the DCS integration with TES. Section 4 investigates a preliminary study, PCM based air pre-cooling concept by storing nighttime ambient cooling and pros and cons are discussed, and section 5 discusses the results of the study. In the end conclusion gives the brief analysis of the article.

THERMAL ENERGY STORAGE

The fundamental function of buildings is to protect people from the effects of extreme weather. Traditionally, high thermal mass materials were employed in building construction, allowing buildings to be less affected by the environment (Tyagi & and Buddhi, PCM thermal storage in buildings: A state of art, 2007). Because of the growth in population and lack of space in cities, high-rise structures were required, and light-weight materials with low thermal mass were employed in their construction, hence heat capacitance was reduced. As a result, the demand for cooling and heating equipment arose in order to maintain thermal comfort. To meet this demand, a substantial amount of energy was necessary. Hence, the use of TES can boost the energy efficiency of buildings and can be a solution to lower peak demands (Heier, Bales, & and Martin, 2015).

When it comes to offering energy flexibility to buildings, TES is at the top of the list (Morovat, Athienitis, Candanedo, & and Dermardiros, 2019). Thermochemical and thermal energy storage are two types of thermal energy. There are three types of thermal energy storage: sensible heat storage (SHS), latent heat thermal energy storage (LHTES), and thermochemical heat storage (TCM-TES) shown in Fig 2. However, sensible and latent heat storage are the most popular options due to the scarcity of thermochemical heat storage and its expensive cost. A solid or liquid receives the heat energy for the purpose of sensible heat storage (SHS). The quantity of heat that can be stored is influenced by many factors, including the medium's specific heat, variations in temperature, and the availability of storage material. Latent heat storage refers to the process by which a storage medium absorbs or releases energy during a phase change from solid to liquid, liquid to gas, or vice versa.

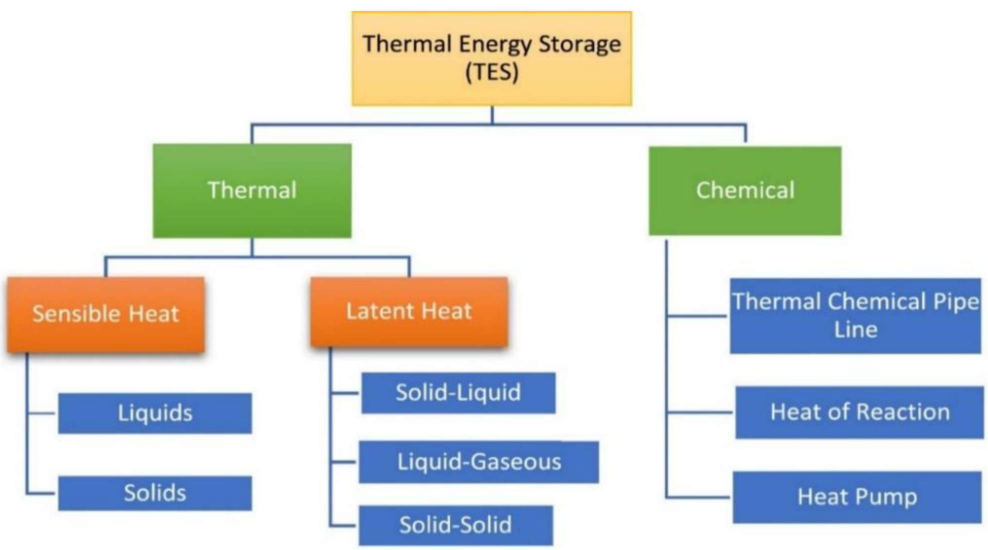

Figure 2. Thermal energy storage branches

The ratio between the size of the building's exterior and the volume of the materials utilized, each of which has its own thermal mass, is the single most important factor in establishing the storage technique to apply.

Phase Change Materials (PCMs)

The term "latent heat storage material" refers to phase transition materials that, when exposed to temperature changes, transform from a liquid to a solid state isothermally during the melting or solidifying phases (Tyagi & and Buddhi, 2007). During the phase change from solid to liquid, PCMs are able to store thermal energy as latent heat. The chemical bonds of the PCM's dissolve during this endothermal process. It release the thermal energy by exothermal process when temperature is being dropped and it changes its phase to solid

(Wang, Matiašovský, Mihálka, & and Lai, 2018). PCM is termed as thermal battery or is said to be act as thermal storage unit. In Fig 3 the phase transition is elaborated (Motahar, 2020). It's also vital to evaluate each PCM's operating range in order to satisfy demand while also considering its thermal capacity.

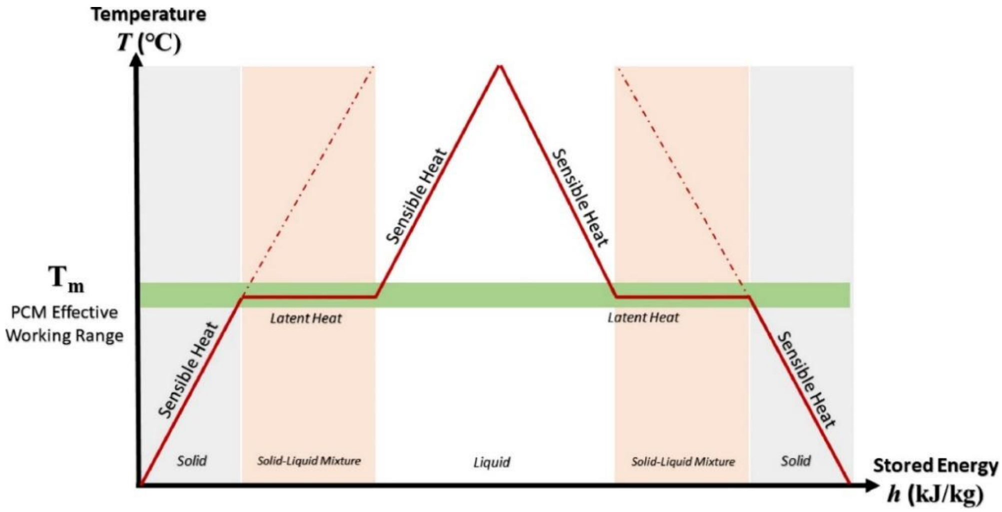

Figure 3. Phase Transition of PCMs

PCM Classification

According to their thermodynamic properties, phase transition materials may be sorted into three broad classes transition from liquid to solid state: Organic, inorganic, and eutectics (Venkitaraj, Suresh, Praveen, & and Nair, 2018) (Mourid, El Alami, & and Kuznik, 2018). The further categories are classified based on the chemical composition and properties of PCMs. The classification of PCMs is illustrated in the Fig 4 (Kalnæs & and Jelle, 2015). It's also essential in determining each PCM's working range in order to meet demand while also considering its thermal capacity.

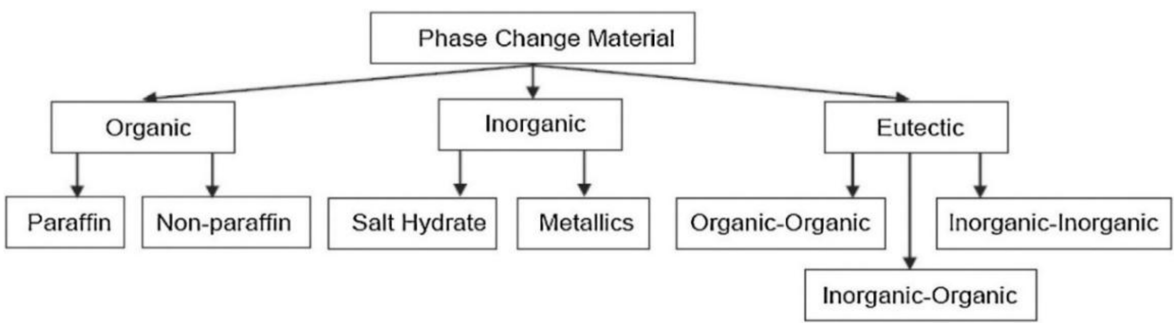

Figure 4. PCM Classification

DISTRICT COOLING SYSTEM INTEGRATION WITH THERMAL ENERGY STORAGE

A traditional District cooling system include chiller plant, pumps, cooling towers, a piping network and cluster of buildings. The primary goal of a DCS is to provide thermal comfort to a set of buildings by supplying chilled water (Werner, 2013). As compared to the typical air-conditioning units installed at individual buildings DCS are known to be more energy efficient and considered environment friendly alternative. Fig 5 explain the assembly of conventional DCS.

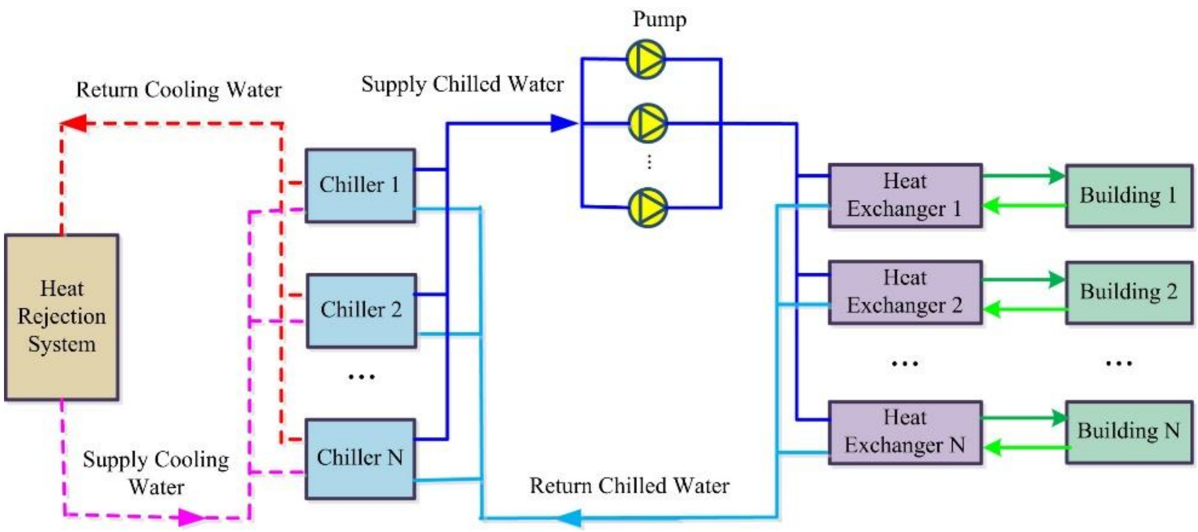

Figure 5. DCS schematic diagram

A potential TES solution for the district cooling system using PCM has been considered. In order to examine TES's adaptability as a retrofit model, it was incorporated into a poly generation, micro grid. A techno-economic study demonstrated a reduction in DCS capital costs by reducing capacity and operating costs by lowering peak demand (Mazzoni, et al., 2021). Another study gave a comparison of cool thermal storage types for DCS and showed that PCM has high cold storage density and high thermal conductivity as compared to other cool storage methods, however it is complex system, encapsulation and high control is required (Zhang, Jin, & and Hong, 2022).

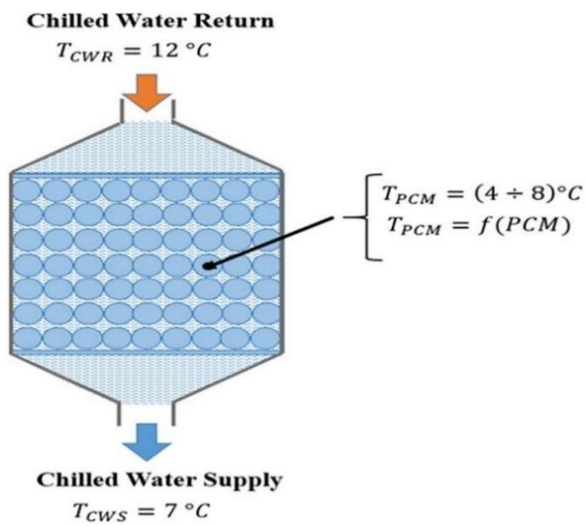

Figure 6. Schematic diagram for cool energy storage from chilled water

The PCM's temperature range is the most important consideration when designing TES for cooling applications. For the use in DCS employing chilled water for cold storage, the temperature must be in the range of 4°C to 8°C. In Fig 6 a schematic diagram has been presented for cool thermal energy storage from chilled water, where T_{PCM} is temperature of PCM. Storing heat provides a system with a measure of versatility that may be put to use in optimization. Dynamic optimal chiller loading with thermal energy storage is more useful when the wet bulb temperature changes more significantly during the day and when there is greater variance in the total cooling demand. TES using PCM and its integration with this DCS has several advantages, compatibility is the key due to complexity of both systems more research is required.

AIR PRE-COOLING USING TES EXPERIMENTAL ANALYSIS

The most common mechanism in an AC duct cooling system is to take air from the environment and pass it through a duct to chilled liquid, where the air transfers its energy to the liquid get cooler. During recycling of the cooled air it loses up to 20% of its cooling energy at during this process. As a result, more power is required for the heat ventilation and cooling (HVAC) system to meet the selected space's reference cooling temperature. The PCM which operates on the latent heat thermal energy storage principal has been used in hot and humid weather of UAE to pre-cool the air before entering the AC duct. Liquid PCM was filled in containers externally cooling was applied to make it solid for the experiment. PCM functionality is obvious as a latent heat storage battery that regulates the temperature of the surrounding environment at lower temperatures and provides pre-cooled air to the cooling system. The average temperature of UAE in summers is 30°C to 35°C, considering this solidifying of PCM (paraffin) was the problem at night. A solution has been proposed to use chilled water as interactor instead of air.

Materials Selection

If PCM are to be used as LHTES in buildings, a specific methodology for selecting the appropriate PCM is dependent on several guidelines. Several key points must be considered before selecting the best PCM. The first step is to determine what melting temperature should be used. When it comes to melting temperatures for building applications, it is recommended that the range between 15–30 °C or 20–32 °C. Thermal energy storage PCM must have the desired kinetic, chemical, thermo-physical properties, and economic properties Table.1. Due to its availability, low cost, and low environmental effect, compared to other PCMs like salt hydrates, a commercial grade of paraffin wax was chosen to meet the aforementioned properties.

Table 1: *Desired properties of PCMs for energy storage application* (Patel, J, Qureshi, M, & and Darji, 2018)

Thermo-Physical Properties	***Chemical Properties***	***Kinetic Properties***	***Economic properties***
Optimal melting point	Complete reversible freeze/melt cycle.	To avoid super cooling high nucleation rate	Availability
High specific heat.	No degradation after freeze/melt cycles.	For heat recovery high rate of crystallization	Low price and cost effective
High latent heat of fusion and small vapor pressure	No corrosiveness		Nonpolluting.
Appropriate thermal conductivity	Fulfilling safety requirements		Environmental friendly
High density and small volume change	Chemical stability		Good recyclability

The experimental study includes a Differential Scanning Calorimetry device (DSC-Q200) was used for the heating of 5 mg PCM. The temperature was raised from 0 to 70 by a constant rate of 5/min while to drop temperature of DSC pan to 0 liquid nitrogen was used. The paraffin wax's DSC schematic diagram has been shown in Fig 7.

According to the DSC curve in Fig 8, paraffin wax has a latent heat of 158 KJ/kg, a large melting range starting at 27 °C for liquidus, 34.2 °C for solidus, and 32.5 °C for melting point. Table 2 lists other material characteristics.

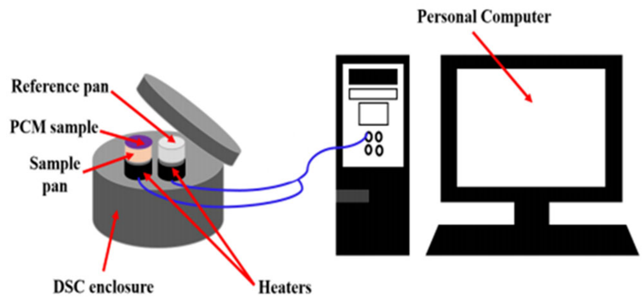

Figure 7. Schematic diagram for the DSC test

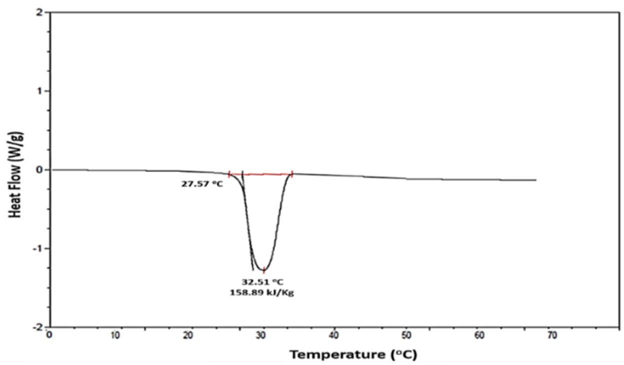

Figure 8. Paraffin's DSC curve (Haggag, Hassan, & Abdelbaqi, 2019)

Table 2: *Properties of PCM*

Properties	***PCM RT-31(a)***
Latent Heat	158± 7.5% kJ/kg
Melting Point	27-33 °C
Congealing Point	33-27 °C
Specific Heat Capacity	2 kJ/kg·K
Heat Conductivity	0.2 W/m·K
Density	0.88 kg/L
Flash Point	157 °C
Volume Expansion	12.5%

Experimental Setup

For the purpose of resembling a conventional duct used for air conditioning, a chamber has been designed of 45 cm × 90 cm × 20 cm. Four PCMs containers were fabricated using aluminum alloy (1050) 4-mm dimensions as: (5x300x20 cm3), filled with PCM and implanted vertically with air gap of 5-cm. Results were recorded by mounting thermocouples, and thermocouples were linked to data logger (Fig 9).

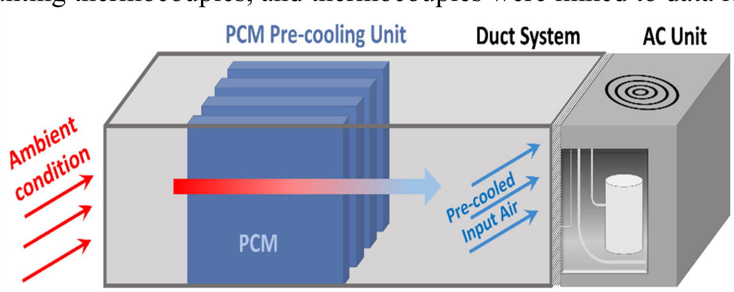

Figure 9. Experimental Setup Schematic.

In order to accurately monitor temperatures throughout the ducting and PCM, many calibrated T-type thermocouples were installed at various locations. The data was stored and retrieved using a data logger made by National Instruments called Compact-Rio, which was coupled to each of the sensors. The containers were filled with PCM as a liquid, which was then chilled to cause it to solidify fully. On top of the container, the solidified PCM left a 7-cm empty area that was meant to account for volume growth during the PCM melting

DISCUSSION AND RESULTS

The Fig 10 shows temperature profile, where temperature of inlet air fed to AC duct starts is 29°C is same as the outlet of air duct containing PCM. As sun heats up the air temperature of inlet rises to 41.5°C and the temperature of outlet air observed a drop of 1.5°C due to the PCM.

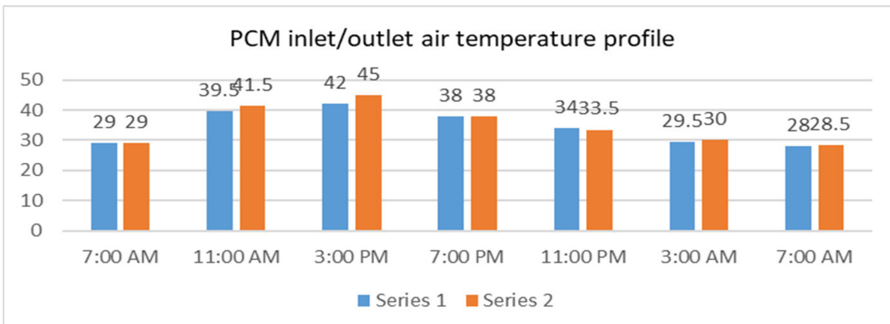

Figure 10. Temperature profile of inlet (Tin) as series 1 and outlet air (Tout) as series 2 with 4 m/s air speed.

It can be noticed that at 11:00 PM temperature of the ambient air falls so PCM starts releasing energy and temperature drop can be noticed. The average temperature drop is measured 1°C and maximum 3°C. Fig 11 shows the maximum temperature change during different velocities, it is notice able that at lowest velocity the maximum temperature drop is 5.5°C, can drop the capacity of the system up to 26%.

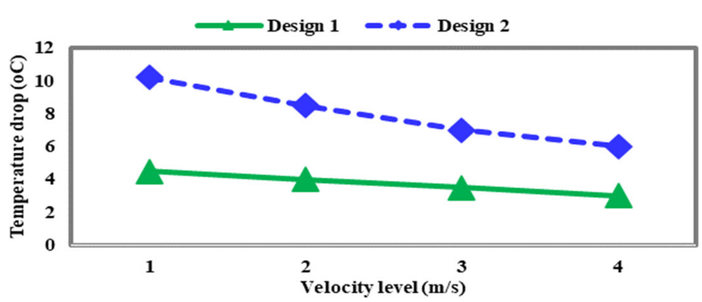

Figure 11. Maximum temperature drops at speed 1 m/s to 4 m/s.

CONCLUSION

A PCM (paraffin, melting point 31°C) based thermal energy storage system for a cooling application in hot UAE weather conditions has been studied in this research. The study is based on experimental setup of a single column of four PCM container embedded in an air-conditioning duct. The system under consideration achieved average 1.5°C and maximum 3°C at speed 4 m/s. While by lower the speed of air a drop of 5.5°C was observed, and 3°C average drop. Due to latent heat storage mechanism PCM was able to achieve the goal of air pre-cooling. The temperature decreases at night, however, was insufficient to freeze the PCM for usage in the next cycle. This finding inspires researchers to investigate chilled water interaction with PCM-based systems in a bigger picture, such as a district cooling system, where returning water at night can transfer cooling energy to PCM, which can then be used during peak demand times during the day. This might result in a drop-in district cooling system's capacity by increasing energy efficiency.

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RETROSPECTING A STUDY TO REDUCE OUTDOOR TEMPERATURE BY EXPLOITING THE SHADOW POTENTIALS OF BUILT MASSES: A CASE STUDY OF PUNE, INDIA

Nirzari Mehta[1]

[1] Associate Prof, Dayananda Sagar College of Architecture, Bangalore, India, nzm.dsarch@gmail.com

ABSTRACT

Urbanization causes many negative effects on the environment which add to the urban heat island (UHI) effect. The main contributor of this impact is the built-up density and the urban form. Dense built development in cities is a strategic response to fast population growth but it increases the solar radiation gain. UHI negatively impacts residents and the associated ecosystems of urban environs. Therefore, it is important to reduce this thermal stress caused by simultaneous processes of urbanization to achieve a better microclimate for the humans for their well-being. With years of sustainable-development oriented practices towards city temperatures, UHI is yet becoming more apparent across different scales of cities. This paper reflects on an experiment undertaken in 2012-13 to understand the relation between built-up densities, building height and shade, for the city of Pune, India. The experiment continues to have contemporary relevance in 2022 as the focus on thinking through mitigation strategies to counter UHI effect intensifies.

The experiment investigated the influence of shadows cast by built masses on ambient temperature. Here, as part of the retrospective analysis, the results are being read against a relevant body of literature. The effectiveness of building shade in minimizing insolation is assessed for the identified areas, based on geometric parameters such as CAR (complete aspect ratio). The experiment's aim was to find out the effectiveness of the urban form, based on solar insolation and shading percentage. The results showcase that change of height increases the shading potential as compared to the effect of change in densities. CAR has positive correlation with shadow area thus lowering the insolation on the ground plane which is beneficial to reducing outdoor temperature. For an average of 20% increase in shaded surfaces a drop of 4 degrees in the sol air temperature is possible. Hence, Shadows have the potential to mitigate UHI of Pune city.

Keywords: Built-up density, Urban shade, Solar insolation, Outdoor temperature, Pune

INTRODUCTION

"Massing should be such as to first prevent the heat build-up in the city and second is to promote convective cooling during the night."
\- *R. Emmanuel, 1993.*

"There is no safe amount of radiation. Even small amounts do harm."
L Pauling (1901-1994)

Cities are getting hotter. Even a pedestrian walkway would be in the shade for one instance and then in direct sun, the other instance. Most people can handle only a few minutes in high heat. As cities add major infrastructure for its growth with the ongoing migration, both result in temperatures in the city to rise relative to their rural surroundings, and create a heat island. With increasing urban development, Urban heat islands (UHI) may increase in numbers and intensity. These heat islands have impacts that range from local to global scale and thus relevant for urbanization with environmental change. High density development in cities is a strategic response to fast population growth. Every increasing built surface receives the solar radiation contributing to heat gain. With decreased amounts of vegetation, cities also lose the shade and cooling effect of trees. Therefore, one of the large contributors to the heat island effect in fast growing cities, is the built-up density and hence the urban form.

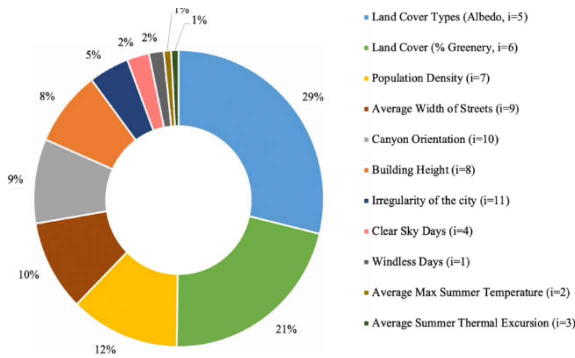


Figure 1: Influence of each parameter in the absolute max UHII phenomenon.
Source: Sangiorgio,2020

There are various parameters contributing to Urban heat island intensity (UHII) (Figure 1). Four of 11 parameters stated in Figure 1 are related to urban morphology which constitute 32% of the total influence. The average width of streets and building height are attributes of built -up density and together contribute 18%, thus implying its importance. Li et al (2020) argues that in addition to the size, the UHI intensity of a city is directly related to the density and an amplifying effect that urban sites have on each other while Voogt (2008) states that geometry itself is the mitigation strategy. (Figure 2), implying the horizontal and vertical dimensions of urban fabric hold the solution to reduce UHI. 'Every time we build anything we affect the quality of life of people. (Gehl, 2020) (Figure 3)'. The urban form not only affects human comfort but also the energy demands, which at any given place can be quite different from those existing in even other nearby places. These effects of urban form on thermal comfort have been well researched during the past decades. However, density of buildings having a more direct-causal relationship to UHI makes it a complex urban feature, to study its impacts on urban climate. Yet, there is an urgent need for mitigation on account of the rapidly declining thermal comfort in urban outdoors.

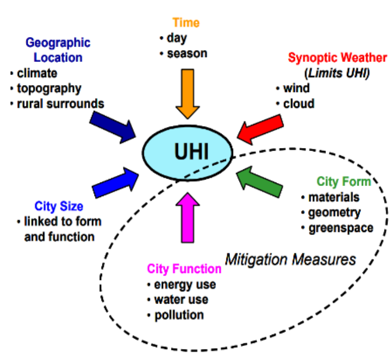


Figure 2: Illustrating factors affecting urban heat islands and the mitigation measures.
Source: Voogt,2008

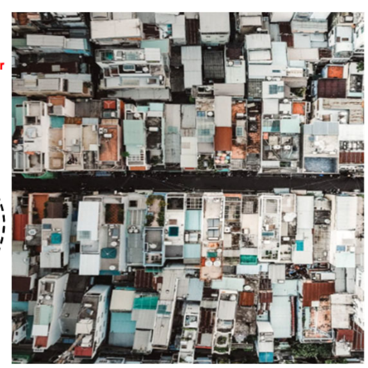


Figure 3: Illustrating impact of high-density fabric on quality of life.
Source: APN Science Bulletin, 2019, Photo credit: Devon Wilson

UHI negatively impacts not only residents of that urban environs, but also others who have their ecosystems associated with that hot spot. With years of sustainable-development oriented practices UHI effect is becoming more apparent across different scales of cities and metropolitan areas of the city. For instance, consider few headlines from Pune city, the location of the case study: (1) *PUNE: The summer heat is on, with the city recording 36 degree Celsius on Wednesday, the fifth hottest day for the month of February in the last one decade" (TNN, 2012) (2) PUNE: The city on Sunday sizzled at 43 degrees Celsius, its hottest day in the last 52 years. The last time when the city touched the 43 degrees C mark was on April 30,1967. (TNN, 2019).*

'An endless number of green buildings don't make a sustainable city. (Gehl, 2020)'. When we try to look into efforts made by leading environmental bodies or individuals, we realize that extremely vast understanding and standards exist for the building as an entity and its indoor comfort, in comparison to the inadequate parameters or guidelines for achieving outdoor comforts. For instance, GRIHA - Green Rating for Integrated Habitat Assessment, a national rating system for green buildings in India, is widely adopted and suggests a design to mitigate urban heat island effect. Under Sustainable site planning criterion GRIHA awards 2 points out of 100 possible points towards achieving that. The focus for the compliance of this criterion is on techniques such as albedo mitigation, cool roofs, vegetation mitigation, wind circulation and opaque vented walls. Green building ratings help to better the heat flux of existing and proposed built masses and majorly deal with the layers of the building, however do not seem to delve on the impact of these structures and their shadows, on the outdoor thermal comfort. Only in very few criterions does it demonstrate the effect of shade achieved by vegetation.

This paper reflects on an experiment undertaken in 2012-13 to understand the relation between built-up densities, building height and shade, for the city of Pune. The experiment investigated the influence of shadows cast by built masses on ambient temperature. Here, as part of the retrospective analysis, the results are being read against a relevant body of literature. The experiment's aim was to understand the effectiveness of the urban geometry, based on solar insolation and shading percentage. The paper reflects on the results and sets out the future possibilities and limitations of the study as it was conducted. Urban climate is significantly affected by the solar radiation and shading conditions, since solar radiation affects temperature (Andreou, 2014). Therefore, alteration of urban geometry can be a great measure for comfort enhancement and is the key attribute of my experiment. The experiment continues to have contemporary relevance in 2022 as the focus on thinking through mitigation strategies to counter UHI effect intensifies.

SETTING OUT THE STUDY AND EXPERIMENT AS CONDUCTED

This section first sets out the experiment's methodology (Figure 4) and then sets out the inferences and findings. The Population of Pune has increased from almost 3.8 million in 2001 to 5 million in 2011. (IIHS Analysis, based on census of India, 2011). Land surface temperature (LST) Maps show the change in city temperatures in relation to change in built-up areas and decrease in vegetation through summer correlations for April 2001 and 2016 (Parishwad & Shinkar 2017).

A wide range of locations within Pune city were examined to understand the extents of the land area required to simulate, for built spaces of varied heights and densities, for the study. As, the building and its full shadow are required for this study, each study grid was decided to be taken ahead as 130 meters by 130 meters. With lesser sized grid, shadows of taller buildings were falling out of the study area compared to the buildings with lesser heights. 36 such locations of Pune were identified for the study grid. The skyline of Pune city in 2012 had G+11 to be the approximate height of most tall buildings. G/G+1 structures are still evident in many other parts as godowns, slums, jails, residential headquarters etc. which have different densities and qualify as hot spots. Similarly, the core city showcases a skyline with G+4 building height approximately. These heights were therefore taken ahead and all locations were grouped according to their heights under G/G+1, G+4 and G+11 respectively. As the study targets building geometry to understand how its height and density affect the comfort levels in its surrounding, the above building height groups are further classified based on their density - Sparse, Medium, Dense and V. Dense.

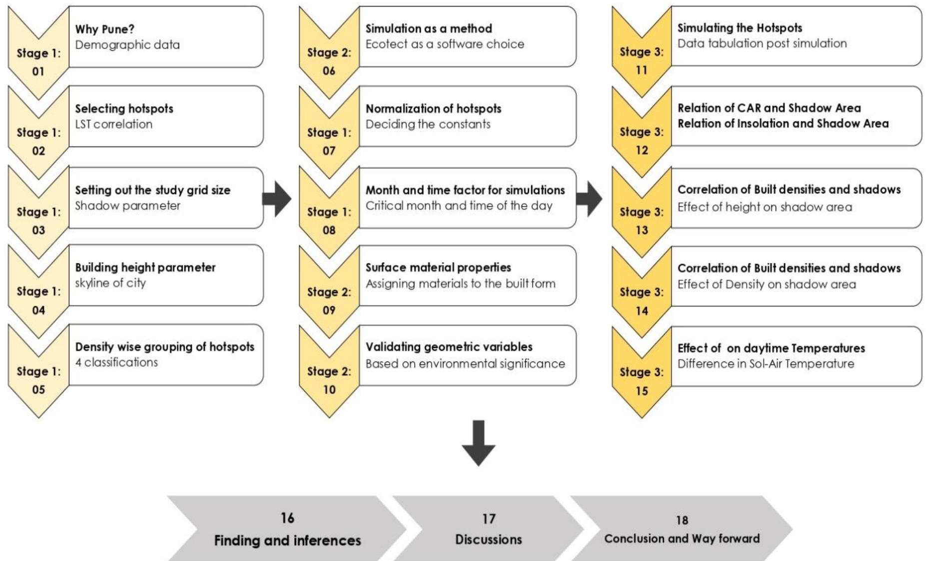


Figure 4: Flow chart of important stages and steps of the Experiment

In the study, building typology, surface material properties, plant cover are kept constant across each hotspot. In reality, the heat transfer from a building due to its activities affects the surrounding temperature levels. However, to draw accurate inferences regarding built geometry will not be possible if these heat transfers are allowed to interfere with the readings of the study. Therefore, the heat gain and losses from a building are not considered while simulating for solar radiation values by considering the built masses to be sealed zones with no openings. Similarly, the building type, vegetation in the grid area and around, distance and height of neighboring masses, social, cultural and economic influences are also not considered. The simulations were taken ahead in the following way:

Summer data and the month of May are considered to study the influences during the hottest time of the year. As the UHI effect reaches its peak during the hottest time of the year, building shadow influences during this crucial time is thought favorable. Assessment of solar insolation and percentage of shading were done on the hot spots between the cut-off hours of 10 00 hr. to 1600 hr. The average daily solar insolation received on the areas were recorded

The shadow areas are calculated by taking the average of shadow area percentages at the two important times of the day i.e., average of 10.00 AM and 4.00 PM. To understand the effect on shadows falling only on the horizontal plane, the ground plane where most of our movement takes place, is considered initially. So, the daily insolation values on Horizontal plane Wh/m2) are used further in analysis. To see the relation of shadows and built masses, the surface properties of building elements are also required to be the same. Therefore, the materials were kept constant and were chosen from the Ecotect material library.

Four geometric variables were considered in the calculations. Some of them are known to be related to environmental performance like solar insolation while others are purely geometric measurements for the built environment (Figure 5).

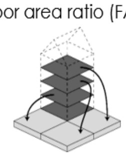
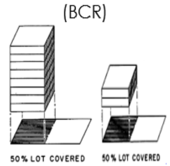
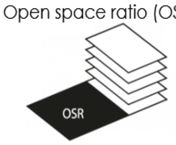
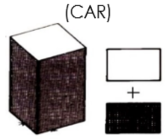
Geometric variable	Definition/ formula	Environmental significance
Floor area ratio (FAR) 	It is the ratio of the total floor area of the building to the area of the land on which it is located.	It is a building density parameter which considers the impact of vertical surfaces in urban areas due to high-rise buildings. FAR has obvious implications on urban climate and reflects the number of obstacles that affect air flow.
Building coverage ratio (BCR) 	It is the percentage of the total ground area of a site occupied by the building or structure as measured from the outside of its external walls.	Built footprints obstruct urban wind flow and increase thermal mass of urban fabric that could heat up the neighborhood. The land covered by buildings cannot be planted, So the land coverage is a relevant factor in evaluating the climatic effect of urbanization.
Open space ratio (OSR) 	It is the percentage of open space to the area of the land. An open-to-sky space without a roof is considered an open space.	The location, size, distribution and surface nature of open spaces could change the local environment by altering the air flow, humidity and heat balance with the urban canopy layer.
Complete aspect ratio (CAR) 	It is the sum of all surface areas of the building (including the area of rooftops) divided by the total building footprint area.	The temperature of the air surrounding the building is affected by the temperatures of both horizontal and vertical surfaces. This multiple impact and the magnitudes of the effects of individual factors are very difficult to determine.

Figure 5: Table of geometric variables considered in the study Infographic: Author’s original.

Building envelopes in terms of complete aspect ratio may impact heat gain or discharge, but can reduce urban ventilation. Amount of surface area exposed to direct solar radiation changes for different densities (Figure 6).

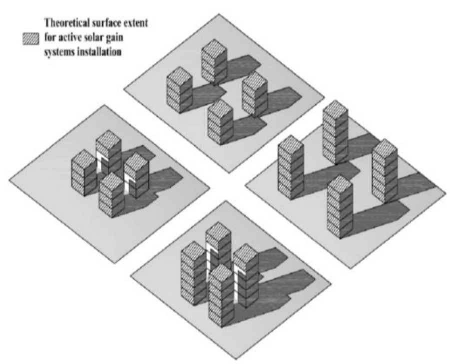


Figure 6: Illustration variation of total surface areas exposed to direct solar radiation
in different densities
Source: Mazzucchelli & Lucchini, 2012

Simulations And Extraction Of Results

The 36 chosen cases were modeled and simulated in Ecotect following all the mentioned considerations and assumptions. For the reference of the reader on how the data is acquired and tabulated post simulation, one location is shown as a process. (Figure 7). The data was then used to find the values of each considered geometric variable for each location. These calculations for the sample location are shown in figure 8.

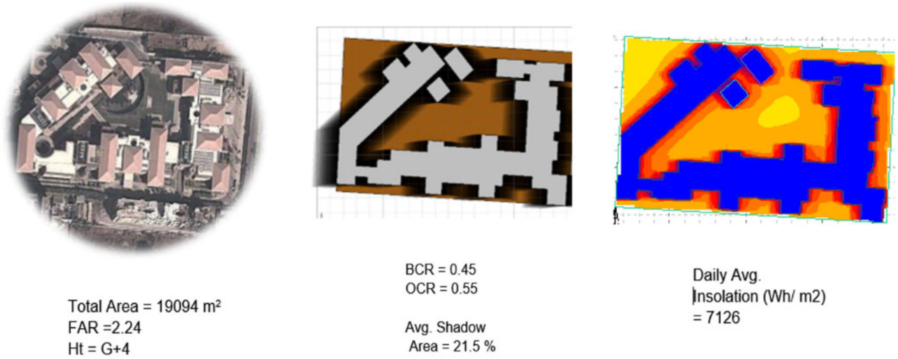


Figure7: Sample illustration of one location i) Existing satellite image and the spatial configuration ii) Shadow range on the hottest day of the year iii) Insolation graph

Sample Location	Total Area (m2)	Total Open Area (m2)	Built Foot print (m2)	Built up area (m2)	Built Perimeter (m)	FAR	BCR	OSR	CAR	Avg. Shadow Area	Avg. Daily solar exposure on horizontal plane- Insolation (Wh/m2)
Suzlon campus (Dense / G+4)	19094	10541	8553	42765	1194	2.24	0.45	0.55	1.45	21.5	7126

Figure 8: Table showcasing values of each Geometric variable for one location

Scatter plots for correlations are used. The relationship between the geometric variables (FAR, BCR, CAR, OSR) and average daytime Shadow areas during the day in summer are explored further. According to the results, CAR has the highest positive correlation with shadow areas by correlation coefficient (R2) 0.70 (Figure 9) while Insolation has a negative correlation with Shadow areas by 0.67 (Figure 10). A positive coefficient indicates that the variable has a positive effect on CAR or that the shadow area increases with the increase of the value of CAR. Whereas, a negative coefficient indicates that Insolation values decrease with the increase in value of CAR. CAR shows an indicative trend but the correlation is affected by 8 outliers. Vast differences were seen in the insolation values of a few locations. The reason for these locations is that the overshadowing takes place. Overshadowing does not happen for the rest of the locations. Moreover, logically a stronger relation might have been established between CAR and Insolation and CAR and shadow areas if it were not for these outliers. Also, The study accounts for existing orientation of the buildings as an aspect that cannot be altered.

Effect of built-up density on the amount of shaded area: To find a relation between height of the built masses and the shadows they cast, the densities have to be uniform. As there are four varied densities in question, four separate correlations are drawn of CAR against Shadow area %, each with varied heights (Figure 11 - A, B, C, D). The correlation coefficient (R2) established for each constant density i.e., Spare, medium, dense and very dense are 0.72, 0.89, 0.65 and 0.008 respectively.

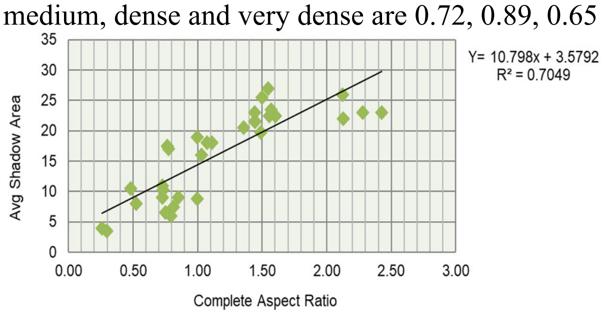


Figure 9: Graph showing the relation between CAR & Average Shadow Area (%)

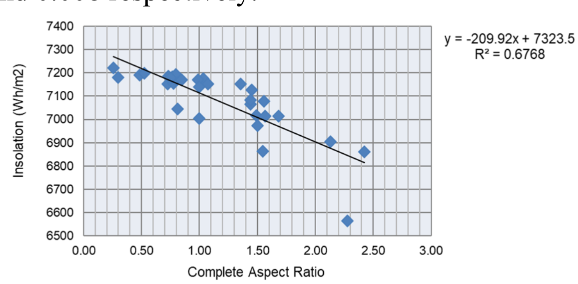
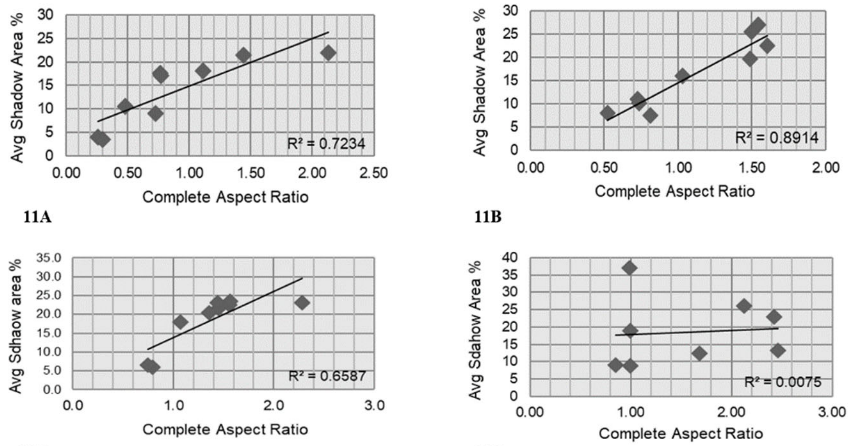


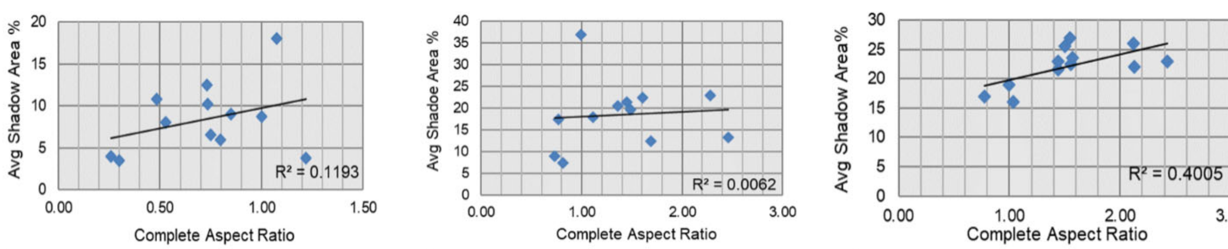
Figure 10: Graph showing the relation between Daily local insolation falling on horizontal plane & CAR

Similarly, to find the relation between densities of the built masses and the shadows they cast, building heights have to be kept constant while plotting the correlation. Therefore, the relation of CAR to Shadow area % was done separately for every height category with each varied Densities (Figure 12 - A, B, C). The R2 values that are generated from the graphs for each constant height i.e., G+1, G+4 and G+11 is 0.12, 0.006 and 0.4 respectively. The correlation of different heights to the shadow areas is stronger (when built up-density is kept constant) as compared to the correlation of different densities to the shadow areas (when building height is kept constant). Therefore, we can say that change of height of the built mass will increase the shading potential as compared to the effect of variation in densities. As CAR increases, the surface area of the built mass increases contributing to more shadow area and hence lowering the incident solar radiation on the ground plane which is beneficial.



11C 11D

Figure 11: Graphs showing relation of CAR with average shadow area (%) for all locations under (A) Sparse category, (B) Medium category (C) Dense category (D) V.Dense category



12A 12B 12C

Figure 12: Graphs showing relation of CAR with shadow area (%) for all locations under (A) G/G+1 Category, (B) G+4 Category, (C) G+11 Category,

Effect of the amount of shade on daytime temperatures: When CAR increases, the surface areas contributing to the heat gain might also increase. So, the possibility remains that even though more shaded area is achieved, the temperature level of the entire premise might not considerably change. Hereafter, we also need to understand the cumulative effect of insolation on the outdoor temperatures. Another element influencing both air temperature and human thermal comfort is the radiant temperature which comes from the surface (Limor et al., 2009). To further establish the relation of shaded area to outdoor temperatures, the insolation values falling on buildings as well as the ground have to be considered. In order to relate the results in terms of their contribution to Urban Heat Island, the amount of solar radiation absorbed by that neighborhood is essential to be known. Thus, the locations were simulated again to acquire the absorbed radiation, the results generated are in terms of percentage of total surface in shade (horizontal and vertical surfaces) on any average day in the month of May (Summer). The insolation values obtained for the buildings are converted to sol air temperatures to gauge the impact of existing shadows and shaded surfaces on the outdoor temperatures. Sol-air temperature value gives similar understanding to the thermal effect of the incident radiation in question and this value is added to the air temperature. The reason being that the incident radiation increases the surface temperature far above the air temperature, dissipating some heat to the outdoors immediately. The phenomenon causes the outdoor thermal levels to rise or remain at a constant discomfort range. The below formula is used for this purpose.

$$Ts = To + \frac{I * A}{fo}$$

Where:
Ts = Sol-air temperature in °C,
To = Outside air temperature in °C,
I = Radiation Intensity in W/m2,
a = Absorbance of the surface,
fo = Surface Conductance (outside), W/m2 °C

Location		Avg. daily Incident radiation (0n objects) Wh/m2	Avg. daily Absorption Wh/m2	Absorption percentage %	Avg Shade %	Difference in Sol-Air Temperature Ts
Sparse						
G/G+1	Soldier Quarters	2012	917	45.6	57.0	9.47
G+4	Dhanukar Circle	1366	639	46.8	69.0	6.43
G+11	Magarpatta	2072	859	41.5	60.0	9.76
Medium						
G/G+1	Rangehill Quarters	1868	845	45.2	59.0	8.79
G+4	Huzurpaga School	1489	701	47.1	69.0	7.01
G+11	Hyatt Regency	2017	865	42.9	62.0	9.50
Dense						
G/G+1	Bungalows, Magarpatta	2096	866	41.3	69.0	9.87
G+4	Suzlon campus	576	247	42.9	93.0	2.71
G+11	Garden city	2119	887	41.9	60.0	9.98
V. Dense						
G/G+1	Shivaji Market	1887	779	41.3	64.0	8.88
G+4	Laxmi Rd Chowk	1271	510	40.1	77.0	5.98
G+11	Cognizant	1531	687	44.9	71.0	7.21

Figure 13: Table showcasing the difference in Sol-Air Temperature (Ts) across 12 locations.

The immensity of the surface conductance is because of the surface qualities and the velocity of the air passing over it. The greater value of Fo is desirable to reduce solar overheating. As the values are different for different orientations of walls, roof and ground, an average of all these has been calculated to consider in the formula. An average of absorbance values of the materials is considered for calculations. The obtained insolation values from the simulation are used to calculate the sol-air temperature values. While calculating, the outside air temperature (To) is kept constant for all. This helps to derive the difference between the sol-air temperature and outside air temperature (Figure 13). Correlations were drawn between the absorption values and the percentage area of surfaces in shade (horizontal & vertical surfaces) for all 36 locations (Figure 14). It suggests the trend that as the area of surfaces in shade increase, the absorption decreases. Parallelly, correlation between the average daily shade percentage and the daily sol- air temperatures for all the locations suggest that increase in the area of shaded surfaces affects the sol air temperature significantly (Figure 15). It shows a temperature drop of 4 degrees with an average increase of 20% of shaded surfaces. This indicates that increase in shaded area alone does not significantly benefit larger scale buildings as compared to also having more surfaces in shade.

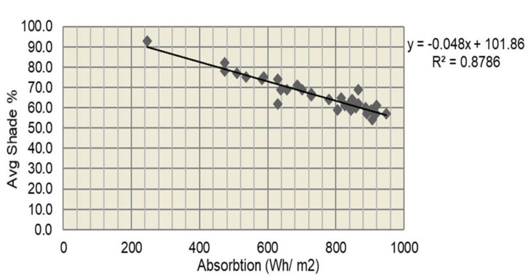


Figure 14: Graph showing relation of average daily absorption and the daily average percentage of shaded surfaces.

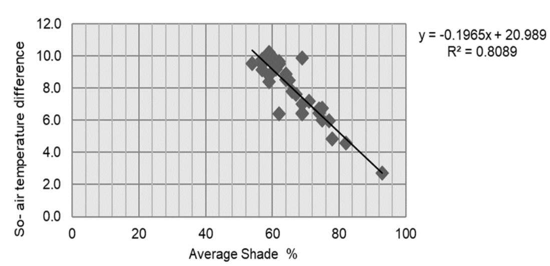


Figure 15: Graph showing relation between average daily shade percentage and the daily sol-air temperatures of all the places.

Findings And Inferences: Amongst all geometric variables, only CAR shows a strong indicative trend. As CAR increases, the Surface area of the built mass increases contributing to more shadow area and hence lowering the incident solar radiation on the ground plane which is beneficial. In such cases, the roads, courtyards, plazas etc. will be in shade. The correlation of different heights (when density is kept constant) to Shadow area is stronger as compared to the varied densities (when height is kept same). Change of height can definitely increase the shading potential as compared to the effect of variation of built density. With the attempt to increase the areas in shade and the surfaces that cast the shadow, the remaining surface areas exposed to the direct sun might also increase and would not help in reducing the Sol air temperature.

For the shadow potential to be exploited, going vertical will be beneficial when the surfaces that cast the shadows and the shaded area itself are more than the surfaces contributing to the heat gain. Reduction in absorption values impacts the sol-air temperature. The cooler surfaces do not contribute much in increasing the overall ambient temperature of the neighborhood. From the graphs we can see that with an increase in 20% of shade, 400 Wh/m2 of reduction in absorption. In high density areas, no strong relation was established between the shadow area and CAR. It means that even manipulation of height would have no benefit to provide in terms of shadows. The reason being that during the day, even if the surfaces are in mutual shade, the dense footprint accounts to an equal amount of exposed roof area that absorbs the radiation which cannot be properly dissipated. Therefore, when the solar radiation is kept low, the ambient temperature is low. The success of keeping neighborhood temperatures low is found to be in height variations of the urban morphology in an appropriate way. To ensure that the sol-air temperatures do not rise, urban geometry is one tool that can be used to mitigate the UHIE by achieving a balance between shaded surfaces, shadows and the exposed surfaces.

DISCUSSION

Nuruzzaman (2015) has effectively argued that shading due to trees is a mitigation strategy for UHIE. He links the destruction of trees with reduction in effective cooling of the outdoors and establishes that green vegetation through trees is the most effective mitigation strategy and other strategies can play a major role under the right conditions. His review recommends that shading is important to curb UHIE and its prominent consequences on human health and paves way for future studies that can examine shading potentials by built masses also. Trees and building shades may have different impacts on land surface temperatures (LST). Tree shades can be porous depending on the species of the tree as the sunlight penetrates among leaves and branches, whereas building shades are impenetrable. This suggest to do the shading simulation for the entire study without tree features also for comparison (Park et.al, 2021). The authors simulated the study with trees and built shades together and concluded that a larger building envelope area is the greatest contributor to LST and the areas of not-sun-facing façades mitigate the heat loads. They support their argument based on the results which showcase reduction by 0.032 ◦C per unit area of the façades not facing the sun which otherwise would contribute 0.068 ◦C to the local LST per unit area of its envelope, in the absence of the building shade. The built form in the hotspots of Pune city also exhibited similar results post simulation. CAR was found to be the most strongly correlating variable. Higher the CAR, higher was the insolation received. The locations with high CAR that showcased less insolation values are because of more non surfaces area in shade. A similar study (Yang et.al, 2021) involving tree cover and building shadow underlined the importance of built-up density in regulating ground temperatures. They argued that vegetation only affects the surface temperatures of patches with vegetation and of adjacent surfaces, if lower than vegetation height. They correlated ground surface temperature and sky view factor (SVF). Their observations were relatable to the Pune simulation / current study - The findings show that shadows caused by built forms of medium density, which relates to SVF as argued by Yang (2021), have significant positive impact on the surface temperatures, ambient temperatures and therefore the outdoor thermal comfort.

Throughout the study, the existing orientation of the built densities was taken ahead. However, all the orientations were not entirely in favor of the thermal comfort of the premise. Empirically, it is understandable that the most favorable orientation would be such that maximum surfaces remain in shade for the maximum amount of time, especially when the sun is intense. Later it should play a role to increase the shadows that it is casting. The built form shadow affects the comfort level in the immediate surroundings as the built form and open space are interdependent. However, Kui (2009) suggests that orientation might not have a significant impact on insolation if densities are not altered. CAR is therefore a factor of horizontal and vertical spread of density itself. In the case of Pune, the sol-air temperatures found are because of the effect of form on Insolation values. In the real scenario, these values would further reduce due to the presence of trees and the prevailing wind. Denser areas obstruct more winds, changing surface conductance and thus add more to heat trapping rather than the shade, shadows and insolation mitigation

CONCLUSION: SUMMARY AND WAY FORWARD

In the case of Pune, vertical growth is favorable with medium density of urban form. The municipal corporation of Pune city appears to favor vertical growth. Such comprehensive studies can provide recommendations in terms of building heights, surrounding masses, the built-up density, footprint of individual buildings, their orientations and material specification towards UHI mitigation. Analyzing Impact of the surroundings and their shadows on the targeted hotspots can help with more accurate parameters of medium density planning with focus on a neighborhood-scale assessment.

The main argument is that shadow potential is exploited to its fullest by achieving maximum shadows from the urban mass mitigating the sol-air temperatures, the entire neighborhood would remain comparatively cooler and many such pockets would help reduce the ambient temperature and the hot air dome over the city. The experiment conducted demonstrated the impact of change in building height and density and therefore the shaded area towards enhancing outdoor temperatures. This strategy alleviates the thermal discomfort in both highly urbanized areas and areas where urbanization is still in process. Similar methods can be adopted to find the influences of shadows for cities in different climatic zones and also for cities which are carefully planned. Reiterating (Andreou 2014) urban geometry is much more crucial at the microscope than thermal behavior of materials and the albedo. Improved shade coverage can enhance multiple aspects associated with a building, such as energy saving and habitat quality, and must be translated to understand the built morphology as a policy informing variable. The paper clearly mentions the main factors which would be affecting Urban Heat Islands and acknowledges the factors which haven't been addressed but do play a role in a real scenario.Therefore, it is suggested that modifying built forms to achieve a conducive shadow percentage and accentuate outdoor comfort can be integrated as characteristics of city planning towards UHI mitigation.

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PASSIVE MEASURES TO IMPROVE THE THERMAL ENVIRONMENT OF NEPALESE SCHOOL BUILDINGS DURING THE SUMMER

Mishan Shrestha[1], Hom Bahadur Rijal[2]

[1] Ph.D. student, Tokyo City University, Japan, born2winmission123@gmail.com
[2] Professor, Tokyo City University, Japan, rijal@tcu.ac.jp

ABSTRACT

It is important for students to have a comfortable indoor thermal environment in order to improve their academic performance and their health. But the concern is how to improve them by using natural resources with as little energy as possible. This study explores the impact of passive strategies that can be used in the early stages of the building to confirm how the building performs for thermal comfort and thermal environment, using a case study of a free-running school building in Nepal. A series of field studies were conducted in the school buildings located in the temperate climate of Nepal. For the case study, the base model was developed using Designbuilder software and validated using measured globe temperature and simulated operative temperature. After that, various kinds of strategies, such as natural ventilation, insulation, thermal mass, and so on, were applied and analyzed to identify the optimum condition. The indoor operative temperature was reduced to near the comfort temperature required during the day in summer. The designers should focus on passive design during the architectural design of schools, which could make the classrooms more thermally comfortable.

Keywords: School building, passive design, operative temperature, thermal comfort, simulation

INTRODUCTION

The school buildings have special characteristics compared to other buildings, as they are used mainly during the day. Under free-running conditions, the outdoor thermal environment has a high chance of influencing the indoor thermal environment during the day. So, an appropriate approach is required to create a comfortable environment while lowering the level of thermal discomfort, which is a key issue. Therefore, it is of great significance to evaluate the indoor thermal environment for improvement and to assess thermal comfort through field and simulation studies. There are various strategies to improve the thermal environment, such as active and passive, that can be used in the required climate zones to maintain thermal comfort and reduce energy use. Having sufficient knowledge of them potentiates energy-saving scenarios and thermal comfort.

The previous simulation studies conducted for educational buildings have validated and shown the effectiveness of passive design strategies in their respective climatic conditions to maintain indoor thermal environments as well as save energy. The previous simulation studies (Popescu et al. 2021, Zilberberg et al. 2021, & Taleb 2014) found that the improvements applied by passive strategies in existing buildings saved a significant amount of energy. Díaz-Lopez et al. (2022) identified from the literature review of the passive design intervention strategies in schools in 43 countries and Koppen climate zones. Such strategies were 24 in number, such as green roofs, thermal insulation, natural ventilation, shading, orientation, thermal mass, solar walls, Trombe walls, evaporative cooling systems, solar chimneys, wind catchers, and so on. Subhashini and Thirumaran (2018) explored a shading device design for warm and humid climates that reduced the heat gain from the windows and external walls and maintained the indoor air temperature. Galal (2019) found that the north, north-east, and north-west orientations could be suitable for heat gain and daylighting for the Lebanese climatic coastal zone. Mohamed et al. (2021) revealed considerable reductions in indoor air temperature from 30.3–44.8 °C before and to 18.9–26.5 °C after activating a passive wall system. Alwetaishi et al. (2021) observed that vertical shading is efficient shading from 7:00 to 9:00, and after that 45 vertical shade is more efficient to maintain the classroom temperature in the local climate of the hot region. Park et al. (2020) found that the phase change materials applied to the shading system reduced the cooling energy use by 44% and improved the number of thermal comfort hours by 34% in educational buildings. According to Stavrakakis et al. (2016), thermal comfort is improved during summer and energy savings are achieved by a cool roof in school buildings in warm climates. Lakhdari et al. (2021) found that the combined passive strategy of window-to-wall ratio, wall materials, glass types, and shadings can provide better thermal comfort in hot and dry regions. Ali and Hashlamun (2019) investigated the effect of insulation on indoor thermal environments in uninsulated old school and thermally insulated new school buildings. They found that the newly insulated school contributed more to lowering the average indoor air temperature.

Based on the literature review, several passive strategies employed in educational buildings have been identified that have improved the thermal environment and energy savings. But, this kind of study is overlooked in school buildings in Nepal. As Nepal needs to follow the medium path for sustainable development from the point of global environmental issues, the role of the passive design is one of the important aspects to improve the thermal environment of indoors (Shahi et al. 2021). Nepal is still in at a stage where it can rethink the passive design strategies to be used in the future using available ambient energy sources to reduce its dependency on fossil fuels, natural gas, coal, etc.

Research Questions and Objectives

A community-driven approach and a non-engineering approach are used to construct most school buildings in Nepal (Anwar et al. 2016), which in fact lack appropriate insulation levels, thermal mass, and other important thermal comfort features. What would be the thermal environment and comfort in those indoor spaces of school buildings? How to improve them? The effectiveness of passive design strategies has not been studied or considered to make the classroom thermally comfortable. Thus, it is necessary to carry out thermal performance studies to improve so that the impact of passive design can be known if new school buildings are to be constructed. A simulation study would be a better way to approach such a scenario. This study was conducted to fill the research gap and answer the abovementioned questions. Moreover, the results and recommendations obtained from the previous study cannot be generalized in the Nepalese context as it has a very diverse type of climate and geography.

This is the first systematic simulation study carried out to the best of the authors' knowledge to develop a comprehensive understanding of the indoor thermal environment in free-running Nepalese school buildings using passive design strategies. This paper aims to investigate the thermal environment and how passive design strategies are effective in maintaining the operative temperature at a level that is suitable for thermal comfort and the thermal environment.

METHODOLOGY

Description of Geography, Climatic Condition, and Buildings

Nepal has three topographic regions: the north is mountainous and Himalayan; the middle is hilly; and the south is Terai, with a cold climate, a temperate climate, and a subtropical climate, respectively. A field study was conducted in three school buildings located in Kathmandu and Dhading districts in the temperate climate of Nepal (Fig. 1a). But in this paper, because of the unavailability of weather data in the simulation software, this study has been restricted to choosing a school building located in Kathmandu as a case study, even though we have investigated other school buildings in Dhading, and collected data investigating the summer case. The outdoor air temperature in this area generally, decreases in October, reaching its minimum in January (Fig. 1b). In terms of temperature, rainfall, and humidity, June to September are the hottest, most humid, and rainiest months of the year. Figure 1(c) shows the simulated school building. The building is a one-story, pitched-roof structure that was naturally ventilated through windows. It is a private secondary school building and is representative of the commonly found school buildings around Kathmandu and other places in Nepal.

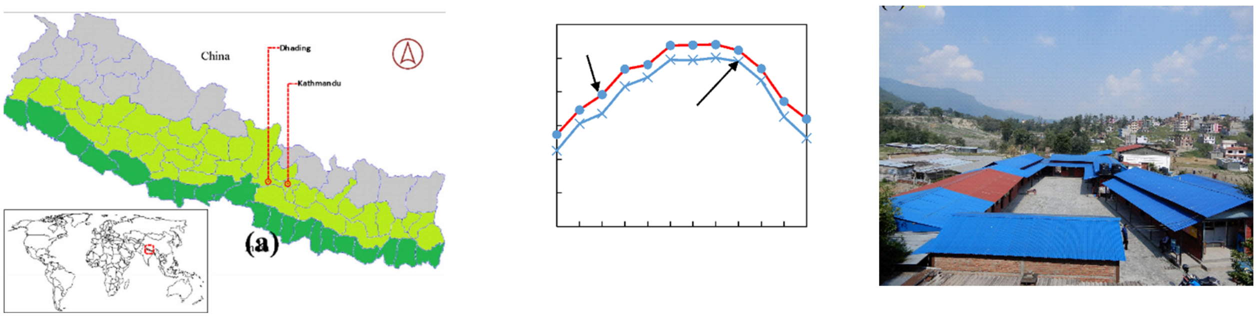


Figure 1. (a) Location of the study area, (b) Annual monthly mean outdoor air temperature and (c) bird eye view of the simulated building in Kathmandu

Thermal Measurement Survey

The measurement of indoor air, indoor globe, and outdoor air temperatures was conducted from May 21st to July 12th, 2019. The data logger automatically measured the data at every 10-minute interval in all classrooms. The indoor measurement was conducted in the middle of each classroom at a height of approximately 1.1 m, minimizing the influence of the students nearby. The outdoor measurement sensors of the data logger were protected from the direct effects of solar radiation and moisture sources. The information of the instruments is given in Table 1.

Table 1: Information of the data logger used

Description	Temperature-humidity sensor (TR-74Ui)		Globe thermometer (TR-52i)	Anemometer (Kanomax6501)
Sensor	Thermistor	Polymer-resistance	Thermistor	Hotwire
Range	0 to 55 °C	10 to 95%RH	-60 to 155 °C	0.01 to 5 m/s
Accuracy	±0.5 °C	5%RH [at 25 °C, 50%RH]	±0.3 °C	±0.02 m/s
Resolution	0.1 °C	1%RH	0.1 °C	0.01 m/s
Response time	Approx. 7 min.	Approx. 7 min.	Approx. 80 sec. in air	Approx. 7 sec.

Calculation of Operative Temperature

Operative temperature is required to describe the actual thermal environment and comfort conditions. Using the measured indoor air temperature, globe temperature, and air velocity on the survey day, the operative temperature was calculated using the method given in ISO 7730 (2005). A strong relationship between the globe and the operative temperature (R^2= 0.99) is found, as shown in Fig. 2. Kazkaz & Pavelek (2013) found that the globe temperature is equal to the operative temperature in the range of air velocities greater than 0.20 m/s and that the difference between the mean radiant temperature (MRT) and air temperature is less than 10 K. This implies that the globe and the operative temperatures can be used interchangeably. The difference between MRT and air temperature in the simulated classroom at 11:00, 13:00, and 15:00 was 0.2 K, 2.2 K, and 0.3 K, where the average air velocity was 0.20, 0.32, and 0.38 m/s, respectively.

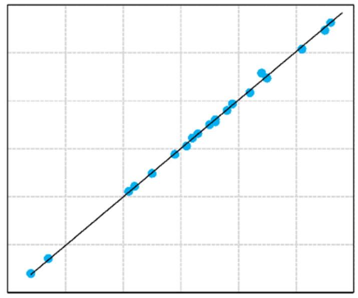


Figure 2: Relationship between operative temperature and indoor globe temperature

Thermal Comfort Survey

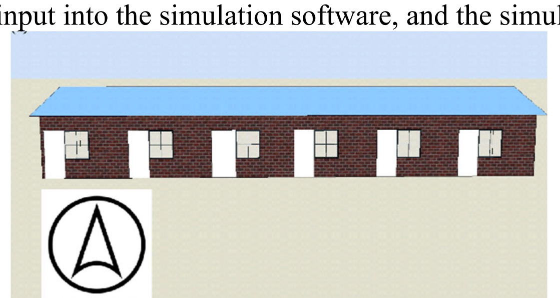
Thermal perceptions were asked to 256 students who participated in the whole survey, ranging in age from 12 to 18 years, from the seven classrooms in three school buildings in Dhading and Kathmandu districts. Students from grades 9 and 10 participated in the case study building, with 19 and 14 students being accommodated, respectively. We used a seven-point thermal sensation scale and a five-point preference scale, as shown in Table 2. The students voted at 11:00, 13:00, and 15:00, and we collected 737 responses in total for each question.

Table 2: Thermal comfort survey scales

Scale	Thermal sensation	Thermal preference
1	Very cold	Much warmer
2	Cold	A bit warmer
3	Slightly cold	No change
4	Neutral	A bit cooler
5	Slightly hot	Much cooler
6	Hot	
7	Very hot	

Thermal Simulation of the School Building

This study used Designbuilder (v6.1) in conjunction with EnergyPlus (v8.9) to design buildings and carry out the simulation. The Energy Plus Weather (EPW) data file of a typical metrological year (TMY) of Kathmandu (Tribhuvan international airport station) loaded in the software is used for simulation. The simulated building is located around 8 km away from the weather station. Fig. 3 shows the 3D view of the simulated school building and classroom with the main façade oriented towards the south. The length, breadth, and height are 18.6 m, 3.8 m, and 2.4 m, respectively. The description of the case study classroom and the building is shown in Tables 3 and 4. All the components mentioned in the tables were input into the simulation software, and the simulation for Zone 3 was performed.



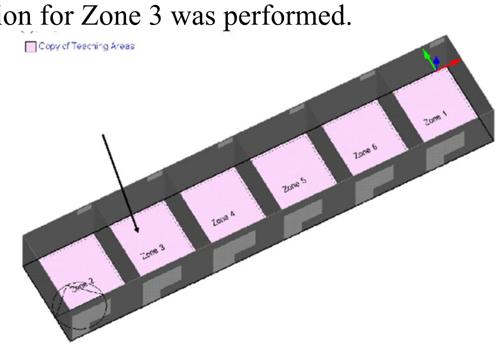


Figure 3. Case study: (a) Building and (b) classroom (zone 3)

Table 3: Input data description

Classroom description	Input data
Floor area	11.78 m^2 (3.1 m x 3.8 m)
Height	2.4 m
Window 1	0.91 m X 1.08 m (South)
Window 2	0.61 m X 0.30 m (North)
Door	0.76 m X 1.8 m (South)
Number of students	14
Occupancy density	1.6 students/m^2
Activity level	Seated
Minimum fresh air	8 l/(s.p) (ASHRAE 2016)
Airtightness	1 ACH
Natural ventilation (windows, door)	59 ACH (Shrestha et al. 2022), 9:30 to 17:30
Occupied period	Sunday to Friday, 9:30 to 17:30

During the break, no occupancy was taken.

Table 4: Description of the building materials and their thermal properties

Component	Description	Thickness (mm)	U-value [W/(m^2.K)]
External walls	Brick, internal cement plaster	102	3.2
Internal partitions	Cement plaster, brick, cement plaster	102	2.3
Floor	Cement/plaster/mortar, brick, soil-earth, common	165	2.4
Ceiling	Plywood	18	3.8
Roof	Zinc	3	7.1
Glazing	Clear type glass	6	5.7

The model is validated using the measured globe temperature and the simulated operative temperature using the result from the base case (zone 3). The accuracy of the model was checked using the room mean square error (RMSE). It measures how close the simulated and measured values are. After validating the base model, various passive strategies were employed. Individually, each passive strategy is investigated separately, keeping other components unchanged.

THERMAL COMFORT OF STUDENTS

Thermal Environmental Measurement during the Voting Time

Continuous environmental quantities were measured in order to observe the trend of temperature and relative humidity, but we only present one-week temperature (2019/5/29 to 2019/6/4) here. The measured indoor air and globe temperatures were quite close and did not change much. Both indoor globe and outdoor temperatures displayed a similar pattern of variation. The maximum indoor temperatures that follow the outdoor air temperature start to occur after 12:30, which is around 30 °C. At the same time, the outdoor air temperature amplitude during the day reaches a maximum of more than 31 °C. The indoor and outdoor temperatures differed among buildings due to their architectural characteristics, orientation, geography, climatic conditions, and so on.

Thermal Sensation and Preference

This section discusses how students perceive thermal environments, as described in the previous section. Fig. 4 shows the overall distribution of thermal sensation and preferences of the students in the investigated three buildings. It shows that most of the responses were towards the hot side, with most preferring a cooler environment. The results showed that 63.6% of the student's responses were within the central three categories, which is representative of satisfaction and acceptance. The responses of the students in the classroom (zone 3) showed that the highest responses of 43.3% and 33.3% were obtained at "5. Slightly hot" and "6. Hot". 54.5% of the student's responses were within the central three categories. The preference for “3. No change” was 21.8%. The responses of 48% and 27.8% were obtained at “4. A bit cooler” and “5. Much cooler”. In the classroom (zone 3), 61.6% and 23.2% of students responded with “4. A bit cooler” and “5. Much cooler” with 15.2% for “3. No change”. The significant number of responses on the hot side and the preference for the cooler environment are issues of thermal environment and comfort in the school buildings. The comfort temperature of the students based on their thermal sensation responses was estimated using the Griffiths method (Griffiths 1990 & Humphreys et al. 2013), which is 26.9 °C. The perceived comfort temperature is high, which must be because of their greater status of adaptation and tolerance to indoor temperature. The average comfort temperature is very close to both the average daytime indoor air temperature (28.0 °C) and the average globe temperature (28.1 °C). However, there are higher than 28.0 °C indoor temperatures and they need to improve.

Figure 4. Distribution of (a) thermal sensation and (b) preferences

THERMAL IMPROVEMENT OF THE CLASSROOM

Thermal Environmental Analysis Based on On-site Measurement

Fig. 4 shows the continuously measured indoor air, globe, and outdoor air temperature variations of the simulated classroom (zone 3) for seven days. The indoor air and globe temperatures did not differ significantly and were quite close on all seven days. But, the variations in outdoor air temperature were a little bit sharp relative to the corresponding indoor air temperature. Both indoor and outdoor temperatures displayed a similar pattern of fluctuation, with the highest temperature peaks occurring during the day. The figure confirms that the maximum indoor temperatures that follow the outdoor air temperature start to occur after 12:30, which is around 30 °C, and from this point on, the temperature decreases. At the same time, the outdoor air temperature amplitude during the day reaches a maximum of more than 31 °C, while it reaches a minimum of less than 20 °C at night. The indoor relative humidity ranges from 38 to 76% and that of the outdoors from 28 to 87%. The students are exposed to the range of indoor relative humidity of 38 to 66% from 10:00 to 16:00.

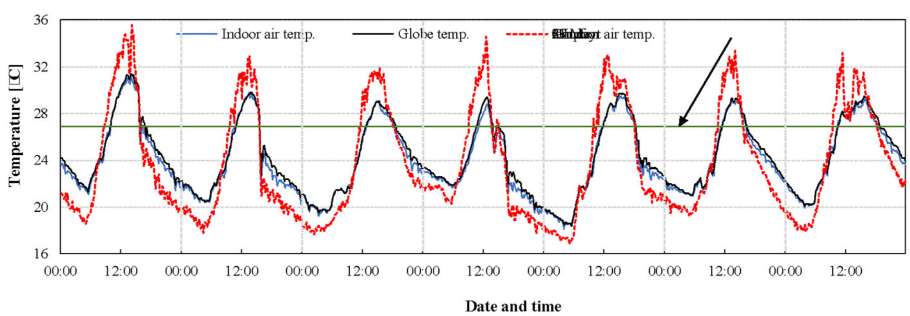


Figure 4. Variation of daily indoor and outdoor temperatures in Kathmandu

As discussed in the previous section, the students are discomfort in high temperatures. This section, therefore, analyzes a few passive strategies to reduce the temperatures of the case study building. The base model is validated using the measured globe and simulated operative temperatures using the results from zone 3 of June 4, 2019. Based on the analysis, good agreement has been found between the measured globe temperature and the simulated operative temperature, with a correlation coefficient of 0.96, which shows the reliability of the simulated operative temperatures. Further, the RMSE value was found to be 0.074. It confirms that the base model is useful for the prediction of the operative temperature fluctuations according to the passive design applied.

Natural Ventilation

It was found in previous studies that the ventilation in naturally ventilated spaces can reach higher levels, up to 160 ACH, if adequate cross ventilation is provided (Rijal & Yoshida 2005, Jin et al. 2015). The recommended ventilation in a school is approximately 5–6 ACH based on typical room sizes and occupancy (ASHRAE 2016). But due to the design of the classrooms, the ventilation is not the same as expected. In the base model, 59 ACH was used, which was estimated as the average ACH value for the classroom in the previous study (Shrestha et al. 2022). A series of values of 20, 40, and 80 air change rate per hour (ACH) were tested to investigate the impact of ventilation on operative temperature. Fig. 6 shows that the operative temperature decreases as the ACH increases and becomes minimal beyond 59 ACH. The maximum temperature for the 80 ACH is approximately 1 °C lower than the base model. Tong et al. (2021) found that ACH could reach up to 91 in a free-running room that is suitable for maintaining the indoor air temperature. Yik et al. (2010) found that in a well-ventilated indoor space with approximately 50 ACH, the indoor air temperature can be kept below 28 °C without using cooling.

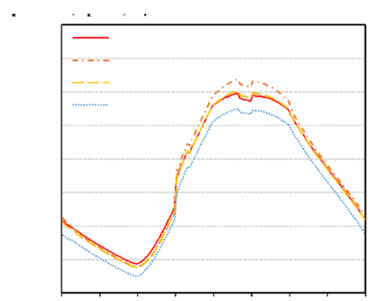


Figure 6. Impact on operative temperature due to natural ventilation

Thermal Insulation in External Wall

Table 5: External wall insulation made of expanded polystyrene (EPS) and their thermal properties

EPS thickness (mm)	U-value [W/(m^2.K)]
50	0.71
100	0.40
150	0.28
200	0.21

Various thicknesses of expanded polystyrene (EPS, lightweight) were applied to the base model to investigate their effects on operative temperature. It was applied to the outer surface of external walls of various thicknesses (Table 5). Thermal insulation with various thicknesses resulted in a low operative temperature because of a low total U-value as compared to the base case [3.2 W/(m^2.K)]. Fig. 7 shows the improvement in operative temperature after using it. The maximum operative temperature for EPS 20 cm is 1.7 °C lower than for the base model. According to Lu et al. (2021), outside-positioned insulation appears to have a greater effect than inside-positioned insulation with the same wall thermal resistance. Kolaitis et al. (2013) found in a numerical study that outside-positioned insulation resulted in approximately 8% higher annual energy savings than inside-positioned insulation.

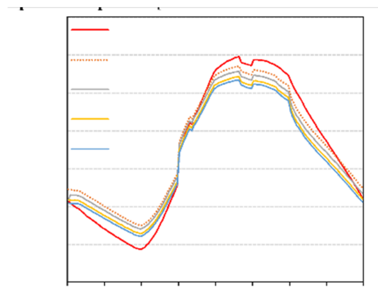


Figure 7. Impact on operative temperature due to external wall insulation

Thermal Insulation in Ceiling

The building had only 18 mm of white-painted plywood as thermal insulation below the pitched roof as its ceiling. Later, we applied 5 to 20 cm of lightweight EPS (Table 6). Fig. 8 shows the operative temperature fluctuation after applying the insulation. The impacts on operative temperature were weak for 5 cm EPS. The reason might be that the ceiling already has 18 mm of lightweight plywood as the thermal insulating material. But, for 10, 15, and 20 cm EPS, the temperature is reduced during the day. The maximum operative temperature for EPS 20 cm is 2.2 °C lower than for the base model. The insulation was applied to the outer side (pitched roof side) of the ceiling. Especially during the daytime, due to solar radiation, the zinc roof is heated up, and ultimately the surface temperature increases. The results showed that the indoor temperature can be reduced by using insulation.

Table 6: Ceiling insulation made of expanded polystyrene (EPS) and their thermal properties

EPS thickness (mm)	U-value [W/(m^2.K)]
50	0.74
10	0.41
150	0.28
200	0.22

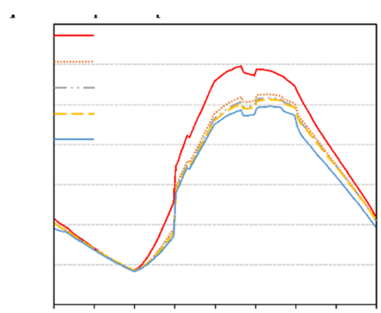


Figure 8. Impact on operative temperature due to ceiling insulation

Thermal Mass in External Wall

Table 7 shows the thickness of cast concrete and the total U-value of the wall after they are applied. Fig. 9 shows that the use of cast concrete (dense) as thermal mass in external walls reduced the operative temperature. At 14:00, the maximum operative temperature is 2.4 °C lower than the base model for cast concrete, which is15 cm. The impact of a thicker thermal mass has less swing than the impact of a low-thermal mass on operative temperature, which follows the outdoor air temperature pattern. The operative temperature is shifted to a later time, so-called thermal lag, which is due to the storage of heat in walls and increases the time of heat release from the outside to the inside. The figure shows that the temperature is higher after 16:00, which is almost the end of the lecture in the school. Zahiri and Altan (2016) suggested using thicker thermal mass to reduce the indoor air temperature during the summer.

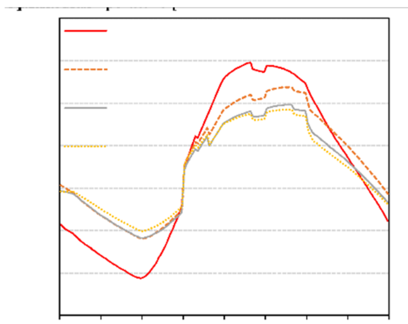


Figure 9. Impact on operative temperature due to ceiling insulation

Table 7: Thermal mass applied to the base case and their thermal properties

Thickness of cast concrete (mm)	U-value [W/(m^2.K)]
50	2.9
100	2.6
150	2.3

CONCLUSIONS

This study was conducted to investigate the thermal environment and improvement using passive design strategies of a free-running school building located in the temperate climate of Nepal. The results showed that the students perceived the hot environment and preferred the cooler environment where the globe temperature reached around 30 °C. The simulation results showed that the maximum operative temperature improved during the day due to natural ventilation, external wall insulation, ceiling insulation, and thermal mass was 1 °C, 1.7 °C, 2.2 °C, and 2.4 °C lower than that for the base model, respectively. The results showed that the temperature was maintained at a close to comfort temperature of 26.9 °C. Therefore, it would be wise to prioritize such strategies to maintain thermal comfort in classrooms. The findings of this study are useful to improve thermal comfort and energy usage in various localities where new school buildings are being constructed.

ACKNOWLEDGMENTS

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DEVELOPMENT OF NOVEL CONCEPT OF ZERO RADIATION SMART BUILDING AND SMART CITIES

Reshna Raveendran[1], Kheira Anissa Tabet Aoul[2]

[1] United Arab Emirates University, Al Ain, UAE, reshnaraveendran@gmail.com
[2] Professor, United Arab Emirates University, Al Ain, UAE, kheira.anissa@uaeu.ac.ae

ABSTRACT

Radiation produced inside smart buildings and smart cities with 5G and the Internet of Things (IoT) is a newly discovered concern as WHO and scientific evidence indicate that the radiation may cause unintended health problems such as tumors and cancer. Currently, sustainability rating systems such as LEED, BREEAM, Estidama or WELL do not consider this radiation aspect though they consider several environmental and health problems. As smart buildings and smart cities are about to become a reality, innovating the design to create a zero radiation smart building helps overcome many health and environmental problems. The novel concept of 'zero radiation smart building' design is one among the first to discuss how to design a building that is both smart and 'safe' besides providing wired connectivity. Different indoor and outdoor design features ranging from zoning in buildings, selection of building materials to landscape design are explicitly modelled to show how radiation generated in a smart building can be made zero. This idea utilizes Computer Simulation technology (CST) and 3D modelling software to showcase how radiation can be reduced to zero for a smart building. The proposed innovation idea is to mitigate EMR impact on humans and the environment in smart buildings and smart cities.

Keywords: Radiation, Smart Buildings, CST, Health, IoT, 5G

INTRODUCTION

Smart buildings are the most modern form of buildings and improve intelligent buildings. Smart buildings are defined as those advanced forms of buildings that utilize artificial intelligence (AI) to provide such structures with the leverage to be flexible, adaptive, and responsive while offering real-time control to users (Cook and Das, 2007) (Kiliccote, Piette and Ghatikar, 2011). These buildings are often seen as an upgraded form of intelligent structures. It also collects data about how and when a building is being used and provide a real-time picture of the status of a building. They deploy several sensors and automation as part of their operations, process data and provide realistic feedback regarding the building's performance to the users (Sinopoli, 2010). As an added advantage over conventional buildings, smart buildings also intend to reduce operating costs and energy consumption and connect to the smart grid (Wang *et al.*, 2012).

Countering the claims about the benefits attributed to smart buildings, researchers and environmentalists believe that there are also negative aspects of these smart buildings that are important yet not found to be given the same weightage as the benefits. Some reported negative aspects include cybersecurity concerns (Ghayvat *et al.*, 2015) and radiation effects. individually or as a group of countries such as Germany, Netherlands, Australia, the European Union (EU), have demanded an impartial assessment of human health, especially from radiation, before a widespread retrofitting to smart buildings. These countries have also opinioned about their concern related to data security implementing 5G (Chamberlin and Roberge, 2020). Other identified threats involved with smart cities include e-waste accumulation, proliferation of under-seas cables and datacentres. These negative threats also needed to be documented and researched further before wireless smart buildings and smart cities with high frequency can be used.

Generally, research studies have been limited to a few and isolated ones where actual EMR measurements have been carried out in cities (Urbinello *et al.*, 2014). Research publications related to buildings and EMR also remain scarce as the few studies that were done were focused on signal path loss and attenuation imposed by building walls, i.e. the target of these papers were to verify wireless data transmission without significant path loss for the indoor and outdoor environment (Ghassemzadeh *et al.*, 2003). Since millimeter frequency IoTs and buildings are not yet developed, no actual measurements can be known beforehand. Nonetheless, several researchers have pointed out that the generic solution they prescribe is to have a wired connection or even have a hybrid (wired and wireless) connection. However, even wired connection will not work as there may be a presence of 'dirty electricity', using unshielded ethernet cables (UTP). Also, these studies did not consider the internal radiation propagation inside smart building. Only a few studies have directly associated the environment and smart buildings. However, indirect correlations have been made between global warming and usage of radiation technology such as military equipment, medical scanners, Wi-Fi, microwave ovens and associated acceleration in CO2 emissions. The indirect impacts derived from the meta-integrative study revealed master themes such as electromagnetic pollution, under-sea cables, datacenters discussed the potential influence on ecology (Raveendran and Tabet Aoul, 2021). For instance, water, soil, vegetation has been found to absorb and react to external radiation.

Researchers also suggested that schools and offices with heavy internet users to be designed to provide hybrid internet service (Clegg *et al.*, 2020). Some studies reported that shielding the building by using appropriate building materials that are opaque to radiation transmission may be used (Panagopoulos and Chrousos, 2019). None of the sustainability rating systems, government policies, or environmental authorities have considered this problem. A previously developed solution only considered shielding interior building materials or wired connectivity instead of holistic consideration. It failed to recognize how to address this problem from an environmental perspective or implement it in sustainability rating systems like LEED, and WELL. This innovative proposed concept of 'zero radiation smart buildings/cities aim to facilitate technologically laced smart buildings and smart cities that are safe, smart, and sustainable.

METHOD

There are two ways to nullify the radiation sourced from inside and outside the building. The following sections separately explain the radiation nullification or mitigation of both interior and exterior sourced radiation generated in a smart building. The interior sourced radiation refers to the radiation produced indoor by IoT devices, smart gadgets. In contrast, the exterior source of radiation refers to the incoming radiation from outside, including from nearby smart buildings, smart vehicles and cellular towers. The strategies proposed for reducing the interior sourced radiation are wired connectivity, zoning in design, shielding effectiveness of interior building materials. The strategies proposed for mitigating the exterior sourced radiation are landscape design, bio-geometric shapes, exterior shielding of building materials.

Proposed Novel concept of zero radiation smart building - interior source reduction

The following section explains the different proposed strategies for reducing interior sourced radiation. The methodology for the proposed performed in Computer Simulation Technology Electromagnetic Suite software (CST-EM).

Wired Connectivity

One of the most common recommendations for reducing radiation in buildings found in research papers is to have a wired connection (Clegg *et al.*, 2020). Wired internet connection, say, the generic ethernet cable produces a significant amount of radiation known as 'dirty electricity'(Havas, 2007), similar to those produced by general power outlets used by household appliances such as television monitors and hair dryers (Williams, 2018). However, the EMF generated in the wired cables is different from wireless radiation. Radiation from the wire occurs as a result of the current flow inside the cable (if it is made of copper)

(Kharote and Ramachandran, 2016) or in light pulses (in the case of optic fibre) (Horak and Poletti, 2012). Radiation from wireless also happens as a result of the operation of antennas and the operational frequency they use to send data packets through electromagnetism by air (Horak and Poletti, 2012).

The frequency used in ethernet cables are lower than that of Wi-Fi antennas, and several categories of wires are available, like CAT 5, CAT 6, CAT 7 (where CAT represents the category). The frequency also varies within each category; for example, CAT 6 uses 250 MHz (Azadet *et al.*, 2000), and Cat 7 uses 600 MHz (Langat *et al.*, 2011). The cables are commercially available in two types, Unshielded twisted pair (UTP) and Shielded twisted pair (STP) (Schulz *et al.*, 2016). STP diminishes the EMF produced by these cables (Schulz *et al.*, 2016), and thus using STP instead of UTP can reduce the indoor radiation almost to zero. Furthermore, utilizing CAT 7 or CAT 8 STP ethernet cables can ensure better radiation mitigation than using older versions like CAT 5 or 6 (Georgevits, 2017). As each product improves, lesser EMF is generated.

It is, thus, imperative to note that even wired cables can produce EMF if not appropriately shielded. Besides, another advantage provided by wired cable is better internet connectivity with less data loss during transmission. The wired cabling can be provided inside walls, thus removing any unsightly condition created by loose cables. Besides, interior furnishings (office desks, conference tables, etc.) are also commercially available to accommodate several LAN connections for flexible building design. For non-flexible construction design, designers can utilize the wired connection to provide a safer indoor dwelling space (Tabet Aoul and Raveendran, 2022).

Zoning in building design

In commercial and office spaces, completely wired design may not be considered optimal. In such cases, where building spaces can be complex, like a mall or stadium where indoor wiring for all devices cannot be possible. Therefore, a hybrid design is proposed to be a viable option (Clegg *et al.*, 2020). Hybrid design for smart buildings, is a relatively new concept, involves strategically using both wired and wireless design for smart buildings, thereby reducing the total EMR generated within the building. Zoning such a hybrid design can further reduce radiation, thereby protecting the occupants who use the wired internet connection from EMR while concurrently allowing them to use smart wireless devices as needed. This prospect can also be applied to regularly occupied spaces in schools, universities, hospitals and similar mixed-use facilities. Two of the design layouts with hybrid combination is given in figure 1 below, the same design layout is later tested to determine the interior finish materials' shielding effectiveness in mitigating EMR in section 2.1.3.

The first office design considers wireless to be provided only in the reception area, hence separate wireless router is placed for the reception and rest of the office interior space. The second design includes wireless design in the meeting room, but the meeting and reception area is so arranged in a way that wireless connectivity is contained in an entirely separate zone so that other interior spaces will not be influenced by the wireless radiation.

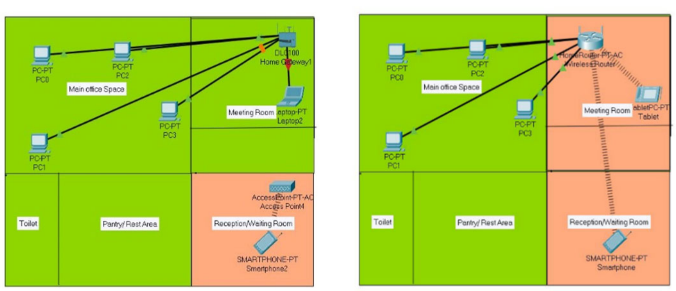

Figure 1. Design Layout for hybrid connection in an office.

Interior building Materials with Shielding Effectiveness

The third design element is the interior building material that must be carefully selected to provide good shielding effectiveness from the wireless zone to the wired zone, lest radiation penetrates the wired (radiation free zone). All materials have concomitant electromagnetic properties, including natural and artificial building materials (Ferreira *et al.*, 2014). Wood, concrete, and glass are the dominant materials used in building construction, and t have varying electric and magnetic fields, which are dependent on the frequency at which they are exposed (Cuinas *et al.*, 2000). Thus, as frequency changes, the electromagnetic properties of these building materials also change, and this is linked to the way they absorb or reflect radiation they received. The simulations were carried out for two frequencies 2.45 GHz (4G) and 6 GHz (5G).

For the design layout in figure 1, a model was created in Sweet Home 3D, which was later imported to CST (figure 2). Wireless excitation was provided by importing field sources of needed frequency. Finally, materials were reassigned to match the operating wireless frequency, the simulation was run. Shielding effectiveness (SE) was calculated by the following equation,

$$SE = 20\, log\, log\, \frac{[E_1]}{[E_2]} \qquad (1)$$

Where, E_1 and E_2 are the estimated electric field intensities with no shielding material and with shielding material respectively at the same point or plane. The same equation can be applied for H-field (magnetic field).

Figure 2. Sweet Home 3D model for testing shielding effectiveness

Design layouts showcased the possible arrangements to reduce EMR generated in an office if a fully-wired connection cannot be provided. For calculating the shielding effectiveness, electric and magnetic fields are calculated at the same plane (30 cm from the reception area wall) with and without the shielding material. E-field computed from CST without shielding material was 5.085 V/m at 2.45 GHz and 34.778 V/m at 6 GHz. Similarly, H-field without shielding material was found to be 0.011 A/m at 2.45 GHz and 0.045 A/m at 6 GHz. Table 1 has recorded the shielding effectiveness of the three building materials for E-field and H-field using equation 1.

Table 1. Shielding Effectiveness of three selected building materials

Frequency (GHz)	Building Material	Shielding Effectiveness of E-field (dB)	Shielding Effectiveness of H-field (dB)
2.45	Glass	-1.043	-2.094
2.45	Concrete	1.472	1.743
2.45	Wood	2.277	1.743
6	Glass	2.383	1.938

6	Concrete	4.284	4.121
6	Wood	17.142	19.084

As frequency increased from 2.45 GHz to 6 GHz (figure 3), shielding effectiveness improved considerably, and all values were positive, especially for glass, whose SE changed from negative to a positive value. This could be due to the fact that can be explained because high frequency causes EMR to scatter significantly and, therefore, get easily attenuated easily. Concrete and glass showed almost the same SE at 6GHz, while glass at 2.45 GHz was negative. The reason can be attributed to the fact that as glass is known to reflect and create multiple reflections inside the space more than concrete or wood. In overall, wood proved to be the best material regarding shielding capacity.

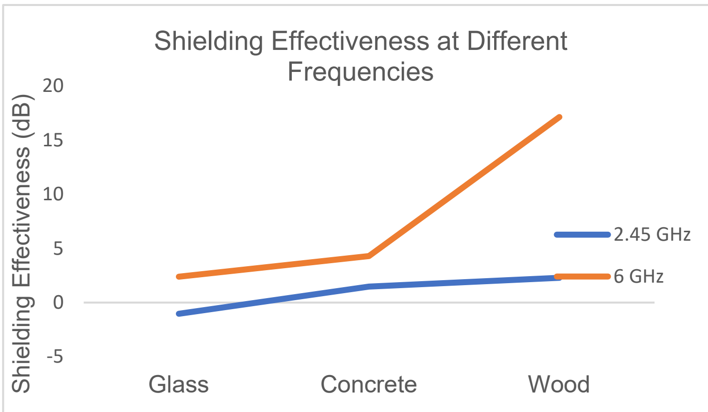

Figure 3. Shielding effectiveness at different frequencies for building materials

Radiation pattern of wood and glass at 6 GHz is shown below as figure 4. While radiation pattern of wood is smooth, scattering of glass is visibly very high.

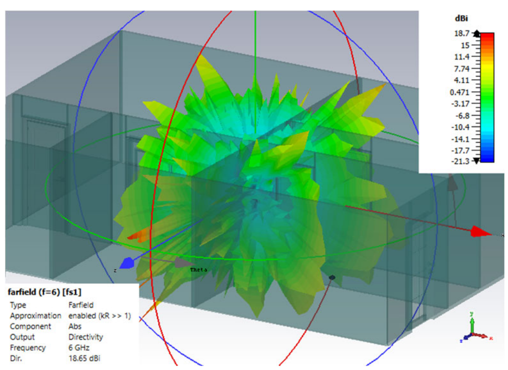

Figure 4. Radiation pattern of wood due to internal EMF source at 6 GHz

Leveraging the Use of Eco-Routers

Typically, wireless routers send broadcasting messages to any client (internet user) trying to connect to this shared medium, even when devices are not used. Even an energy-efficient rated router uses high power to enhance its connectivity and performance (*JRS Eco Wireless Routers*). To alleviate this issue, eco-friendly routers are developed that reduce power consumption during idle time, i.e. when no devices are active on the network. Though most of these routers developed aim to reduce energy savings, this principle can indirectly aid in reducing radiation. For example, JRS eco wireless router utilizes a firmware that runs compatible with the Asus router while not compromising speed or functionality (*JRS Eco Wireless Routers*).

Generally, a wireless router produces a beacon signal 100 ms (beacon signals are sent periodically to make the presence of wireless LAN available for providing internet service); however, the eco-wireless routers can be set to function to reduce EMR by 90% compared to conventional routers. Algorithms can also be set to zero radiation eco- standby mode when the wireless connection is unnecessary (*JRS Eco Wireless Routers*). Thus, the use of such routers that are intentionally designed to reduce EMR can be implemented in the hybrid design and even in wireless networking for smart buildings. The disadvantage of eco-router is its high cost; where in 2021, a conventional router costs 20 USD, the latter can be around 250-300 USD. Hence, if more companies can manufacture similar products, this can be made affordable for public usage.

Exterior Source Reduction
The following section briefly explains about the potential ways to reduce the radiation from exterior sources or neighbouring buildings.

Exterior building Materials with Shielding Effectiveness
Electromagnetic shielding thus acts as a barrier to an external source of radiation. Reflecting away all the incident electromagnetic radiation is vital. A material such as copper insulation, a material known to block away radiation, can increase the radiation in the exterior of the building. General electromagnetic shielding materials include copper, nickel, tin, steel, silver, brass, and if metal foams or mesh are used, the openings must be significantly lower than the wavelength of the incoming radiation (Miaskowski and Krawczyk, 2006).

Table 2 shows the shielding effectiveness of building material, in this case, the antenna is kept outside the dwelling space. For all cases, the operating frequency of antenna is 2.45 GHz and no interior objects are kept to reduce simulation run time and to distinguish between the difference in the dissipation of E-field. E_1, the E-field intensity at point (P) inside the simulated free space (assigning material as 'air' for walls) is evaluated as 4.567 V/m. The point, P, is selected at 30 cm from the innerwall and 50 cm from the field source at midheight of the interior space and shielding effectiveness is calculated as per the equation 1, figure 5.

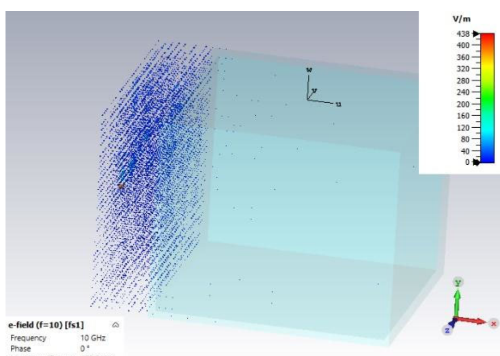

Figure 5. CST result visualization of E-field due to external EMF source at 10 GHz

Table 2. Exterior shielding effectiveness of building materials

Building Material	Frequency	E-field at point P, E_2 (V/m)	Shielding effectiveness (dB)
Concrete	2.45	5.608	-1.783
Wood	2.45	4.327	0.468
Glass	2.45	6.546	-3.126
Steel	2.45	0.684	16.491
Concrete	10	1.195	13.926
Wood	10	2.699	6.85
Glass	10	1.338	12.945
Steel	10	0.102	35.302

There was a significant difference in the behaviour of materials regarding their shielding effectiveness as frequency was changed (figure 6) . Concrete and glass blocked less EMR at 2.45 GHz while proved to have good shielding effectiveness at 10 GHz. These materials increased the electric field intensity at the measured point compared to the scenario when no shielding was present at 2.45 GHz but caused a decrease in the E-field value at 10 GHz. One plausible reason could be attributed to the back scattering and multiple reflections from the presence of the building envelope to the external source of radiation. Moreover, high frequency typically scatters and attenuates more than the low frequency. The calculated shielding effectiveness in the interior space revealed that steel has the highest shielding capability of 16.491dB at 2.45 GHz and 35.302 dB at 10 GHz, nearly 114 % increase in SE as frequency increased. While steel, a conductor of electricity reflected much of the incoming radiation, behaviour of wood was more consistent than concrete and glass. Wood proved to be an effective absorber and helped in attenuating the radiation gradually than the other materials at both frequencies. Overall, the material reflectivity and absorbing capability played an important role in determining its shielding effectiveness.

Even though, the general trend differed with frequency, increase in frequency informed that building materials can block high frequency incoming radiation easily, figure 12. This is because scattering of radiation is directly proportional to the frequency, and when scattering combines with natural reflective property of the material, shielding capacity is maximized.

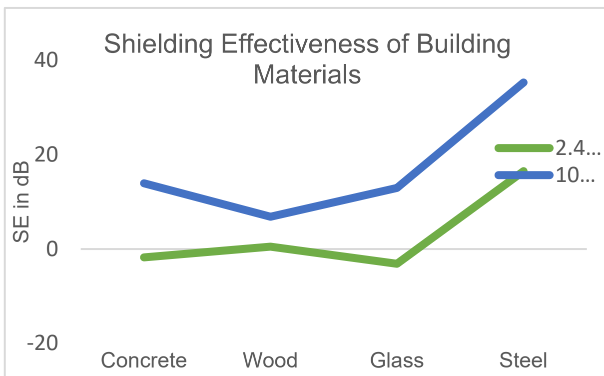

Figure 6. Graphical Depiction of Shielding Effectiveness of Building Materials at different frequencies

Radiation patterns of concrete and steel at 10 GHz is shown in the below figures 12 . There is a clear distinction in the way steel acts as an electromagnetic barrier compared to concrete. Steel's radiation pattern is confined to one side of the building close to the EMF source, while radiation pattern of the concrete building is more broadly distributed showing its low SE capability.

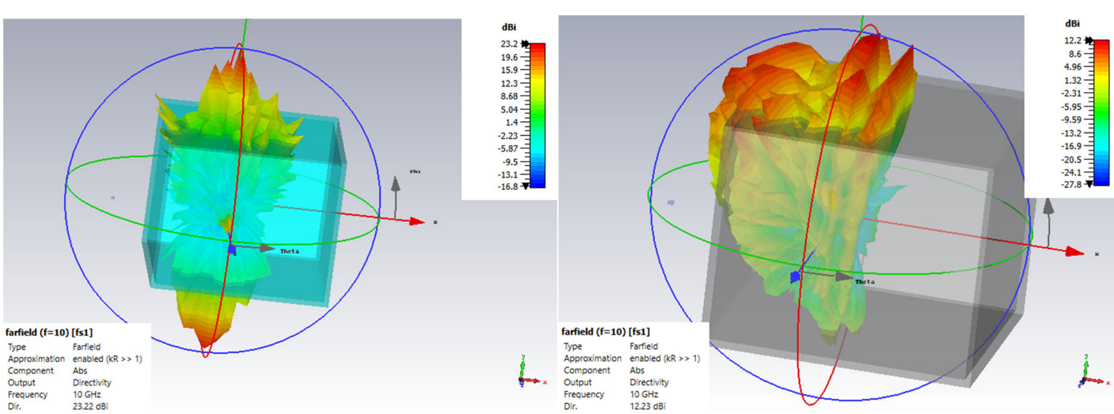

Figure 7. Radiation pattern of concrete and steel towards external EMF source at 10 GHz

Simulations showed that metal-based material, steel can reflect off majority of the incoming EMR thereby providing good shielding to the occupants inside from unwanted radiation. However, if the radiation is from the interior space, materials with high reflective properties like steel and glass, it would trap the radiation produced inside and causes multiple reflections and back scattering effectively increasing the radiation produced in the indoor environment. Therefore, careful selection of materials is vital in mitigating EMR. From simulation result, it can be said that if the building is isolated from other buildings, only the indoor radiation needs to be reduced, and in such a scenario, using wood would be helpful in reducing radiation. Similarly, to protect the building occupants from external radiation, external surface can be made highly reflective, or even metal embedded inside concrete or wood. However, care must be taken that reflecting away all radiation can damage occupants in other buildings or even flora and fauna outside the building.

Bio-Geometry Design

Bio-Geometry is the term coined by architect and scientist Dr Ibrahim Karim in the early 1970s that inherently uses the energy principles in geometric forms to recreate the natural balance of energy associated with any living entity (Farouh, 2009). This concept is similar to bio-electromagnetics, but applied to the building to synchronize with the energy interactions with the environment. This concept considers both EMFs and geomagnetic frequencies of the planet to design peripheral geometrics to interact with the ecosystem. The first application of bio-geometry was in collaboration with Switzerland's mobile service provider, 'Swisscom' (Farouh, 2009). The project aimed to mitigate the EMR related problems such as insomnia, headaches, and impaired cognitive functioning from an antenna placed on top of a church in Hemberg, Switzerland. The biogeometric shapes were installed on the antenna, electric distribution cables, and water pipes in the affected houses. A survey was conducted after two years of installing biogeometric shapes, and it was concluded that there was a significant reduction in the health problems of the neighboring community (Farouh, 2009).

Landscape Design

Trees, plants, water bodies interact with EMR similar to humans. Generally, trees are considered to divert away the incoming radiation and antenna engineers try to incorporate it as a loss for wireless radiation design. However, this concept when applied from a mitigation strategy, works seamlessly with the building materials to protect the occupants from unwanted external radiation.

However, there are research findings that mention that EMR is harmful to trees and the entire local ecology. Thus, care must be taken to use and utilize those trees that are naturally radiation resistant like the gingko trees, a naturally grown landscape tree in many countries. Research evidence have found that gingko tree can withstand radiation without any defect as they have living cells inside them that annihilate radiation. Thus, conducting more research into the domain of finding radiation resistant plants and trees and planting them as peripheral trees in the landscape design elements for the building is a safe measure for both plants and occupants alike.

CONCLUSION

Health and environmental risks from mobile phone and cellular tower radiation have been recorded since the 1960s, although policies and laws addressing this problem were limited. Though WHO and FCC have classified radiation from radiofrequency to cause brain tumor, the complete impact on human health and the environment of wireless radiation to this day remains unknown. Further, with the envisioned deployment of the Internet of Things (IoT) using 5G, millimeter frequency, radiation on people and other environmental species has made several countries seek its ban until impartial research findings are determined. This innovative solution has proposed a novel concept of 'zero radiation smart buildings/cities' and its implementable strategies both at the social and environmental levels. The innovative solution has primarily used CST simulation to show how interior and exterior sourced radiation can be reduced to zero, such as using shielding effective building materials, landscaping with radiation resistant trees, and leveraging eco-routers bio-geometric designs. The strategies were formulated fundamentally from a transdisciplinary perspective so as to bring a holistic vision of the problem stated. Further, the strategies targeted academia, industry and policy changes to transform cities that are not 'just smart and sustainable' but also safe for humans and the environment.

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THEME IV

Prefabrication, Digital Construction and Planning

SINGLE USERS' PERCEPTION TOWARDS ACCEPTANCE OF PRECAST TECHNOLOGY IN THE CONSTRUCTION INDUSTRY: CASE OF ABU DHABI, UAE

Abdelmoneim Mohamed Abdelmoneim[1], Mohammed Albattah[1], and Aysha AlMuhairi[1]

[1] Department of Architectural Engineering, College of Engineering, United Arab Emirates University, 15551, Al Ain, Abu Dhabi, UAE

ABSTRACT

The construction industry plays a major role in the UAE economy. As the residential segment accounts for the largest element in the industry with rapid urban growth and increased demand in this sector, the adoption of time and cost-efficient technologies becomes increasingly important to overcome the different challenges in the construction industry. Precast concrete has proven to be one of the most promising prefabricated systems to address this gap through its numerous benefits and it's taking global attention as an ideal solution for the residential segment. However, despite its benefits and governmental direction for its adoption in housing projects, end-users are highly reluctant to adopt this technology in their single houses. This study aims to investigate and observe the different reasons behind the reluctance toward the adoption of precast. It follows a quantitative approach by forming a questionnaire survey to consultants and construction professionals in Abu Dhabi as it is a major city for the residential sector. Findings indicate that the main reasons behind the lack of precast utilization in end-users houses are cost, limited design flexibility, aesthetics, and resistance to changing the conventional methods.

Keywords: Construction Industry, Fourth Industrial Revolution (4IR), Precast, Prefabrication, Single Housing Project

INTRODUCTION

The construction industry is one of the top leading industries worldwide and is a key economic player in the United Arab Emirates (UAE). In 2019, it represented 14% of the UAE's gross domestic product (GDP) (Albattah, Shibeika and Sami Ur Rehman, 2021). Rapid urban growth and increasing expatriate population have triggered a significant demand for the construction industry in the country. This is particularly in the residential sector, which is accounted for the largest segment in this industry (Rao, Jartarghar and Ramamurthy, 2014). Consequently, the UAE government has set different strategic plans and agendas to improve the residential sector in the country and provide suitable housing for the UAE nationals and residents in a record timeframe. These innovative and digital transformation strategies include Projects of the 50 (*Projects of the 50*, 2022), Abu Dhabi Economic Vision 2030 (*Abu Dhabi Economic Vision 2030*, 2022), and Dubai Plan 2021 (*Dubai Plan 2021*, 2022). However, several negative factors affect the construction market in the United Arab Emirates (UAE), including low productivity, higher costs, delays in completion, and defects during construction. A major contributor to these issues is the involvement of unskilled craftsmen (Jones, 2018; Albattah, Shibeika and Sami Ur Rehman, 2021).

With the current advancement towards digital transformation and the emphasis on the 4th industrial revolution (4IR) (Skilton and Hovsepian, 2018; Mohamed Abdelmoti, Tariq Shafiq and Sami Ur Rehman, 2021), the adoption of time and cost-efficient technologies become critical to overcome the challenges and meet the increased demand in the construction industry (Al Amri, Puskas Khetani and Marey-Perez, 2021). 4IR is a key contributor to the future of the UAE. In 2017, UAE launched its 4IR strategy (*UAE launches strategy for Fourth Industrial Revolution*, 2017). In 2019, UAE became the first nation on the global scale to have a practical framework for policymakers toward the digital advancement and adoption of the latest innovative technologies to expand future opportunities. In the context of 4IR, Sheikh Mohammed bin Rashid Al Maktoum, UAE Vice President, Prime Minister, and Ruler of Dubai stated, "The Science, Technology and Innovation Policy is our roadmap to building a better future for generations to come. We have the human capital, effective governance and financial resources to accomplish a transformation of scientific progress in the UAE (*Science, Technology & Innovation Policy in the United Arab Emirates*, 2015)."

4IR aims to make the construction industry more efficient and effective by providing high-performance and sustainable materials and innovations. To meet the 4IR requirements, policymakers have increased the adoption of cost-effective and time-efficient building methods. One of the most promising developed systems that can meet the growing construction demand and add a variety of time and performance benefits is prefabricated systems. It can be defined as a concrete member cast in a reusable mold/form, cured in a controlled environment, and then transported to its destination or construction Site. Precast offers numerous benefits to the whole phases of the construction project lifecycle and has been proved to be efficient in the construction industry compared to the conventional in-situ method (Tam *et al.*, 2005; Jaillon, Poon and Chiang, 2009). It decreases the project time by eliminating the forming, framing, pouring, and/or curing processes during construction. Moreover, it offers a range of cost reduction advantages, including simpler construction processes, higher productivity and safety, reduced labor, and decreased waste (Yee, 2001). The different potentials pre-cast concrete offers compared to other systems are the key drivers behind its adoption by policymakers.

Despite the various advantages offered by the precast concrete system, its main utilization lies within the public sector. Considering the residential/private housing sector, cast-in-situ is widely preferred over the modular precast method (Elkaftangui and Basem, 2018; 'Employment of Unskilled Craft Workers in the UAE Construction Projects: Explicating the Reasons', 2019). According to a study done in Al-Ain city, UAE, most citizens prefer to build their own house rather than buy a (built) one (Albattah *et al.*, 2021). Furthermore, the most desirable features that participants specify are those that they can take advantage of while occupying the house (for example, adding or removing space and changing house elements). However, precast facades are often rigid, lack design flexibility, are difficult for future modifications, and lack aesthetic features due to the nature of modular construction systems, leading to their low adoption. On the other hand, its construction operations energy, transport, and skills requirements might be other factors of its low adoption in single houses. These factors indicate a general preference for the dominating system in construction which is the reinforced concrete system from contractors, stakeholders, and end-users (Albattah *et al.*, 2021). Consequently, it becomes crucial to explore and analyze in detail the reasons for the low adoption of the precast concrete system, in the private housing sector, from consultant perspectives. This paper aims to detect the awareness of the full potential of this system and observe the barriers and challenges of its implementation. In addition, the objective is to promote the utilization of this system in the private housing sector and achieve its economic, sustainable, and time-efficient benefits.

MATERIALS AND METHODS

This research aimed to determine the current state of precast single housing in the UAE construction industry. Within the emirate of Abu Dhabi, a qualitative exploratory case study was conducted to explore the views and experiences of construction and consulting offices. The purpose of this exploratory design is to identify a problem that can be addressed in future research studies and to find the reason for the reluctance of citizens to use precast in the construction of their detached homes, using a theory-oriented approach or an interpretation-based approach, considering the prevalence of this type of construction in residential projects in the United Arab Emirates. It aims at unearthing the reasons and challenges associated with using precast for building single houses in the UAE. Architects' and engineers' perspectives are important because they directly deal with the owners and understand their reasons. A total of 92 surveys were conducted with consulting firms and companies responsible for single housing construction projects in the emirates of Abu Dhabi. The survey comprised four main sections. Table 1 presents the category and contents of the questions for each section.

Table 1: Categorization of the interview questions.

Section	**Category**	**Contents**
1	Personal information	Educational background, experience, company type, and company name (if possible)
2	Familiarity with precast	previous experience working on the precast project(s), number of projects, and type of projects
3	Perspective	Reasons and ideas associated with precast for the end-users, and new ideas on the precast system if they have any
4	Expectations and challenges	state of precast single housing projects in the UAE

To conduct the research, the authors contacted First Abu Dhabi Bank (FAB) to obtain a list of consulting companies involved in single-house projects. Emails were sent requesting these offices to participate in the survey, and in some cases, personal calls were made to the offices. The authors were able to find and recruit participants using this method, including busy project managers who might otherwise be hard to reach. To ensure a diverse range of backgrounds and perspectives, both genders with different academic degrees were invited to participate in the survey. Also, as all participants in the study worked on a group of housing projects, the authors gained an understanding of the viewpoints of young people new to the market as well as the older generation. The results of the study are analyzed using statistical analysis software, SPSS (IBM, 2022). However, this paper has limitations as its analysis only focuses on consulting firms. In the future, the survey will be extended to the end-users, and other data collection methods, such as interviews, may help the authors obtain more accurate information.

RESULTS

The survey collected data from the participants based on four categories: 1) demographic information containing participants' gender, generation based on the group, occupation, company type and years of experience in the UAE, 2) participants' awareness of the precast system compared to the type and number of projects they have worked on, 3) reasons for the owners' lack of interest in the precast system in general as well as the consultant suggestion on precast, and 4) participants' view on expectations and challenges that the precast construction system may face in the UAE.

Demographic Composition of the Participants

The demographic composition of the study participants is shown in Table 2. Regarding gender, females made up 27.2% of the sample, while males made up 72.8%. Furthermore, the study participants are divided into two generations: 1) generation X and 2) generation Y. Generation X represents the participants born between 1965 – 1979, whereas Y represents the ones born in the 1980s (Albattah and Attoye, 2021). Generation Y made up the largest percentage of the sample, i.e., 82.6%, followed by generation X with 17.4% of the total sample respectively. Generation Y age group was majorly targeted during the dissemination of the survey to reduce the inclusion of managers or junior engineers in the study as they do not deal directly with the client. Based on the nature of the topic under investigation, the architecture & engineering group represented 80.4% of the participants, while all "Others" made up 19.6% which includes participants from IT and Management-related professions. Regarding company type, the consultant made up 79.3% of the sample, whereas non-consultants (contractors and clients) made up 20.7% respectively. According to the results of the study, 34.8% of the sample have UAE-based work experience of 1 – 5 years in the field, 20.7% have 5 – 10 years of experience, 13.0% have 10 – 15 years of experience, and 26.1%

have more than 15 years of experience. In contrast, 5.4% of the respondents have no work experience in the UAE.

Table 2: Demographic composition of the study participants (n = 92).

Gender (n = 92)	Male	72.8%
	Female	27.2%
Generation (n = 92)	X	17.4%
	Y	82.6%
Background (n = 92)	Architects & engineers	80.4%
	Others	19.6%
Company type (n = 92)	Consultant	79.3%
	Non-consultant	20.7%
Years of experience (n = 92)	1-5	34.8%
	5-10	20.7%
	10-15	13.0%
	15+	26.1%
	None	5.4%

Participants' Awareness of the Precast System

The following subsection presents the responses to the questions regarding the participants' experience with precast in context to the type and number of precast projects they have worked on. As shown in Figure 1, 65.2% of the participants have worked on precast concrete projects in general, while 34.8% have not yet worked on them. Among the participants who answered yes to the question on their experience with precast projects, 59.5% responded to have worked on housing precast projects, 28.5% of them worked on a single precast house project, and 12% of them have worked on both housing and single house projects (Figure 2). Furthermore, as depicted in Figure 3, 42.4% worked on 1-3 single precast housing projects, whereas 34.8% have not worked on any, 11.6% worked on 3-6 projects, 5.8% worked on more than 10 projects, and only 5.4% of the participants worked on 6-9 projects. It is evident that single precast housing projects do not gain great popularity in the UAE construction industry, as the majority of those who worked on precast projects said that they were housing projects and the majority of those who worked on individual projects admitted that they did not exceed three projects.

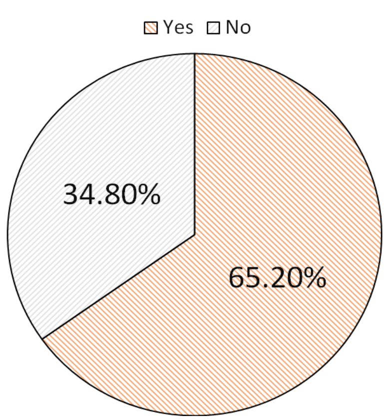

Figure 1. Distribution of participants who have worked on precast projects (n = 92).

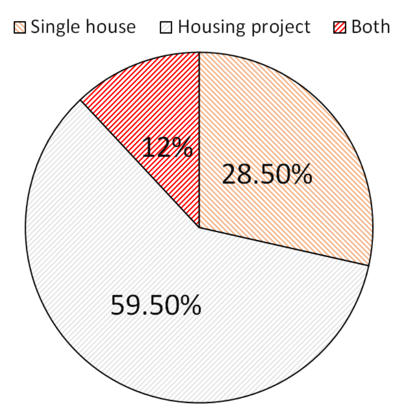

Figure 2. Distribution of participants based on type of precast projects they worked on (n = 60).

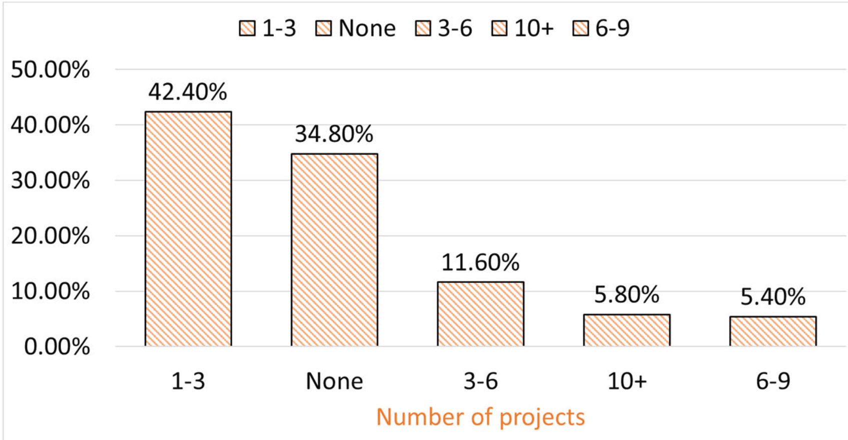

Figure 3. Distribution of participants based on the number of single house projects (n = 92).

Reasons that End Users do not implement the Precast System for Their Single Houses

The participants in this study were given the option of selecting more than one reason for the owner's reluctance towards the adoption of the precast system. This is to analyze the reasons for reluctance and to provide suggestions or develop appropriate strategies for increasing the adoption of the precast system (P Karthigai and M, 2018). The following options were provided to the participants: 1) technology awareness, the end-users are not fully aware/informed about the precast system, 2) resistance towards technology change, the end-users are aware of the precast system but still refuse to use it, 3) cost, price the end-user will pay for a single precast house, 4) appearance and form of rigidity, limited design options, 5) the flexibility of expansion and modifications, 6) build quality, for instance, some factories gives a bad quality of precast elements which might give a bad impression of the system, 7) cultural issues, Emirate governmental housing projects usually use the precast system, that helped to associate the precast system with Low-income from the Emirati society From point of view, and 8) others, for the reasons that might not be covered in the previously provided options. As illustrated in Figure 4, The flexibility of expansion and modifications is selected by 64.1% of the participants as the reason for not implementing precast by the end-users for a single housing project. Furthermore, cost and cultural issues were selected as the second and third most significant reasons respectively by 55.4% and 39.1% of the participants. In addition, 34.7%, 31.5%, 28.8%, and 10.8% of the participants selected technology awareness, resistance towards change, appearance and form of rigidity, and build quality as the reasons respectively. In contrast, only 3.2% of the participants selected others as the reason, indicating that almost all the reasons were provided as options in the study.

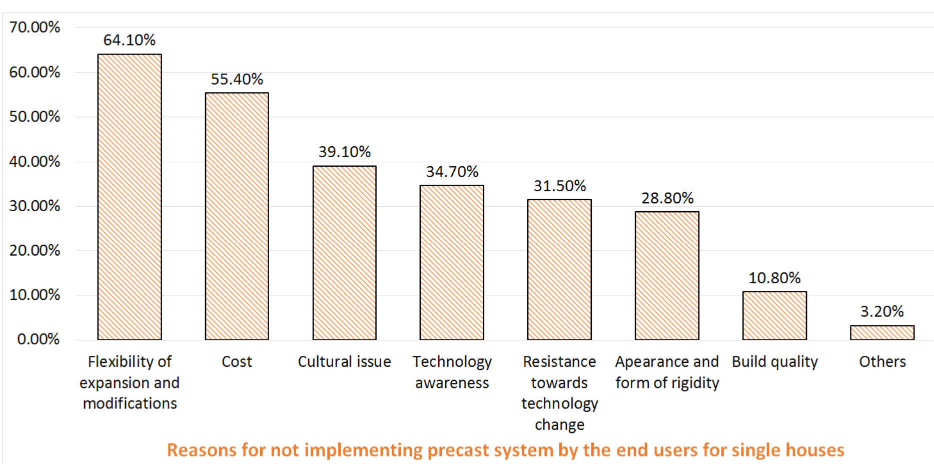

Figure 4. Frequency of reasons selected by the participants for not implementing a precast system by the end-users for single houses projects (n = 92).

Expectations and Challenges

This section presents the respondents' answers, considering whether the consultants inform end-users about the precast system or not. The options provided were "Yes", "No", or "I'm not sure". The results showed that 47.8% of the sample believes that they do inform the end-users about the precast system, while 25.0% didn't inform, and 27.2% were not sure (Figure 5). To get a clear picture of the participant's view of the situation, the authors asked them if precast is widely utilized in single houses in the UAE. As shown in Figure 6, the results were disagreed with a percentage exceeding 56.6%, followed by 20.6% neither agree nor disagree, and 22.8% agreed, concluding that precast is not widely used currently in the UAE for single housing projects.

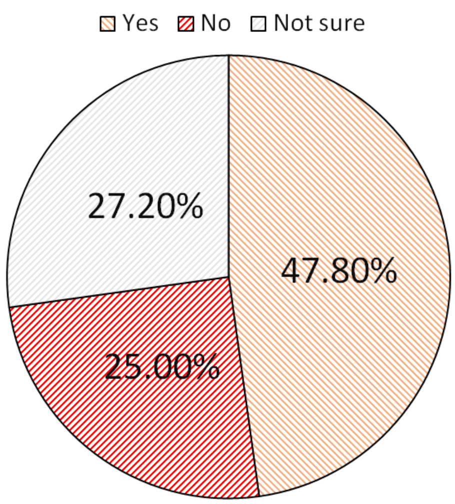

Figure 5. Distribution of consultants who informed end-users about the precast projects (n = 92).

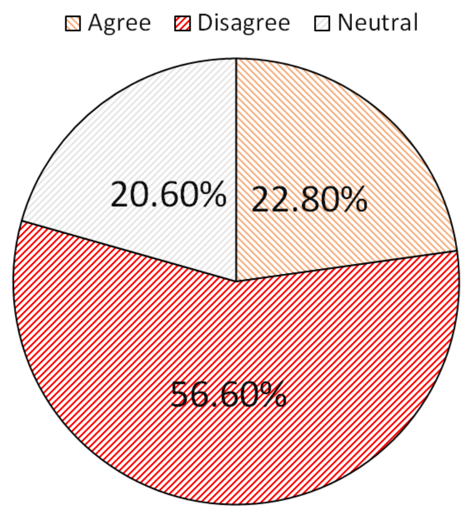

Figure 6. Participants' view on the use of precast for single housing projects in the UAE (n = 92).

Challenges

Figure 7 depicts the results generated by combining the ones obtained regarding the questions about whether the end-user is informed about the precast system or not, and the most common reasons they receive from clients for rejecting the precast system. Only the responses of the participants who do inform the end-users regarding the precast system are included in the figure. As shown in the figure, 81.8% of the participants agree with the claim that the difficulty of future expansion or modification is the reason why end-users don't use this system for their houses, 13.6% neither agree nor disagree, and 4.6% disagree. "Cost is the reason why end-users don't use this system for their houses" – 59.0% of the participants agreed with this sentence, 16.0% were neutral, and 25.0% strongly disagree. When the participants were asked whether aesthetics and form are the reasons why end-users don't use this system for their houses, 50.0% of them agreed with that, 27.3% neither agree nor disagree, and 22.7% disagreed. The most frequent reason for a reluctance to the precast system that the participants yielded from the end-user was a difficulty with future expansion and modification, as only 4.6% of the respondents disagreed.

Future Adoption of Precast for Single Houses

The use of precast in the future for single houses is quite debatable. Consequently, the authors had to put the opinion of those in the market into account to get a preliminary prediction about the future of precast single housing projects in the UAE (Table 3). Among those who belong to generation X, 31.2% agreed and the same percentage of participants had a neutral opinion regarding the use of precast for a single housing project in the future, while the majority, 37.6%, disagreed by a slight difference in percentage from those who agreed and had a neutral opinion. In contrast, the participants in generation Y were more optimistic about the future of precast single housing projects, with 61.8% of the participants in generation Y agreeing, while 18.5% and 19.7% had neutral and negative responses respectively.

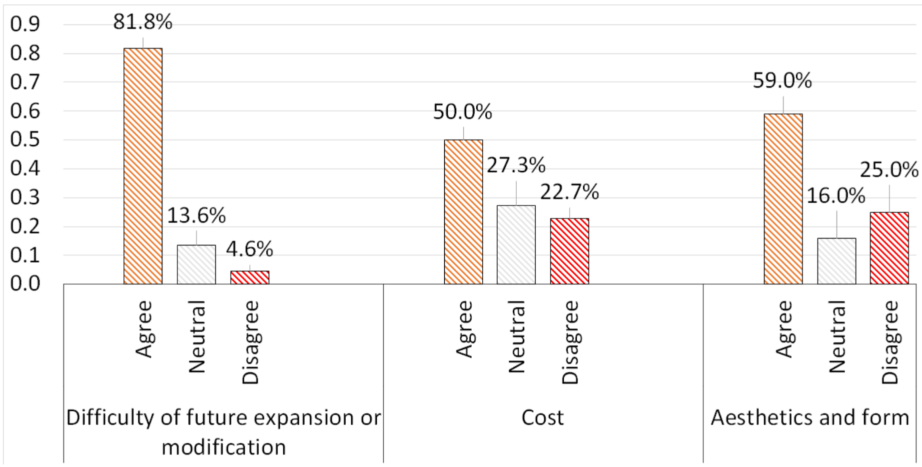

Figure 7. Frequency of participants based on most significant reasons for reluctance towards precast and their consultation with the end-users (n = 44).

Table 3: Distribution of participants based on generation on their views regarding the future adoption of precast in the UAE for single houses.

	Opinion	**Generation (n = 92)**	
		X (n = 16)	**Y (n = 76)**
Precast will be widely utilized in single houses in the future	**Agree**	31.2%	61.8%
	Neutral	31.2%	18.5%
	Disagree	37.6%	19.7%

DISCUSSIONS

The results of the study revealed that the precast system is popular within the UAE, but only in housing projects and does not receive the same attention in individual housing projects. Although most consulting offices propose the precast system to the client, the proposal is usually rejected. One of the most significant reasons for refusal that was found in this study is the cost, as it was chosen by 51 participants. Consequently, the larger the project, the more likely it is to use the precast method in construction. On the other hand, for an individual housing project the cost may be higher as the cost of the molds and transportation may not be effective to build one house as opposed to building several models in a large project (de Albuquerque, El Debs and Melo, 2012). One of the limitations of the precast system is the inflexibility of expansion and modifications. In contrast, houses in the UAE are frequently expanded/modified as it was selected by 59 participants. Perhaps, this could be one of the reasons that the UAE citizens are reluctant to use the precast method, as it does not meet their requirements for constant change and expansion to create space that is capable of accommodating the expansion of the Emirati family. Most of the UAE government housing projects use the precast method of construction ('Sheikh Zayed Housing Programme', 2022), and perhaps this has built a cultural barrier between the citizen and the precast system, where a cultural image has been formed that indicates a low level or limited income since 36 participants thought that culture is a reason why end-users do not implement the precast system for their single houses. From a more optimistic point of view, most of the participants in generation Y thought that precast has a better future in the field of single housing projects in the UAE, whereas the majority of those in generation X disagreed. This is because the participants in generation Y might have adopted more easily the technological change compared to generation X. Although currently, the precast system might have several disadvantages such as cost, lack of flexibility, and limited designs, the use of precast might be increased in the future due to automation in the process using 4IR technologies.

CONCLUSION

Despite numerous benefits of the globally adopted precast system, end-users in the UAE are reluctant about their use for single housing projects. In this research, the authors investigated the reasons behind this negative attitude toward the precast system and give insights into these reasons. This is done by surveying a group of 92 construction professionals (architects and engineers) and consultants in Abu Dhabi, a major city in the UAE. Our results reveal that the most significant reasons for not adopting the precast system for single house projects in the country are limited design flexibility, cost of the precast system, and cultural issues. However, the results indicate the positive adoption of the precast system for single house projects in the UAE. The results of this study can help the government to develop effective strategies to make the citizens aware of the precast system. In our future work, we will analyze the results of descriptive answers of the participants as well as perform a crosstab analysis between different responses.

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USING MODULARITY TO IMPROVE THE BUILDING CONSTRUCTION PROCESS

Bruna Liliane Brenner[1] , Manoela Conte[2], Daniela Dietz Viana[3]

[1 2 3] Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil 90035-190

ABSTRACT

Producing and assembling modular products allows companies to differentiate its product, combining a limited number of standard parts. In addition, breaking complex systems into smaller parts through modularity helps to deal with complexity. Despite the potential benefits of modularity, in construction there are gaps related to its application, since it is challenging to adapt the concept from manufacturing and there is a need to change the mindset of early design stages. This study aims to bring advances in the use of modularity in construction projects by adapting the concept for its effective application in house buildings projects. The methodological approach was Design Science Research with an empirical study carried out in a design office in Brazil. A modularization proposal was developed for the standard floor of high end residential Building designed by this company, identifying its modules and combinations from spatial perspective, also analysing issues related to their interfaces. The proposal was important for better understanding challenges faced by the architects. The results show that in the design stage, segmentation of customization options into independent modules support the development of the executive project based on the customer's choices. It was also perceived the importance of considering modularity from the initial design stages so that more benefits can be achieved. Regarding the operations planning, it was found that the construction method can influence the definition of the modules so that the same modularization proposal is reflected in the different steps.

Keywords: Modularity, early design stages, buildings

INTRODUCTION

Producing and assembling modular products allows a company to differentiate its product, combining a limited number of standard parts (MUFFATO, 1999) and providing a wide variety of products efficiently with low impact on production (PILLER; KUMAR, 2006). This is a necessary strategy to improve the performance of the housing construction industry (HOFFMAN et al., 2009; VOORDJIK et al., 2006). According to Da Rocha et al. (2015), modularity can benefit both conventional and industrialised construction. For greater benefits, this should be considered from the initial design stages. Although modularity strategies should be born in the design stage, their benefits can be seen beyond this stage, advancing to the customization of units (BARLOW; OZAKI, 2003), operations planning (DA ROCHA; KEMMER, 2018) and facilitation of recycling or renovation (KRIKKE et al. 2004).

Despite the potential benefits of product modularity, in construction there are gaps related to its application. It is still unclear how the main conceptual foundations of modularity are applied, such as the definition of modules, interfaces between modules and product variants (DA ROCHA et al., 2019). In addition, buildings have several specificities that make it difficult to directly apply modularity and the notion of modules used in manufacturing (DA ROCHA; KEMMER, 2018). The uniqueness of the products and the construction site (KOSKELA, 1992) are examples of these specificities.

This article seeks to bring advances in the application of modularity in construction projects through the discussion of factors that impact the module definition. For this, a proposal of modularization of a typical floor plan of a high-end residential building will be presented, identifying its modules and combinations from a spatial perspective, also analysing issues related to their interfaces. In this article, modularity is analysed from a product perspective. A brief discussion of its possible impact was also held regarding the operations planning.

MODULARITY

The concept of modularity is based on the idea of decomposing a system into independent modules (ULRICH, 1995; BALDWIN; CLARK, 2000). In the design step, modular products should be divided into modules which involve a manageable set of tasks (SAKO and MURRAY, 1999). The modular design is applied considering dimensions, interchangeability, tolerances and standardised interfaces (GIBB, 2001). The module is defined by Miller (1998) as an essential and independent functional unit in relation to the product of which it is part and has standardised interfaces in which each module is physically independent and performs only one function. In this case, modules can be mixed and matched in distinct combinations (ULRICH, 1995; MILLER, 1998).

A product can be modular or integral, although most products are not strictly modular or integral (ULRICH, 1995). The modular structure increases flexibility, accommodates made-to-order products and works with decoupled design teams, while the integral architecture works with tightly coupled design teams (ULRICH; EPPINGER, 2004). In integral architecture there is a complex mapping from functional elements into physical components, and coupled interfaces (ULRICH, 1995). Most buildings are integral, and not just from a product perspective, but also from a process and supply chain perspective. From a product perspective, in manufacturing, most assets are broken down into components that contribute to its function at the highest level. In buildings it is not appropriate to focus only on components, because modules are a mixture of components and spatial voids. In this kind of product, the main function is provided by the spatial voids and not by the components (DA ROCHA et al. 2015). Modules can be produced on-site or off-site and can be volumetric (containing the spatial voids) or non-volumetric (GOSLING et al., 2016). From a design perspective, modularity can be applied through standardised product platforms and defining modules through the product architecture (BALDWIN; CLARK 2000; ULRICH 1995). Platform is a specific module that is used in all product variants that can be generated in a given system (SALVADOR, 2007). Ulrich (1995) proposed a taxonomy with three types of modular architecture, one of them considering the use of platforms where all modules are linked to a single module (platform) through the same type of interface.

Modularity has greater potential if there is alignment between product and production, that is, the work needs to be structured according to the project modules and platform (DA ROCHA; KEMMER, 2019). In construction, although product definitions have a clear influence on process and supply chain definitions, the articulation between them is usually not clear and decisions are made in a fragmented way. This aspect is adverse to the use of modularity in this segment.

The use of modules has been identified as one of the necessary strategies to improve the construction industry performance (VOORDIJK et al. 2006). The use of modularity has shown potential benefits such as increasing value by providing customised units (BARLOW; OZAKI, 2003) supporting Mass Customization (MC), that combines the benefits of mass production with systems that offer more options for the customers. MC in buildings that use traditional construction methods usually has little support from modularity (FETTERMANN et al. 2014), although Da Rocha et al. (2015) demonstrate that product modularity concepts can be beneficial for traditional construction performed on site, supporting customization during the operations phase.

RESEARCH METHODOLOGY

Design Science Research (DSR) was the methodological approach adopted in this research. DSR seeks to reduce the distance between practice and research by the development of innovative solutions for problems faced in the real world, while contributing to the existing theory (LUKKA, 2003). This approach describes and analyses alternative courses of action to deal with organisational problems through a prescriptive knowledge development (HOLMSTROM et al, 2009). The study was carried out with an architectural firm (Company A) located in Porto Alegre, Brazil. Company A has 8 members, develops around 20.000m² of projects per year. Besides, Company A has over 10 years of experience in using BIM practices to support design development and management, and operates in the construction sector with a large portfolio of high-end multifamily buildings. Most of the projects use conventional construction methods, such as cast-in-place reinforced concrete structure and masonry walls. The scope of the analysis was restricted to one project of a high-end multifamily building (Building X), whose architectural design and coordination were developed by Company A and were finished at the time of the research, but its construction had not yet started, by the time the case study was carried out. Building X has 24 apartments, 14 floors, 2 basements and 7019 m² of built area.

The study was conducted in four stages: (i) understanding of the problem of the company's design processes for the project under discussion; (ii) analysing the modules and platform defined by the company and its implications on the design process, including BIM features, in collaboration with the firms' architects; (iii) proposing new modules and platforms based on the literature review taking a space-oriented perspective considering customization options; and (iv) reflecting about the possible factors that impact in module and modular perspective definition. The main sources of evidence were: (a) semi-structured interviews with designers and managers of the architectural firm involved in the project; and (b) analysis of the existing design documents (e.g. BIM model, promotional material). The main focus of the research is to bring advances in the application of modularity in construction projects through the discussion of factors that impact the module definition.

RESULTS

Using a software solution to group repeated parts, inside the BIM model, motivated the attempt to modularise building X design. This grouping facilitated the modelling by configuring repeated sets, and it was easier to manage small parts. This grouping is called modules from now on.

Analysing Company A design, the standard floor was divided into 5 modules: two standard apartment modules, balcony 1, balcony 2 and a common circulation core. The division can be seen in Figure 1. The two apartments on the floor are mirrored equal modules so that the apartment module is repeated twice on the floor; balconies 1 and 2 have different dimensions and positions in relation to the apartment, appearing once each on the floor. The division aimed to simplify the detail design process through the repetition of modules from the standard pavement. It was observed that the main objective of the modularization adopted in the product was to develop process modularity for design development. The modules facilitated the distribution of work through the different teams, allowing the simultaneous work, and also eventual changes in the design model, according to the interviewees'. The proposal does not consider the customization possibilities offered by the enterprise and is made without the use of a specific parameter.

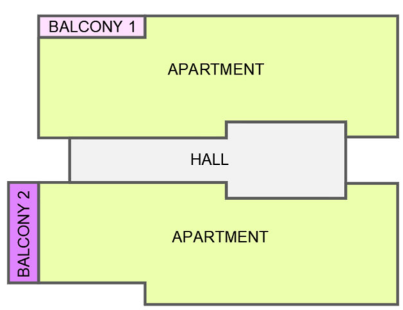

Figure 1 - Modularization proposal made by Company A

Project X allowed the customer to change the internal layout of the units. However, this customisation option was not considered in the modularization proposal developed by the office. As a result, employees reported difficulties in developing the executive project regarding customer choices. In these cases, the modules were manually changed, as in non-modularized projects.

Figure 2 shows the apartment floor plan developed by Company A. The dashed lines represent the walls that can be removed or altered in the layout based on the customization options offered. The customization options include: kitchen integrated into the living room (M1a) or closed (M1b); toilet (M2); two suites (M3a) or merging them into a master suite (M3b). In M3a, the bathroom (Figure 2) belongs to suite 1. In M3b, the bathroom faces the corridor. The variants are configured from the different combinations of these options. Certain parts of the unit are not changeable in any of the customization possibilities. The dashed walls in the living room (Figure 2) indicate changes in the interface due to the different possibilities for positioning the balcony. This position is defined by Company A, that is, although it changes, it is not a customization option offered to the customer.

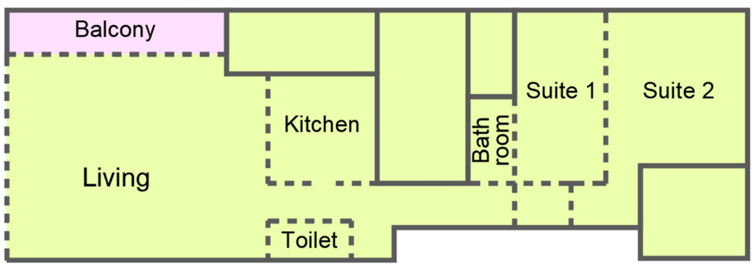

Figure 2 - Apartment layout in Company A proposal

In the original proposal, hydraulic and electrical designs are in separate modules from the architectural design, with one module per design per floor. In this case, the division occurred because these projects were developed by external teams, which made it difficult to integrate with the architectural design modules. According to the designers, the integration would be easier if they had been made by the same company. The structural design is also in a separate module, being a structural module for the entire building. It is common for the structural design to have an integral architecture, since there is usually a concern to avoid redundancies in the structure. This integrality doesn't interfere in the customization options offered since the structure doesn't change with the customization options.

Although Company A's proposal for Building X floor plan modularization has presented benefits, as it facilitates the distribution of work through the different teams, there are more possibilities to explore in relation to modularization, especially those related to the customization options offered in the project. Thus, within the layout options previously defined, a proposal was developed for apartments modularization, considering the literature and aiming at the possibility of previous modelling of all the modules that set the variants. The new proposal divided the typical floor plan into modules, identifying the different possibilities of combinations, also analysing issues related to their interfaces, as well as the potential impact on the following design stages. This modularisation aims to minimise the problems of developing the executive design after the customer's choices, considering the customization possibilities offered and postponing product differentiation.

In this research the space perspective, proposed by Da Rocha et al. (2015), is adopted. The floor slab was considered as part of the platform, that is a module that doesn't change. The entire floor slab belongs to the platform and the modules are configured by the spaces involved by walls.

In the modularization proposal, the following were determined: (i) which are the modules that set the apartment floor plan; (ii) number of product variants from the modules' combinations; (iii) definition of the platform, isolating the complexity of the customizable part. In Figure 3, the typical apartment floor plan is presented with the modularization proposal that considers the customization possibilities. For modularization, two changes were proposed in the original apartment floor plan: (a) Balcony dimensions have been unified. In the original proposal there were two different balcony sizes, now there is only one, varying only its position. For this unification it was necessary to reduce the hatched area represented in Figure 3; (b) In the original proposal, the partition that contains the door of suite 2 has two position options. In the new modular floor plan, in both options the partition is positioned in the same place. The purpose of change “b” is to unify the format of the module that contains the suites. In Figure 3, the platform is represented in grey, the three customizable modules in green and the balcony module in purple. For each module there are two customization options, which follow as in the original proposal. The customer can choose between a kitchen integrated into the living room (M1a) or a closed kitchen (M1b), between having or not a toilet next to the living room (M2) and between two smaller suites (M3a) or a master suite (M3b). In addition to the customization options, the balcony changes position according to the floor. For module M2, that contains the toilet, the use of redundancy is proposed. The module overlapped the platform. Here the possibility of variation consists in the option of having the room or not. The functional redundancy proposal is presented by Khalaf et al. (2011). Redundancy, according to the authors, occurs when the same function is presented by two modules, even if for one of them the presence of the function is not essential. In this case, it consists of keeping the structure ready for both layout possibilities. If there is uncertainty about the choice, there is preparation for both. In this case, the existence of facilities even for the non-occurrence of the toilet at the initial moment, keeps the possibility open for a later situation, which can also add value to the product.

The eight layout possibilities for the apartments of the original proposal by Company A were maintained. They are a result of the different module combinations. Complementary projects must receive attention so that the customization options can be previously modeled and positioned according to the client's choice in the executive project. In this case, three options can be considered: (i) hydraulic and electrical facilities are not customizable, working as a separate module that are not changed with customization; (ii) hydraulic and electrical facilities are customizable and modeled together with the architectural project, leading to a facilities module for each architectural module; (iii) Hydraulic and electrical facilities vary according to the customization options through the concept of redundancy. In Building x, the options for customising the architectural project change the hydraulic and electrical facilities. In this case, option i cannot be applied. In option ii, changes in the position of hydraulic and electrical points require modifications to the slab that belongs to the platform, deconfiguring its inalterability. Option iii allows for later product differentiation. However, redundancy must be used with caution and its impact needs to be evaluated before a decision is made. According to Khalaf et al. (2011), redundancy is often not interesting in terms of costs and profitability.

In the original proposal, the structural design of the entire building was part of a single module within the model. In this case, the structural design remains unchanged regardless of the customer's choices. An in-depth analysis regarding the modularization of the structural design and its impact was not carried out in this research.

Interfaces between modules are another important issue for modularity analysis. In the model presented, the interfaces are the walls that surround the modules. Considering the analysis from the spatial perspective, the same wall (interface) will belong to two different modules in some situations. When the same element belongs to two modules and one of these modules is modified, physical changes occur in both. In these cases, its execution can only begin after the customer choice, which affects the delayed product differentiation. All modules of the modularization proposal for Building X have at least one interface that varies with the options and hamper interchangeability between modules. In M1, the differentiation between the customization options occurs precisely in the interface, where the difference between M1a and M1b is having or not the wall that divides the kitchen from the living room. M2 impacts the presence or not of three new walls that interface with the platform. Between M3a and M3b there is a difference in the position of a door, modifying one of the interfaces. There is also a conflict caused by an interface in the balcony module, which, despite not being customizable by the customer, represents an element that changes according to the floor. The door that connects the balcony to the living room remains in the same position in the balcony module, but the interference occurs because the module itself changes its position, changing the location of the door on the platform.

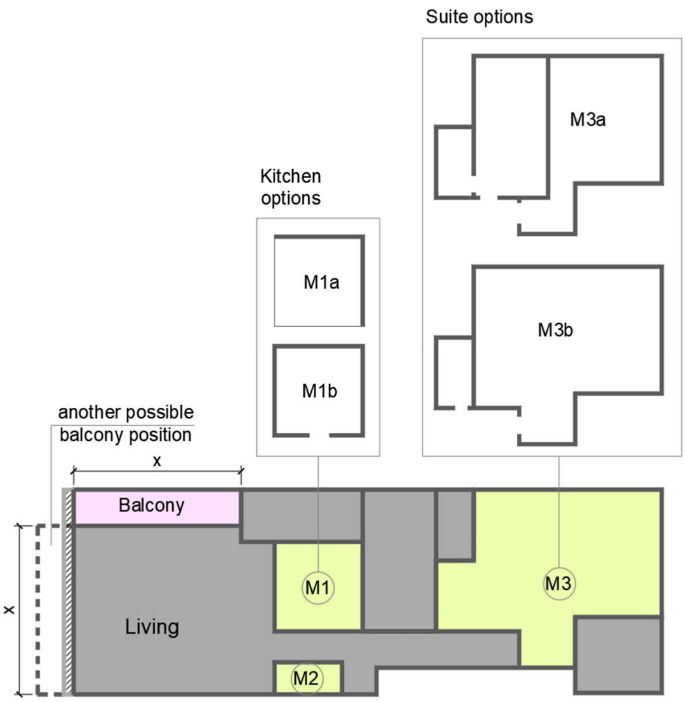

Figure 3 - Apartment modularization proposal

Lehtonen et al. (2003) state that modularity cannot be seen as a strategy only for product development, and suggest that the production system should consider modularization. For the product and production to be aligned, the work needs to be structured according to the modules and platform contained in the design (DA ROCHA; KEMMER, 2018). Regarding the use of the same modules both for the design stage and for the operations planning, the interviewees cite aspects related to the used construction method particularities. In the case of masonry walls built on site, as in Building X, there is great interdependence between modules. The execution of walls, for example, for technical reasons imposed by systems such as masonry, is planned in a way that does not consider this type of separation, being performed continuously.

DISCUSSION

The definition of the modularization perspective was identified as the first step towards the use of modularity and should consider the objectives of modularization, as well as the customization options and construction system to be used. It is understood that different perspectives can be adopted for different needs. Authors such as Da Rocha et al. (2015) and Da Rocha and Kemmer (2018) adopted the spatial perspective in their research. Hofman et al. (2009) adopt other modularization perspectives. Each perspective presents certain difficulties and benefits that must be evaluated in the definition of the perspective. From the collected results, the research identified key factors to promote the use of modularity in construction projects considering the spatial perspective. These factors will be discussed below. First, the consideration of customization options in modularization allows modules to advance beyond the basic design, expanding their functionality. Without this consideration, after client definitions, changes to the modules need to be made, making the sense of modularization to be lost. Shape and dimensions adaptations were too important for the case analysed. The unification of the balconies dimensions increased the number of module repetitions, which is positive considering the modularity assumptions. The shape and dimensions standardization was also fundamental for the options in the customizable modules to be interchangeable. In addition to shape and dimensions, interchangeability, considering the spatial perspective, requires interface standardization. The module is not fully interchangeable if its interfaces are not identical, since changes in one interface generate the need for adaptations in another as well. In this case, the interfaces of the customizable modules are not standardized, which was seen as a problem, especially considering the operations planning stage, which is another key factor to analize. The adaptation of the original floor plan to a modular floor plan didn't allow the interface's standardization, considering the customization options already defined. This also demonstrates that the design must be thought of in a modular way and not adapted later so that more benefits can be observed. Regarding the construction process, the definition of the slab as a part of the platform proved to be important considering the standard executive sequence for the construction system used in Building X. The slab is the first element to be executed on the floor, therefore, the definitions of this element must necessarily arrive before the others. The definitions of the hydraulical and electrical designs are also related to the platform configuration, since changing the position of the points can generate changes in the slab. The use of redundancy can be adopted in specific situations so that the platform does not suffer interference and does not lose its principle of inalterability. The relationship of the hydraulical and electrical facilities with the architectural modules must also be defined, considering the customization options.

Still in the construction process, in the modules of the rooms that change with the customer's choice, factors like executive sequence, interdependence between modules and characteristics of the masonry system, make site managers to prefer executing as an integral architecture. This makes it difficult for the modularization proposed for the design stage to be consistently reflected in the operations planning in this type of construction, thus limiting the benefits of using modularity. Therefore, it may be necessary to consider the constructive method when defining the modularization perspective, as its execution sequence will inevitably influence the operations planning, which, for greater benefit, must take into account the design modules. According to the interviewed employees, the proposed modules that represent the customization options could not be considered in the execution stage due to the standard executive sequence of the construction method used in Building X. Construction process planning was not studied in this research, it will be the following steps of this research. According to Da Rocha and Kemmer (2018), the modules under construction must be project-specific, that is, what is a module in one project may not be in others. This definition must consider aspects such as the executive sequence of the adopted construction system. The transit of modules through the different stages of a construction project is important so that more benefits can be observed, but it is still a challenge to propose modules that meet the different project stages.

Table 1 - key factors to enhance modularity considering spatial perspective

Customization options	Consider customization options in modules definition
	Standardization of shapes and dimensions of customizable modules for interchangeability
	Standardization of interfaces in customizable modules for interchangeability
Constructive system	Consider constructive system when define modules and modularization perspective*
	Consider the standard executive sequence in the construction system for modules and platform definition

Both customization and constructive system	Consider the interdependence between modules in the specific constructive system in modules and platform definition Interfaces standardization in the customizable modules considering the operations planning Define the relationship between the hydraulical and electrical facilities with the architectural modules considering the customization options and operations planning

The key factors to enhance modularity considering spatial perspective found in this research are summarized in Table 1, which divides them into three categories: factors related to customization options, construction system and both. These factors are interdependent, so decisions should not be taken in a fragmented way. It is important to note that although the factors related to customization options appear at the top of the table, followed by the construction system and finally the consideration of both, this does not represent a definition of a sequence in which decisions must be made. The decision and considerations are iteratives and there isn't a defined sequence. The line that presents the consideration of the construction system in the definition of modules and modularization perspective (marked with an asterisk in Table 1), although not exclusive to the spatial perspective, was considered as an important item to include in the summary table. This is a fundamental definition that must be analyzed in the early design stage.

CONCLUSION

This study discussed the application of modularity in construction projects through the modularization of a residential multifamiliar building typical apartment. The results indicate that the use of modularity can bring benefits to the basic and executive design stages, mainly if the modules consider the customization options offered. In order to expand the use of modules beyond the design stages, the modules definition should consider the construction method to be used and its executive sequence. In this research, the typical apartment floor plan modularization was carried out after the finished design, which hampered the modules functionality, mainly in terms of interchangeability due to the interfaces. Therefore, design definitions should address modularity assumptions from the early design stages since its delayed proposal leads to a loss of some of its benefits. The factors to consider when determining the modules and the modularization perspective depend on the objectives to be achieved with their implementation. They are interdependent with each other, so that, one factor can influence others. Definitions of hydraulic and electrical points interfere with the platform, and definitions of shape and dimensions interfere with interchangeability. For this reason, decisions should not be taken in a fragmented way and should consider the general context. The definition of which parts of the building should be modularized and how this modularization will be done are important so that the benefits can be achieved. Strategies must meet the needs of each particular project. Although the modularity benefits can be obtained independently of the construction system, their specificities must be considered so that their use goes beyond the design stages. The executive sequence, as well as other system characteristics, influence the construction process stage. In building X, the conditions of the modules' interfaces make it difficult for the design modularization to be reflected in the construction process considering the conventional construction, representing a relevant aspect to be analysed in future studies. An important limitation of this study is that the results are based on a single empirical case. It represents a step towards this application of modularity in construction projects.

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OPERATIONS MANAGEMENT BEST PRACTICES TO SUPPORT MASS CUSTOMIZATION IN HOUSING PROJECTS

Carlos Torres Formoso[1], Cynthia dos Santos Hentschke[2], Helena Utzig[3] and Luciana Gheller Amorim[4]

[1] Professor, Postgraduate Program in Civil Engineering: Construction and Infrastructure (PPGCI), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, formoso@ufrgs.br
[2] Postdoc Researcher, Postgraduate Program in Civil Engineering: Construction and Infrastructure (PPGCI), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, cynthiahentschke@gmail.com
[3] MSc Student, Postgraduate Program in Civil Engineering: Construction and Infrastructure (PPGCI), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, helenautzig@gmail.com
[4] MSc, Postgraduate Program in Civil Engineering: Construction and Infrastructure (PPGCI), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, lugheller@gmail.com

ABSTRACT

Mass customization is a business strategy that enables the production of a variety of products and yet keep delivery time and product cost within acceptable limits, thus increasing consumer satisfaction. It has been widely used in the manufacturing industry, and there has been growing interest in the construction industry. However, companies that deliver residential projects still find difficulties in the implementation of mass customization. Some of these difficulties are related to the fact that, by increasing the number of options offered to clients, the complexity of the production process increases, resulting on several process changes to be managed, a larger variety of materials and components to be purchased, and an increasing amount of data to be exchanged in the project. This paper describes a set of best practices that have been used by construction companies from different parts of the world for managing production in mass customized housing projects. Moreover, in-depth analyses of some of those practices have been made in an empirical study carried out in a Brazilian residential building company. The aim of this paper is to propose decision categories related to operations management for adopting mass customization in housing projects. The main contribution is understanding some underlying ideas of those practices, which are strongly related to the Lean Production philosophy.

Keywords: operations management; mass customization; lean production, best practices; construction management

INTRODUCTION

Mass customization (MC) is a strategy widely used in manufacturing, which aims to deliver products that meet the diversity of requirements and demands of a specific market, bringing competitive advantages to the company (Hart, 1995). A major challenge in MC is to deliver products that fulfil customer requirements by adopting flexible processes, while maintaining time and cost within market expectations (Pine II, 1993; Silveira et al., 2001). Addressing these challenges depend on the interrelated efforts of three areas of a company: customer integration, product design, and operations management (Ferguson et al., 2014; Schoenwitz et al., 2017).

In this study, the focus is on operations management, which includes both production and supply chain management. Introducing product changes in residential building projects contributes to increase the complexity of project execution, thus production planning and control systems are required to manage these uncertainties and changes in production sequences and volumes (Naim and Barlow, 2003; Noguchi and

Hernandez-Velasco, 2005). In this context, companies must adopt some operations management practices that help reducing the impact of customization on efficiency. Several practices have been previously reported in the literature, based on studies carried out in different countries, considering diverse degrees of industrialization (e.g., Barlow and Ozaki, 2003; Noguchi and Hernanez-Velasco, 2005; Linner and Bock, 2012). Most of them are strongly related to the Lean Production philosophy (e.g., Formoso et al., 2022; Martinez et al., 2017). However, there is a gap in knowledge due to the fact that MC-related operations management practices adopted in residential building projects have not been discussed yet at a high level of abstraction, based on core operations management concepts and principles. This has limited opportunities for transferring ideas or learning among different contexts. Therefore, the aim of this investigation is to understand a set of operations management practices used in customized housing projects based on a set of operations management concepts and principles related to the Lean Production philosophy, so that those practices can be adapted and applied in different contexts. Additionally, as a theoretical contribution, a set of decision categories related to operations management for mass-customized residential building projects has been proposed.

LITERATURE REVIEW

Mass Customization

Khalili-Araghi and Kolarevic (2016) state that mass customization is a relatively new business strategy in the construction industry, being used to reduce the impacts of product personalization. The birthplace of MC in construction was Japan, where this strategy is still largely applied in the house building industry (Gann, 1996; Linner and Bock, 2012). In Japan and in the USA, the advanced adoption of mass customization is closely related to prefabrication and industrialization of construction (Linner and Bock, 2012). Meanwhile, in other countries such as Brazil, UK and Ecuador, residential building companies also customize their products, but still adopt traditional construction methods (Martinez et al., 2017; Fettermann et al., 2019; Roy et al., 2003).

Martinez et al. (2017) argue that producing completely personalized products and maintaining the balance of efficiency and flexibility is not economically feasible once the full consideration of preferences and needs significantly increases the project and production management complexities. According to Brandão (2002), the difficulties of maintaining competitive prices of customized houses in the Brazilian market is directly related to the lack of effective management of processes related to customization.
According to Barlow and Ozaki (2003), the streamlining of processes is essential to adopting MC in the construction industry, while Fogliatto et al. (2012) pointed out that the Lean philosophy can be considered as an enabler for MC. These are the main connections between MC and Lean Production suggested in the literature:

a) Focus on value generation (Koskela, 2000; Piller et al., 2004) and production efficiency (Nahmens and Bindroo, 2011);
b) Adoption of pull production, enabling the production of customized goods to be pulled by customers' orders (Pine II, 1993);
d) Using economic batch or reducing batch sizes to rapidly respond to frequently changing market demands (Pine II, 1993);
e) Supply chain integration and collaboration (Naim and Barlow, 2002); and
f) Reduction of lead time by adopting prefabrication and integrating the supply chain (Barlow et al., 2003; Linner and Bock, 2012).

Product customization can be introduced both in different construction stages, ranging from the full customization of the products down to the adaptation of products after delivery by the users (Rudberg and Wikner, 2004). The customer order decoupling point (CODP) can be defined as the moment when the customer order starts to be considered in product customization along the value chain, dividing the activities into based on forecast demand (pushed) and to achieve customers' preferences (pulled). The CODP is strongly dependent on the definition of product customization level. In practice, this point can represent the postponement of some activities to be carried out until the customer order determines choices for the remaining activities (e.g., finishings).

Best Practices

Best practices can be defined as activities, techniques, methods, processes, and tools able to improve the performance of a company (Cleto et al., 2011), recognized as the best way to perform such activities. Fetterman (2013) states that jointly using those practices allows the introduction of changes in new product development (NPD). Cleto et al. (2011) suggest that best practices can be described as know-how knowledge established by a kind of consensus that is developed over time, based on criteria of efficiency and effectiveness. According to Loo (2000), adopting and creating best practices requires specific capabilities and knowledge to achieve the expected results and high performance. Lillrank (1995) argues that practices can be converted into abstract concepts and ideas and be conveyed to distinct contexts or cultures. Moreover, such translation into abstract ideas enables the improvement of practices through critical thinking and reflection.

Several MC practices have been discussed over the last few decades for manufacturing (Echeveste et al., 2017) and housing (Fettermann et al., 2019; Hentschke et al., 2020). In this research study, some operations management related practices were identified in the literature, such as: (i) implementation of information and communication technology systems for managing production of customized products (Shin et al., 2008; Martinez et al., 2017; Hentschke et al., 2020); (ii) use of industrialized components produced off-site to reduce lead time (Barlow et al., 2003; Linner and Bock, 2012); and (iii) adoption of postponement strategies for late customization, through additional work at the delivery point (Formoso et al., 2022; Rocha et al., 2016; Valente et al., 2019).

METHOD

The research method used in this investigation fits the Design Science Research (DSR) approach, which aims to develop an innovative construction, intended to solve problems faced in the real world and, by that means, to make scientific contributions (Lukka, 2003). The practical problem addressed in this research study was how MC housing companies can learn from operations management best practices, based on Lean Production concepts and principles, and reduce the impact of customization in costs and duration.

The study had three phases: (i) identification of operations management practices related to MC; (ii) assessment of some of those practices by carrying out an empirical study; and (iii) identification of underlying ideas of best practices by establishing connections between them and Lean concepts.

The first phase was based on academic publications that described MC practices from the industry. These practices were analysed and categorized according to a set of four categories that were proposed in this study.

The second phase refers to an empirical study undertaken in a Brazilian company that develops and builds residential and commercial building projects, named Company A. Two main reasons led to the choice of this company: (i) the provision of customized housing projects as part of its competitive strategy and (ii) the company has a business unit dedicated to the customization of housing units, which was interested in taking part of this investigation. In this empirical study, an in-depth analysis of some of the practices selected in the first stage of the investigation was undertaken, and the set of practices identified from the literature was extended. Multiple sources of evidence were used to increase the reliability and validity of research results through triangulation. These were: (i) semi-structured interviews; (ii) direct observation at construction sites; (iii) analysis of document that described the customization process; and (iv) participant observation (planning and control meetings). Table 1 presents details about the different sources of evidence. The best practices were captured in 20 interviews carried out with architects, production managers, and other professionals (36 hours in total), and through visits to two construction sites. Those visits contributed to the analysis of the impacts of customization in execution stages. Moreover, semi-structured interviews and site visits were also useful to understand and map the customization process, which provided insights on improvement opportunities, including communication failures. The third phase involved the analysis of data and reflection on the findings. Two meetings were held to discuss the results with Company A's representatives: (i) in the first one, improvement opportunities were discussed with customization team members; and (ii) in the second meeting, the final results of the research study were presented to representatives of different sectors of the Company A involved in customization processes.

Table 1: Sources of evidence

Source of Evidence	Details and Participants	Duration
Semi-structured interviews	Customization Coordinator (architect)	2h
	Customization Architect	1h30min
	Project Coordinator (architect) and Project Analyst (civil engineer)	2h
	Product Development (intern)	1h
	Construction General Manager (civil engineer)	2h
	Customization Director (civil engineer)	1h30min
	Construction Manager (civil engineer)	2h
	Construction Manager (civil engineer)	1h
	Product Development Manager (civil engineer)	1h
	Construction (civil engineer intern)	2h
	Customization Architect in charge of "point of delivery customization"	1h
Interview	Product Development (intern)	1h
	On-site construction (civil engineer intern) A	3h
	On-site construction (civil engineer intern) C	3h
	Product Development (intern)	30min
Observations	Customization status on-site (PCP meeting)	2h
	Design and Product Intelligence (PDCA meeting)	2h
	Participant observations of the customization team (CT)	1h30min
Document analysis	Design drawings, Project customization management spreadsheet (from CT, Construction team, Design and Product Intelligence team)	
	Photographic records from construction sites (from CT, Construction team, Design and Product Intelligence team)	
	Documents used in the construction site	
Meetings	Meeting with the CT to discuss research findings	4h
	Meeting with the CT, manager, and representatives from other departments to discuss research findings	2h

RESULTS

Identification of Operations Management Best Practices in the Literature

Table 2 presents the 24 operations management practices concerned with MC that were identified in the literature review. These were described in research studies from different countries: Brazil, Ecuador, Germany, Japan, Mexico, South Korea and UK. The operations management practices were assessed and divided into four categories: (i) Communication of Customization Options, (ii) Supply Chain Management, (iii) Production Planning and Control and (iv) Production System Flexibility.

Communication of customization options practices are concerned with creating effective and standardized information flows, as companies often face difficulties and constraints in communicating the scope of customization across the different processes involved in MC. Eight practices were identified in this category, and these were strongly related to collaboration, continuous improvement, increase transparency, systematically considering customers' needs and simplify by reducing the number of steps and parts.

Practices associated with **supply chain management** are related to the off-site production of industrialized components and sub-systems, and also with the need of establishing a close relationship with product and service suppliers, so that they can get involved in customization processes. Four practices in this category were identified and these were related to several Lean principles, such as simplify by reducing the number of steps and parts, increase flexibility, increase transparency, reduce lead time, and systematically considering customers' needs.

Regarding **production planning and control**, eight practices were identified in this category, and these were strongly related to the principle of pull production. Some of these involved the use of planning techniques and tools which combined push and pull mechanisms, and visual management, so that project flexibility could be achieved without negatively affecting time and cost performance.

Lastly, practices related to **production system flexibility** are associated with processes and tools that enable late customization. Four practices were identified in this category, and these were related to the principles of increasing flexibility, reducing lead time, and reducing set up time. Most studies pointed out that effective MC strategies are the result of the combined adoption of these practices. Some of them support decision-making towards product definition and production system design, while other practices provide support to implement those decisions.

Table 2: List of practices from the literature

n◦	Practices' brief description	Related Lean principles
Communication of Customization Options		
1	Carry out routine construction site visits to check customers' orders compliance by the design team (Hentschke et al., 2020; Formoso et al., 2022)	Collaboration, continuous improvement
2	Clearly present the customization options (Rocha, 2011; Valente et al., 2019)	Increase transparency, systematically considering customers' needs, simplify
3	Cost modelling of customization options (Rocha, 2011)	Increase transparency, simplify
4	Share among different sectors a status control board of customers customization orders regarding the housing units (Valente et al., 2019; Hentschke et al., 2020)	Increase transparency, systematically considering customers' needs, simplify
5	Use prototyping to test and communicate technical and design solutions to stakeholders (Hentschke et al., 2020; Valente et al., 2019)	Increase transparency, continuous improvement
6	Use of visual devices to plan and control workspace (Valente et al., 2019; Formoso et al., 2022)	Increase transparency, systematically considering customers' needs
7	Use of information and communication technology systems for managing production of customized products (Shin et al., 2008; Martinez et al., 2017; Hentschke et al., 2020)	Increase transparency, simplify, continuous improvement

8	Document modifications requested and performed by customers (Rocha, 2011; Formoso et al., 2022; Piller et al., 2004; Linner and Bock, 2012)	Continuous improvement, systematically considering customers' needs
Supply Chain Management		
9	Apply product modularity to increase interchangeability and decoupling of components (Rocha, 2011; Fettermann et al., 2019; Schoenwitz et al., 2017)	Increase flexibility, simplify
10	Use of industrialized components produced off-site to reduce lead time (Barlow et al., 2003; Linner and Bock, 2012).	Simplify, reduce lead time
11	Establish supply chain partnerships (Barlow et al., 2003; Rocha, 2011; Formoso et al., 2022)	Increase flexibility, reduce lead time, systematically considering customers' needs
12	Use visual planning tools for supply management (Valente et al., 2019)	Increase transparency
n◦	**Practices' brief description**	**Related Lean principles**
Production Planning and Control		
13	Define customization levels according to decoupling points in long-term planning (Rocha et al., 2016).	Increase transparency, pull production
14	Use of postponement strategies for late customization through additional work at the delivery point (Formoso et al., 2022; Rocha and Kemmer, 2013; Valente et al., 2019)	Increase flexibility
15	Define deadlines to pull sets of customization activities (Rocha, 2011)	Increase transparency, pull production
16	Define sets of customization options that can be ordered according to the production stage (Formoso et al., 2022)	Increase transparency
17	Devise a process mapping involving multiple sectors of the company (Rocha et al., 2016)	Increase transparency, reduce lead time
18	Use of precedence diagrams for pointing out the customer order decoupling points (Formoso et al., 2022; Valente et al., 2019)	Increase transparency, pull production
19	Use of location plans to point out windows of opportunities for customization options (Valente et al., 2019)	Increase transparency, pull production
20	Use of visual devices for managing chains of constraints related to customization (Valente et al., 2019)	Increase transparency, pull production
Production System Flexibility		
21	Adopt processes that allow late customization or postponement strategies (Rocha, 2011)	Increase flexibility, reduce lead time
22	Use of additive manufacturing technologies for the production of customized components (Linner and Bock, 2012)	Increase flexibility, reduce set up time
23	Use of building systems that result in very low cost of customization options for customers (Formoso et al., 2022; Piller et al., 2004; Schoenwitz et al., 2017)	Increase flexibility, reduce set up time
24	Include redundancy in design to allow product flexibility, for instance, by including additional pipes or connections (Formoso et al., 2022)	Increase flexibility

Company A's Operational Management practices assessment

From 24 practices identified in the literature review, eight were found in the company involved in this empirical study. The set of practices was assessed by the degree of implementation and classified into three categories: applied, partially applied, and not applied. Company A fully applies 12,5% of the operations management best practices (practices 1, 13, 23 in Table 2) and partially applies 20,8% (practices 2, 4, 5, 13, 23 in Table 2). Sixteen practices (66,6%) were not applied in Company A.

The list of operations management practices pointed out improvement opportunities for Company A: 54% of them were not applied in Company A, but can potentially improve the customization process (practices 2, 6, 7, 8, 10, 11, 15, 16, 17, 18, 19, 20, 21 in Table 2). By contrast, three practices were not immediately applicable in the company due to technological issues. In other words, its implementation would require substantial efforts and investment compared to the other practices recommended. Therefore, Company A's implementation of MC practices was low, considering the large number of practices identified in the literature.

In relation to the previous literature, two additional practices were identified in the empirical study related to **communication of customization options**. The first one was the use of visual devices for identifying units to be customized: visual signs were displayed at the entrance doors of the units. When the unit is personalized, the symbol of the customization business unit was used to call the attention of the crews. The second one was also related to visual management: the use of visual devices to provide details about the design of the customized units. Moreover, Company A also offered several types of redundancy in design, especially related to building services (practice 24 in Table 2), as this provided opportunities for late customization during the construction stage, for instance, by having spare electrical pipes in the concrete slab in the case customers would like to add new drywall partitions.

Decision Categories related to Operations Management for MC in Housing

The division of MC operations management best practices into categories enabled several connections to be established to concepts and principles from the Lean Production philosophy. Table 3 presents a connection between the different decisions involved in those categories and Lean principles.

Table 3: Decision categories related to operations management for MC in housing

Decision categories	Set of decisions	Lean Principles
Communication of Customization Options	Use of a standardized information flow	Standardization, increase process transparency and collaboration
	Effective communication of customization options	Continuous improvement, collaboration and increase process transparency
Supply Chain Management	Apply supply chain modularity	Interchangeability and increase flexibility
	Use of prefabricated components or construction industrialization processes	Reduce lead time and simplify
	Establish supply chain partnerships	Collaboration and increase transparency
Production Planning and Control	Use of a hierarchical planning and control process and define decoupling points (CODP)	Increase process transparency, collaboration, pull production and introduce continuous improvement
	Apply process modularity	Reduce batch size and introduce continuous improvement
	Operations management of additional customization activities	Increase transparency, collaboration and systematically considering customers' needs
Production System Flexibility	Apply multifunctionality in the process	Autonomy and collaboration

	Use of flexible automation technologies	Increase flexibility and reduce set up time
	Use of technologies for late customization (postponement strategies)	Increase output flexibility, simplify and reduce batch size
	Design redundancy	Increase output flexibility

Decisions related to **communication of customization options** are concerned with both standardisation of information flows and effective communication of customization options. The former refers to the information flows involved in customization processes, which must be reliable and standardized to support the execution of tasks, while the second one is concerned with creating information fields, with the support of visual devices, which communicate up-to-date information in the working environment.
Some decisions regarding the **supply chain management** category have been proposed. First, the concept of supply chain modularity can be used to increase the number of possible suppliers, assuming that some components are interchangeable. Second, the use of prefabricated components can potentially reduce lead times and simplify the process. Last, establishing partnerships with supply chain members can provide the necessary collaboration to involve suppliers in customization processes.

Decisions associated with the **production planning and control** category are concerned with the adoption of hierarchical production planning and control systems, process modularity, and the management of complementary activities. Using a hierarchical planning and control process and identifying decoupling points (CODP) allow some production activities to be pulled by using collaborative and transparent processes, reducing the impact of customization on production efficiency. Applying process modularity is important for reducing batch size, and creating repetition, enabling learning and continuous improvement. The last one depends on specific managerial procedures for very late customization by enabling the execution of activities just before product delivery to avoid disruptions in the main production management system.

Regarding **production system flexibility**, a set of decisions are presented and related to labour multifunctionality, use of technologies for flexible automation, and design redundancy to allow late customization. Multifunctionality provides some degree of autonomy to the production system, making it capable of performing different functions. By using flexible automation technologies, it is possible to reduce the set-up time and by using technologies that allow late customization, reduce batch size, and simplify by reducing the number of steps or parts. Design redundancy, especially in the case of building services, allows the postponement of some customization decisions, even after project delivery.

CONCLUSION

This paper has identified operations management best practices from the literature and made an in-depth analysis of some of those practices in the context of a housing company. The set best practices identified in this study have been described by using Lean Production concepts and principles, which may facilitate their adoption in different companies and contexts. The empirical study undertaken in this investigation enabled the reflection upon the adoption of operations management practices, and provided an opportunity to get in-depth understanding of some of those practices. From a practical point of view, several operations management practices were identified and their impacts analysed. In addition, some new practices related to visual management were identified in the empirical study.

Four operations management decision categories for customized housing projects have been proposed and connected with lean principles. The **communication of customization options** decision category is concerned with standardization of information flows, and the use of process transparency for communicating information about customization. This decision category strongly affects the effectiveness of information exchange and collaboration, which contributes to increase the efficiency of the production system. The **supply chain management** decision category is concerned with the involvement of suppliers in the customization processes, by increasing the level of collaboration in the supply chain, which can contribute to increase efficiency and reduce lead time. A strong synergy was found between the **production planning and control** decision category and lean principles, especially the concept of pull production. This is strongly associated to the adoption of hierarchical planning and control systems and to the definition of customer order decoupling points. Finally, the **production system flexibility** decision category is mostly related to minimizing the trade-offs between efficiency and flexibility, involving the adoption of design redundancy, multifunctionality, automation, and postponement strategies.

This paper has scratched the surface of the connection between the mass customization operations management best practices and lean principles in the context of housing projects. There are still several opportunities for future research regarding the operations management best practices and decision categories, including their influence on core decision categories, and other areas (e.g., customer integration and design). For instance, the use of redundancy in design and operations to increase product and process flexibility must be explored, including the assessment of trade-offs. Another future research opportunity is to investigate the use of advanced operations management practices in highly industrialized building systems, such as modular construction.

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IS INDIA'S CONSTRUCTION INDUSTRY READY FOR PREFABRICATION: A MACHINE LEARNING VIEW

Zehra Zaheer[1], Furquan Azeez[2], Ajith Salvin Atony[3]

[1 2 3] Student, BMS School Of Architecture, Bangalore, India, zehra02zaheer@gmail.com, furqan.s123@gmail.com, 1bq17at003@bmssa.ac.in

ABSTRACT

The construction industry in India suffered tremendously during the pandemic, and to regain its place in the market, people are looking for quicker, sustainable, and labor-efficient alternatives. Sustainability is a huge blanket where prefabrication is explored by investigating and utilizing data-driven machine-learning techniques. The study identifies concrete as a commonly used construction material, having an enormous carbon footprint. Incorporating an alternative like prefabrication is an economical and environmentally sustainable solution to this problem as it generates minimal waste compared to conventional construction methods.

A questionnaire-based survey will be used to investigate the factors that are hindering the stakeholders working in the construction industry and the common masses from using prefabricated structures. This scenario will be further examined with a qualitative approach where different observations are recorded by interviewing various stakeholders such as manufacturers, contractors, investors, architects, and engineers involved in the industry. Following stages of implementation, we use artificial intelligence tools, by forwarding chaining data sets. Our study found that artificial intelligence can be used in four different ways: (a)in the design of a single module; (b) in an arrangement of prefabricated modules in optimal orientation that conserves energy; (c) in topological optimization, and (d)climate responsive design. The strategies presented in the paper are explored by finding solutions for tangible and intangible situations. Solving the tangible factor comes when selecting the most applicable and convenient iteration of a few parameters. Integrating solutions based on artificial intelligence for these practical situations will accelerate the design process.

The paper highlights the adaptability of prefabricated structures which allows them to be employed in a variety of sectors including military, disaster relief, mass manufacturing for housing, and commercial purposes. They have the potential to reduce construction costs and time while simultaneously enhancing efficiency with the use of computer-assisted tools.

INTRODUCTION

Given that it generates investment opportunities in a number of linked industries, India's construction industry is a significant indicator of the country's development. It made an estimated 6,70,778 crores in factor-cost contributions to the national GDP in 2011–12, or around 8.2 percent. The industry is labor-intensive and employs more than 49.5 million people, including indirect jobs. The labor force is a crucial component of the construction industry since they perform various duties that support daily operations on the construction site. (*Construction industry of India - Wikipedia*,*2012*) The National Industrial Development Corporation (NIDC), the first established professional consulting firm, was founded in the public sector in 1954. Numerous architectural, design, and construction firms were subsequently established in both the public and private sectors, including Indian Railways Construction Limited (IRCON), National Buildings Construction Corporation (NBCC), Rail India Transportation and Engineering Services (RITES), Engineers India Limited (EIL), and M N Dastur and Co., Hindustan Construction Company (HCC), Ansals, among others. Over the past 50 years, around 40% of development investments have gone toward India's construction. Construction provides a living for about 16% of the country's working population. More than

30 million people are employed in the construction sector in India, which also generates assets worth more than 200 billion.

Countries are becoming more open to sharing knowledge and combining their diverse foreign experiences. With businesses looking to adopt and implement international best practices, a trend that could lead to significantly higher profits, higher levels of customer and employee satisfaction, improved safety and productivity, and reduced environmental impact is beginning to find its rightful place in India as well. There is an increasing demand from customers and businesses all over the world to reduce the carbon footprint of the built environment due to the associated material flows, energy consumption, use of embodied energy and fossil fuels, environmental impact, and waste involved in traditional "brick and mortar" construction of real estate and infrastructure projects. Industrialized assembly line production mechanisms that employ prefabricated, precast technologies are becoming more significant and are being evaluated for implementation as a response to the increased need for green and sustainable development.

The introduction of new construction technologies and their integration into the construction industry has created tremendous changes in the way buildings are designed, planned, and implemented. Prefabrication, topology optimization, and 3D printing are some of the techniques used and supported by artificial intelligence and machine learning tools. A prefabricated construction method is a construction method in which building components are assembled on-site after being cast off-site in a factory or manufacturing facility. Assembling parts at the workplace is not complicated and saves time. Almost every component of the structure can be custom installed, from windows, wall panels, and stairs to the construction of roof slabs, roofs and entire building modules. Prefabricated construction is applied to highly regulated production conditions and requires extensive planning. Recently, it has become more popular because as it has made it possible to manufacture important building components offsite and transport them directly to construction sites for installation.

For more modern methods like topological optimization and generative design, which may be built off-site with the aid of 3D printing, prefabrication is godsent. Topological optimization is used to lighten a shape by removing material from non-essential areas, but in this case, the shape is already defined. In contrast, with generative design, you ask the computer to generate several options while considering the preferred material and manufacturing method to produce various feasible outcomes that are appropriate for the situation. For many years, mechanical and civil engineers have utilized topology optimization to reduce the amount of material needed and the strain energy of structures while preserving their mechanical strength. To create the most effective design, topology optimization physically removes material from a 3D design space. The technique is unconcerned with aesthetics, conventional methods, or any other typical design limitations that are employed in the design. In its most basic form, provided the loading and constraint systems are specified, the system will calculate the amount of material required to create that load path. With the use of a mathematical model (algorithm), topology optimization is a type of generative design software that creates designs for problems that are optimized for material, density, shape, and space. It takes advantage of designer-entered metrics such as applied load, space restrictions, development approaches, and more. The method repeats a design space using 3D modeling to optimize the design for performance and material costs.

PREFABRICATION

Prefabrication has played an important role in architecture and has been applauded for its capability to boost production and efficiency without compromising quality. the industrialized and developed nations like the united states of America, Japan, and Europe where there is a continued demand for better, faster, and cheaper buildings amongst the middle-class groups that vary from the extraordinary to the mundane structural equations. On the other hand, prefabrication also has the potential to help developing nations, such as China, India, Africa, and much of South America, build dwellings swiftly and inexpensively.

However, there is still a long way to go where we can develop such models which are more culturally inclusive and environmentally friendly. The numerous methods and technology aided by machine learning tools are further elaborated on in this paper. Over the past few decades prefabrication has significantly changed the way the global construction industry has evolved. This technique is preferable to the conventional way of construction as it guarantees stability, durability, affordability, and environmental or climatic performance of the construction. The different terminologies used to describe the methods of generating modular units on-site or off-site include pre-assembly, prefabrication, modularization, system buildings, and industrialized structures. India is a rising and developing country where there is a continuous demand for fast and affordable construction which should also be environmentally and socially conscious of its surroundings. The whole concept of this technique began with the establishment of the Hindustan Housing Factory in India which further progressed with the support of our first Prime minister, Pandit Jawaharlal Nehru as a response to the housing need to be brought on by the 1950s flood of refugees from West Pakistan.

History

The technique of prefabrication is not a recent addition to the construction industry, rather it dates back to ancient times, from prehistoric to River valley civilization followed by historic period including Vedic Aryan civilization and Hindu temples. Although the technique has undergone various improvements and modifications concerning its execution and design keeping in mind various factors like environmental conditions, skilled technicians, and material availability. A few examples of prefabricated structures during prehistoric times are discussed as follows:

The Stonehenge: The 66m high structure which was built in stone during the Neolithic period (3100) known as 'the Stonehenge' is a great example of a prefabricated structure during ancient times. Arranged in a concentric ring pattern the monumental structure utilizes mortise and tenon joints to ensure its stability and aid in the assembly of the structure as shown in Figure1 below. (Prasher, 2016)

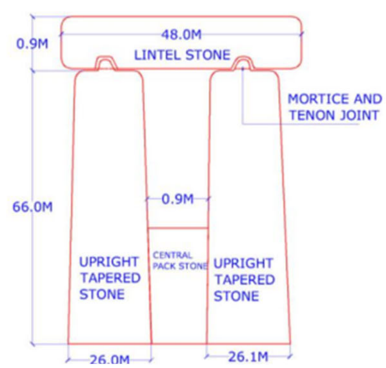

Figure1: Stonehenge with section showing the joining of stone lintel and post

Source:(*Architecture Design Architectural Images Drawings History and More - ArchitectureWeek Great Buildings*, 2011)(Prasher, 2016)

Ancient Sri Lanka (3000 BC): The "Ancient Sinhalese King of Sri Lanka" experimented with the construction method 2000 years ago. Building components were individually prepared off-site before being assembled on-site. Years later, we can still see evidence of the impressive success of this strategy in creating individual parts and assembling them in the field. (Prasher, 2016)

Figure 2: Vatadage Temple, Polonnaruwa (Left) and Nissanka Latha Mandapaya Polonnaruwa(Right)
Source:(*Nissanka Latha Mandapaya - Ancient City of Polonnaruwa | www.lankatraveldirectory.com*)

Prefabrication was not only used in built forms but also has been used in the construction of the world's oldest roadway in England known as 'The sweet Track' in the year 38000BC. Additionally, after the great Lisbon earthquake of 1755, the Portuguese capital was rebuilt to an unprecedented scale with the help of prefabrication mainly in the Baixa district under the supervision of Sebastio Jose de Carvalho e Melo. It led to the development of an entirely new architectural and urban design style for the Pombaline region, utilizing cutting-edge prefabricated building techniques and pioneering seismic design concepts. (Engineering seismologyAMBRASEYS N, 1985; Zayas, Low and Mahin, 1990; Lindeburg and Baradar, 2001; Pollini, Lavan and Amir, 2018)

METHODS FOR PREFABRICATION

Plant prefabrication and site pre-construction are two major methods of prefabrication wherein the former is the process in which the prefabricated components are manufactured offsite in a factory under precise quality control, inspection, and testing and then transported to the construction site for final execution. Now coming to the latter method which components are manufactured and assembled on-site, no transportation is required, but it requires lifting equipment to assemble the prefabricated components. Moreover, there are other five methods for prefabricated building construction including concrete panels, steel frames, timber frames, Panelized wood frames, and sandwich panels. after the manufacturing process, these components are transported and brought to the construction site through flatbed trucks and further assembled with proper finishing.(Hamza Asif, 2017) Other environmentally sustainable materials used in prefabrication are hempcrete panels, bamboo, reclaimed or recycled steel and wooden members, recycled plastic, and cork panels.(Rinkesh, 2021)

CURRENT TRENDS AND FUTURE POSSIBILITIES

The prefabricated building sector in India is predicted to increase at a compound annual growth rate (CAGR) of more than 8% throughout the forecasted period. (2022-2027). By 2022, India will be in need of 50 million homes, and more than 90 smart cities are now under construction. Prefabricated housing and off-site construction, according to industry observers, will be crucial for achieving such sizable goals in such a short amount of time. There are many opportunities for prefab businesses in India, and thousands of factories are expected to be required in the future. In the coming years, India's building production is predicted to increase at one of the fastest rates, necessitating technological intervention. By 2025, India is anticipated to overtake China as the third-largest building market in the world. (“Construction industry of India”,2012)

LITERATURE REVIEW

Post-war social housing development in a south-eastern Mediterranean climate:
It proposes an innovative methodological framework for optimizing post-conflict social housing development in south-eastern Mediterranean climates. The purpose of this study is to understand concerns related to building overheating comfort assessment, occupant behavior, modeling, and design approaches. In addition, the authors include the range of occupant behavior, variation in building thermal properties, energy governance structure, and energy financing objectives(Cristino *et al.*, 2021) This is why the Republic of Cyprus lacks strict building regulations and various control systems that can verify the effectiveness of energy efficiency subsidies.(Ozarisoy and Altan, 2021a). To reduce the burden on existing stock, the government has changed the delay framework and adopted The Energy Performance of Buildings Directive EPBD guidelines to make significant changes to the thermal performance of existing building stock. It was one of the first to recognize social housing stock as a typical building type to address energy efficiency gaps. The thermal performance of building components in a base-case post-war social housing estate in Famagusta, Cyprus, was examined in this empirical study, and several retrofitting initiatives were implemented to maximize the energy performance of each structure.(Ozarisoy and Altan, 2021b)

Researchers from Cyprus have created a brand-new benchmark standard for evaluating and enhancing the energy efficiency of post-war social housing constructions. The research was not restricted to Cypriot homes; it applied to other European nations as well. This modification will make it possible for academics to better understand how governance capability is used to control intricate social and material linkages.

Capsule tower Tokyo:
Built-in 1972 the Nakagin Capsule Tower is located in Ginza District, Tokyo, Japan by Kisho Kurokawa. This building is one of the few unique examples of metabolism architectural movement which exhibits combined innovative concepts of megastructures with those of organic biological growth and a physical expression of Japan's postwar economic and cultural revival. This tower was constructed using 140 self-sufficient prefabricated modular units which measure 2.5m by 4.0m with a 1.3m, window diameter functioning as a living pod that can also be used as an office space as and when required. The construction process took place both on-site and offsite where the former included the construction of two towers with their energy supply systems and equipment whereas the capsules were prefabricated offsite and assembled on the construction site. The capsules are interlocked and attached to the main shaft with the help of only four tension bolts and are utilized for vertical circulation. These units were designed in a way such that they can be mass-produced and replaced according to the needs of the users.

The vertical core was constructed with steel frames and reinforced concrete. Lightweight concrete was used for floors above the basement and the staircase was pre-casted assembled and fixed on site. The 3-D frames, tracks, and anchor indicator boxes were included into precast concrete parts and prefabricated cages were used to speed up the assembly of the elevators on-site. The building is still in use as of 2010 but is falling into disrepair. Earlier in 2007, the building's residents decided to demolish the building and replace it with a much larger, more modern tower due to its dirty, cramped conditions and concerns about asbestos. Kurokawa suggested using the flexible design by "removing" the existing box and replacing it with an updated unit to preserve the design. From this example, we can also conclude using prefabricated units helps in the reduction of waste generation and also allow us to recycle and reuse individual components which can adapt to the evolving needs of the end users with changing times thus making this prefabricated model sustainable in every aspect (*Decaying but beloved, Tokyo's Capsule Tower faces uncertain future | Japan | The Guardian,2021*).

ADVANTAGES OF PREFABRICATION

Prefabrication provides several benefits, including improved energy efficiency, reduced waste creation and disposal, tight product inspection, effective construction, quick work pace, protection, sustainability, and high quality. In addition to these, prefabrication has the following additional advantages:

1. This technology in the construction industry helps in saving time and buildings are completed sooner allowing an early return on capital investment.
2. Quality control is easier in an offsite manufacturing process thus the end product is of precise and good quality.
3. It is very using building structures on an uneven or difficult terrain
4. The construction of each module is not affected by weather conditions as all the units are manufactured in a factory environment and its construction and manufacturing are not hampered by the exterior site conditions.
5. Self-supporting readymade structural components can be easily generated and manufactured according to the requirements.
6. This technique is very useful in the production of mass production and customization of units.
7. Costs of labour, power, materials, space, and overheads are lower.(*Uses and advantages of the HDPE*, 2022)
8. Lower environmental impact
    a. Accelerated offsite production of parts results in reduced emissions and work disruption. This minimizes local plant and wildlife disturbance and protects surrounding wetlands or protected areas.
    b. The controlled, dry environment of modular construction saves water consumption and allows scrap and other materials to be recycled. Additionally, fossil fuel consumption plummets with less on-site traffic and streamlined transportation.(VIN Civil World, 2021)
9. Flexibility: It is easy to disassemble and move modular construction to various sites. This greatly decreases the demand for raw materials, minimizes the resources spent, and overall reduces time. Modular construction also allows for versatility in the structure's design, allowing for an infinite number of possibilities. Since prefabricated building units can be used in various spaces, their neutral aesthetics can be combined with almost any form of construction.
10. Upcoming techniques like topological optimization integrated along with prefabrication can help in the production of more efficient and optimized.

DISADVANTAGES OF PREFABRICATION

Many researchers have shown that prefabrication adoption has an equal number of challenges in addition to the advantages that are linked to its application/usage. A few of them are listed below:

1. Inflexible for design changes during later stages of the construction process.(K and K, 2020)
2. Lack of adequate transport and logistics in India. Since prefabrication is a recently developed and upcoming technology in developing countries like India there are a few difficulties with respect to its transportation and logistics which can be improved and made efficient in the future with the help of computer-aided machine learning tools making it suitable for the Indian context.
3. Leakages may occur in prefabricated units if not precisely fixed.
4. The cost of manufacturing is more due to a lack of demand and awareness about this technique but since India is still a developing country and has a higher probability of future growth prospects wherein prefabrication may play an important role. As the demand in the future increases, the cost of production automatically decreases making it economically feasible for all.
5. Heavy-duty cranes and precise measurement from handling to a location on site are needed for large prefabricated items.

6. The necessity for experienced labour on-site and a lack of on-site automation are two major obstacles to adopting prefabrication technology in construction that demands accuracy and precision.(VIN Civil World, 2021)

Like all other construction techniques prefabrication too has its own drawbacks as mentioned above which can be overcome with the advancement and innovation of new technologies(*Uses and advantages of the HDPE*, no date b)

RESEARCH METHODOLOGY

The research approach chosen for this paper comprises a questionnaire-based survey that was circulated to different stakeholders including architects, civil engineers, manufacturers, contractors, investors, and end users or the consumers who are directly or indirectly part of the construction industry in India. Various criterias were derived from the understanding of various literature studies and a set of 34 questions were formulated along with seven questions which were about the respondents' personal profile.

QUESTIONNAIRE SURVEY

Table 1: Percentage of respondents for each category under occupation.
Source: Courtesy of the author.

S.no	Occupation	Number of respondents	% of respondents
1.	Architect	26	22.6
2.	Engineer	15	13
3.	contractor	13	11.3
4.	Manufacturer	7	6.1
5.	academician	16	13.9
6.	Student	15	13
7.	Other	23	20

The survey consisted of two major parts which aimed at investigating the perspective and understanding of various stakeholders on prefabrication and artificial intelligence. Further we identified and established three additional sustainability criterias namely: environmental, social, and economical that is aimed at understanding the significant role of prefabrication aided with machine learning tools that could assist various stakeholders in designing and living in better, more efficient, and sustainable built environments. The questionnaire was then circulated by email and social media platforms to 200 including industry professionals and the end users/consumers. As presented in table-1, there were 115 respondents, resulting in a response rate of 57.5%.

DATA ANALYSIS

The questionnaire consisted of a closed ended question where the respondents were required to give rating on a scale of 1 to 5 for different criteria in each section. Majority of respondents were of age ranging from 28 to 39 years where 55.7% were male and 42.6% were female. 54.8%of the majority was observed to have 0-5 year's experience in the construction industry. Moreover, maximum responses received are from architects which account to a total of 22.6% followed by academician (13.9%), engineers (13%), students (13%), contractors (11.3%) and manufacturers (6.1%) along with respondents who are the end users or consumers.

Table 2: Response recorded to understand the perspective of various stakeholders in the industry.

S.no	Questions	Strongly agree	Agree	Neutra l	Disagree	Strongly disagree	Remarks and findings
		Number	of	people			
1.	Prefabrication is the future in the Indian construction industry	42 (36.5%)	50 43.5%	21 18.3%	2 1.7%	0 0%	Majority of the respondents believe that prefabrication is the future of construction industry
2.	Increase in demand of prefabrication in the near future	52 (49.6%)	37 (32.2%)	20 (17.4%)	1 (0.9%)	0 (0%)	From the survey it is observed that there is high demand of prefab construction by the majority
3.	Prefabrication is better than the conventional way of construction.	40 (34.8%)	45 (39.1%)	19 (16.5%)	9 (7.8%)	2 (1.7%)	34.8% majority feels that prefabrication is better than conventional way of construction.
4.	To what extent can prefabrication sustain in India	28 (24.3%)	64 (55.6%)	15 (13%)	6 (5.2%)	2 (1.7%)	There are high chances of people accepting prefabrication as a sustainable alternative.
5.	How useful AI can be in the construction industry	41 (35.7%)	52 (45.2%)	21 (18.3%)	0 (0%)	1 (0.9%)	35.7% of majority people believe that AI is a useful tool in deigning efficient built environments.
6.	Do you fear AI will take over the jobs of different stakeholders in the construction industry	19 (16.5%)	32 (27.8%)	29 (25.2%)	27 (23.5%)	8 (7%)	A majority of people fear that due to the advancement in machine learning technology might be a risk in their employment.
7.	Is AI the future of the construction industry	27 (23.5%)	56 (48.7%)	24 (20.9%)	8 (7%)	0 (0%)	Maximum respondents (48.7%) agree that AI is the future of construction industry.
8.	Prefabrication is supportive in unforeseen scenarios like epidemics, pandemics, wars, national emergencies, etc.	42 (36.5%)	53 (46.1%)	18 (15.7%)	2 (1.7%)	0 (0%)	It is strongly agreed by 36.5% respondent that prefab structures can be highly useful in unforeseen scenarios.

9.	Prefabrication helps in controlling construction costs by economizing on time, wages, and materials.	51 (44.3%)	50 (43.5%)	11 (9.7%)	3 (2.6%)	0 (0%)	Above 51% stakeholders strongly agreed that construction costs can be controlled by prefabrication.
10.	Prefabrication technique aided with artificial intelligence helps in easy and efficient construction over difficult terrains (like mountains, underwater, desert etc.)	45 (39.1%)	51 (44.3%)	14 (12.2%)	4 (3.5%)	1 (0.9%)	44.3% people accept that AI aided prefab structures assist in faster and efficient construction over difficult terrains.

Total number of respondents (n) = 115

From the survey responses it is observed that majority of stakeholders (54.8%) are currently not using AI tools but are willing to accept it in their design process as most of them (41.7%) believe that AI is very useful and 48.7% also believe that it's the future of construction industry in India.

Apart from these observations we also found that majority of the stakeholders (70.4%) showed their interest towards partial prefabrication as they (44.3%) simultaneously believe that prefabrication aided with artificial intelligence helps in easy and efficient construction over difficult terrains. Moreover 94.9% of respondents also believe in the economically sustainable aspect of prefabrication.

Table 3: Different criteria under sustainability (social, environmental, and economical) were identified and evaluated as shown below**.**
Source: Courtesy of the author**.**

S.no	CRITERIA:					
1	**ECONOMICAL SUSTAINABILITY**	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
1a	Prefabrication helps in saving construction costs	**38**	**57**	**18**	**2**	**0**
2a	reduction of construction time	**48**	**48**	**16**	**3**	**0**
1B		**Most significant**	**More significant**	**Neutral**	**Less significant**	**least significant**
1b	Reduction in labour due to prefabrication method	**37**	**52**	**23**	**2**	**1**
2b	Executing cost (the costs of construction activities' execution and operation on site.)	**39**	**42**	**29**	**5**	**0**
3b	Weather disruption (total duration of schedule delays due to adverse weather)	**41**	**37**	**26**	**10**	**1**
2	**ENVIRONMENTAL SUSTAINABILITY**	**Most significant**	**More significant**	**Neutral**	**Less significant**	**least significant**
2a	Site disruption (construction activities influenced by labor, materials, machinery equipment, and environment on site)	**38**	**46**	**26**	**5**	**0**
2b	Construction waste (the amount of construction waste produced onsite).	**37**	**43**	**26**	**10**	**1**
2c	pollution generation (pollution level on site (e.g., noise, dust, etc.)	**48**	**28**	**24**	**13**	**2**
2d	Energy consumption (the amount of diesel and electricity used during the construction phase)	**28**	**45**	**30**	**11**	**1**
2e	Water consumption (the amount of water used on site.)	**42**	**33**	**32**	**7**	**1**
2f	Formwork consumption (the amount of form-work used on site.)	**30**	**52**	**27**	**3**	**3**
3.	**SOCIAL SUSTAINABILITY**	**Most significant**	**More significant**	**Neutral**	**Less significant**	**least significant**

3a	Constructability (the difficulty degree of construction)	**27**	**49**	**31**	**5**	**3**
3b	Health and risk factors [risks of health and safety issues in the workplace (e.g., injury, fatality, etc.).]	**32**	**41**	**28**	**11**	**3**
3c	Construction quality [the quality and durability of a building (e.g. fewer debonding tiles and water leakage).]	**33**	**47**	**25**	**9**	**1**
3d	Aesthetic options (visual appearance of the internal and external building.)	**41**	**42**	**24**	**6**	**2**
3e	Labor availability (the amount of available labor to need.)	**31**	**40**	**34**	**9**	**1**

TOPOGRAPHICAL OPTIMIZATION

Topology optimization is a mathematical approach to optimizing material placed inside a given design area for a certain set of loads, boundary conditions, and constraints in order to maximize system performance. Topology optimization deals with the design's capacity to take on any shape within the design space rather than dealing with fixed configurations, in contrast, to form and size optimization to bear the load required. Topology optimization has various applications with its uses in the field of engineering, including civil, mechanical, biochemical, architecture and aerospace. At the moment, engineers frequently employ topology optimization at the concept stage of a design process. The result might be difficult to obtain at times because of the naturally occurring free forms. The topology optimization solution is usually modified for manufacturability as a result. The addition of restrictions to the formulation to enhance manufacturability is an ongoing research field. Since the outcomes in certain cases may be generated directly using additive manufacturing, topological optimization has an important part to play in the same.

HISTORY

In order to create the best shapes for structures and sculptures, architects and engineers have employed cutting-edge and unique techniques throughout the 20th century. The works of Robert le Ricolais, Frei Otto, Pier Luigi Nervi, Heinz Isler, Félix Candela, and Antonio Gaudi are particularly noteworthy. The common goal of all of these people was to design shapes that were both aesthetically beautiful and effective from a structural standpoint. It is unclear when structural optimization officially began. Michell's 1904 paper on optimization is usually considered the first work on the subject. The author of the article immediately emphasizes that the theory is a generalization of Maxwell's theory from a study from 1870.

The authors of this review research claim that today can be considered the beginning of topology optimization. This article summarizes the latest achievements in topology optimization over the past 150 years. Because many encounters in the early history of topology optimization were classified and the results were not published, selecting successes is a difficult task. Few people in the optimization profession are familiar with topological optimization publications from the 1950s. Around that time, some information can be found about conferences and meetings associated with the universities of Cambridge or Oxford with researchers such as Foulkes, Cox, Hemp, and Shield publishing significant results; however, these communications are usually not known for the above reasons. After the 1970s, this situation changed, and, as a result of changes and the introduction of digitization, new alternatives for placing publications appeared. As already mentioned, a subjective selection of works from a period of 150 years is assessed here, with an emphasis on the first 120 years.(Lógó and Ismail, 2020)

ADVANTAGES

Cost Reduction
Topological optimization is a computer program that allows users to create products by optimizing the materials necessary, which increases energy efficiency at the same time. This is done with the use of cloud computing consulting services and the power of AI (Artificial Intelligence). The machine produced intricate design structures that combined several pieces into one, lowering the overall cost of manufacture.

Short Product Development Cycle.
Artificial intelligence (AI) is used by the program to create any product design imagined. This rapid design development enables rapid prototyping and testing to complete the designs that your market wants, ensuring that design decisions are made with better certainty. As a result, there is a rapid launch of the final product and a lean overall product development cycle.

Reduction of Weight
The program's algorithm examines every design option that would reduce overall weight while keeping the lowest density. By employing one interchangeable body part and leaving the rest of the product alone, this is achieved. As a result, designing lightweight, effective products is no longer an impossible task.

Complex and Scalable Designs
One of the main issues with conventional industrial design development was the lack of available designs. After all, a single designer is not capable of offering an infinite number of design options. Topology optimization, however, offers an infinite number of design options. To create every plausible design, topology optimization employs machine learning (ML). The best part is that as your machine gains knowledge from past patterns that it has retrieved, the quality of its designs will continue to rise.

Sustainability
The Topology Optimizer is a powerful tool that helps you to create designs that use the fewest raw materials. It does this by applying structural reasoning that encourages the use of sustainable construction techniques. Its fundamental design makes it ideal for manufacturing sectors that care about the environment. Waste of unfinished goods, fuel, energy, heat, and other resources is frequently avoided in this way. You must be familiar with both sides of topology optimization if you want to have a thorough knowledge of how the technology fits within your business. The advantages are only one side of the story. The other is the restrictions (*Topology Optimization: 6 Benefits And Disadvantages*, 2022).

DISADVANTAGES

Complex Designs
Although they are simple, scalable solutions for ideation, mass manufacturing is a significant challenge. In this situation, additive manufacturing may be used to give production flexibility. It is a good idea to check the bandwidth it can give for your scaled production before making a final design selection. The three main factors for designers in this situation are function, quality, and efficiency. Both traditional production barriers and topological optimization barriers can be surmounted.

Expensive Manufacturing
A topology optimization program is designed to solve complex problems in computer programming. Complex designs can be difficult to make, and may have an impact on the way things are produced. To overcome the problems with mass production, you may use 3D printers and injection molds.

Manual Constraints
Topology optimization software can provide you with an unlimited number of design options, but it can also present a significant challenge. If your restrictions are too tight, even the most effective designs might not be as effective as they might be. As a result, the constraint quality is essential for the finished design you develop.

Proper Training
Topology optimization software can provide you with an unlimited number of design options, but it can also present a significant challenge. If your restrictions are too tight, even the most effective designs might not be as effective as they might be. As a result, the constraint quality is essential for the finished design you develop.

Limited Use of Raw Materials
The design process explores how artificial intelligence can be integrated with architecture right from the design stages and later applied to energy and topological optimization. The research aims at understanding how a creative mind works and how artists use inspiration to come up with their designs. what if the same principles are structured systematically to aid machine learning.(*Topology Optimization: 6 Benefits And Disadvantages*, 2022)

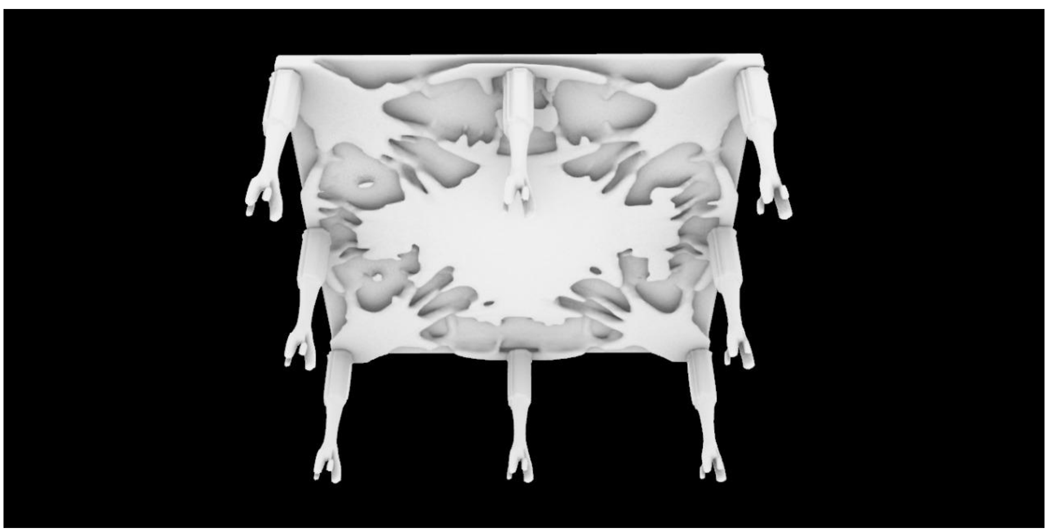

Figure 3: Demonstration of topologically optimized concrete slab.
Source: Courtesy of the author.

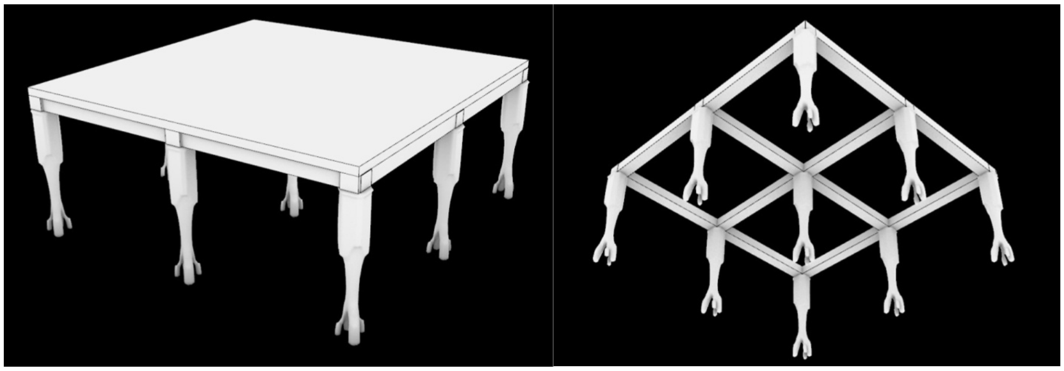

Figure 4: Topological optimized columns supporting structural framework and topologically optimized columns.
Source: Courtesy of the author.

APPLICATIONS OF TOPOLOGICAL OPTIMIZATION:

Topology optimization in high-rise structural design: the need for high-rise structure solutions in urban cities has arisen as a result of the congestion of cities this has caused a challenge for architects and engineers. the difficulty is that more materials are needed to build high-rise structures than low-rise structures, mostly because bracing standards are more stringent. Topological optimization is used in structural elements like columns and beams: reduces the weight of the column and beam while retaining their use and structural integrity. the material cost is reduced by a huge amount. Topologically optimized bridges can be built using this technology. Topological optimized load-bearing walls can be constructed for a more efficient outcome. Slabs and other structural members can also be optimized.

SOFTWARE USED FOR TOPOLOGICAL OPTIMIZATION:

The method that we have followed to achieve the topologically optimized structure is with the help of grasshopper which is a part of rhinoceros software where grasshopper uses a plugin namely, Topos.
The Procedure is as follows.

Step 1 - The model to be optimized is connected to the boundary domain which consists of material properties namely, Young's modulus, Poisson's ratio, and density value along with the form being topologically optimized.
Step 2 - The model to be optimized connects to the boundary condition set up which consists of the load details acting on the model and the supports applied to the model.
Step 3 - The model along with the boundary domain and boundary condition set up is connected to Optimus, which is the 3D topological optimization engine based on Bendsoe and Sigmund theorem using optimality criteria algorithm to update densities.
Step 4 - Optimus command is connected to a button and a boolean toggle (True/False), where the button helps in resetting the topological optimized form and the boolean toggle aids the production of multiple iterations of the optimized form.
Step 5 - To get the resultant topologically optimized form, the optimus needs to be connected to isomesh or voxel mesh. Isomesh gives the result in a more defined form whereas the voxel mesh gives the output in pixilated manner.

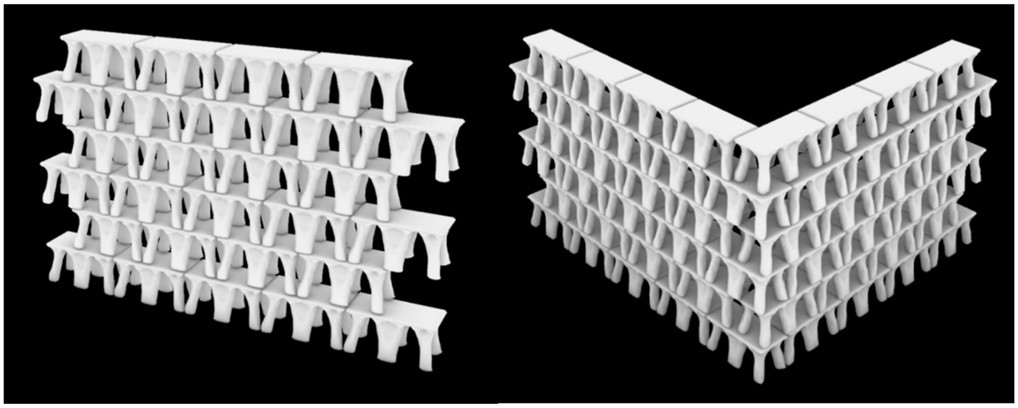

Figure 5: Topologically optimized building blocks.
Source: Courtesy of the author.

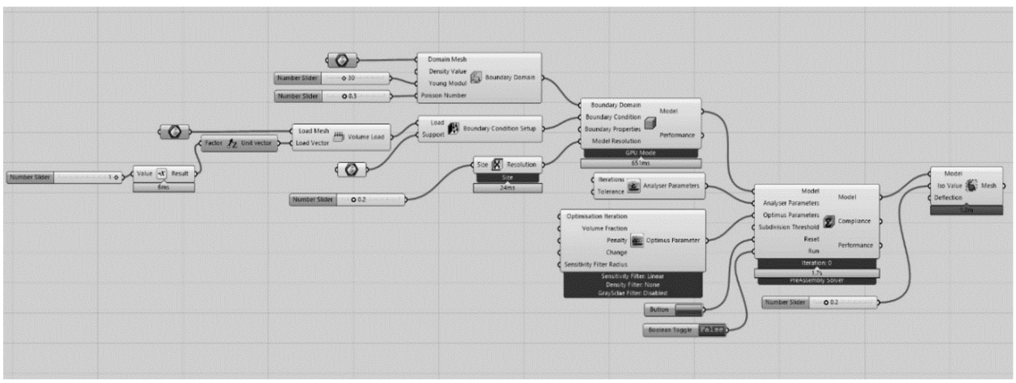

Figure 6: Grasshopper code for topological optimization.
Source: Courtesy of the Author.

SIGNIFICANCE OF TOPOLOGICAL OPTIMIZATION IN PREFABRICATION

Topology optimization is a design technique that may be used to cut material without sacrificing an object's functioning. Despite being one of the most resource-intensive industries, the building sector has not yet adopted these design principles. This is frequently because producing solutions resulting from computer optimization approaches can be challenging, especially at a larger scale but due to the development of technology such as 3d printing, which has made it easier to prefabricate topologically optimized structures.

In the present scenario, advancements in materials like concrete along with technology like 3d printing make it possible to generate optimized structures in minimum time. Concrete offers the structural strength required for large-scale components, and 3D printing makes it possible to prefabricate fine topology optimization features. Before being assembled, the topologically optimized structure is 3D-printed off-site. Massive slabs and columns are 3d printed piece by piece and then assembled on location. To minimize structural leaks, joining these structures needs precision and specialized labour.(*(3) (PDF) 3D-Printed Stay-in-Place Formwork for Topologically Optimized Concrete Slabs*, *2016*)

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING TOOLS

The design process explores how artificial intelligence can be integrated with architecture right from the design stages later applying till energy and topological optimization. The research aims at understanding how creative minds work and how artists use inspiration to offer their designs. what if the same principles are structured systematically to aid machine learning, giving us an effective and suitable form (Bengio, Courville and Vincent, 2013; Tillmann, 2015; Caliskan, Bryson and Narayanan, 2017; Fleer *et al.*, 2020). There are multiple ways of generating 3-dimensional and 2-dimensional models, and the few existing algorithms are described below:

Cellular automata (Puente *et al.*, 2015)
It is a computational technique that can model the process of growth by portraying a complicated system as a collection of simple units following basic rules. The idea was introduced by John von Neumann and gained popularity when Martin Gardner described John Conway's "Life," a game that generated two-dimensional patterns. but this method of pattern generation is rudimentary in application since many issues remain in the program, namely, what should be the initial configuration of cells, which generation to stop at, neighborhood definition, type of growth rule, the definition of the cell, the shape of the spatial unit, overall scale, support conditions, lattice configuration, restriction to the number or area of placed cells, the introduction of existing or fixed elements, other concepts for connecting cells, and other methods to interpret cell locations. It is useful in grid-based design both in planning and zoning

Genetic algorithms (GAs) (Fasoulaki, 2007)
A search-based optimization technique called Genetic Algorithm (GA) is based on the concepts of natural selection and genetics. It is frequently utilized to locate ideal or almost ideal answers to challenging issues that would otherwise take a lifetime to solve. It is frequently employed in machine learning, research, and the solution of optimization problems. Genetic computation offers practical solutions to optimization problems and problem-solving concerns, which is relevant to the population problem. Genetic algorithms in architecture firstly act as an optimizer tool and secondly as production tools. The structural qualities of genetic algorithms are used in the first technique to address issues with structural performance, mechanical, thermal, and lighting; more architects and other building professionals are involved in this communication. The second approach is wonderful, innovative, and free in terms of concept and form architecture. The design is predicated on the discussion of the design parameters. We can implement GAs in multiple methods, but all methods share the following elements. 1. genetic representation of a solution 2. A function to create new solutions 3. Fitness function 4. Selection function 5. Cross over function 6. Mutation function. GA is used to simultaneously pursue multiple design alternatives meeting the fitness criteria.
The fitness function **-** It is a function that takes a potential solution to the issue under consideration as input and outputs how "fit" or "excellent" the answer is in relation to the issue at hand.
Selection function **-** it is the process of choosing parents who will mate and recombine to produce offspring for the following generation.
Cross over **-** It is comparable to biological crossover and reproduction. In this, more than one parent is chosen, and using the genetic makeup of the parents, one or more offspring are created. A GA is typically subjected to crossover with a high likelihood.
Mutation function- is an operator that keeps the genetic variation of a population of genetic algorithm chromosomes intact from one generation to the next.

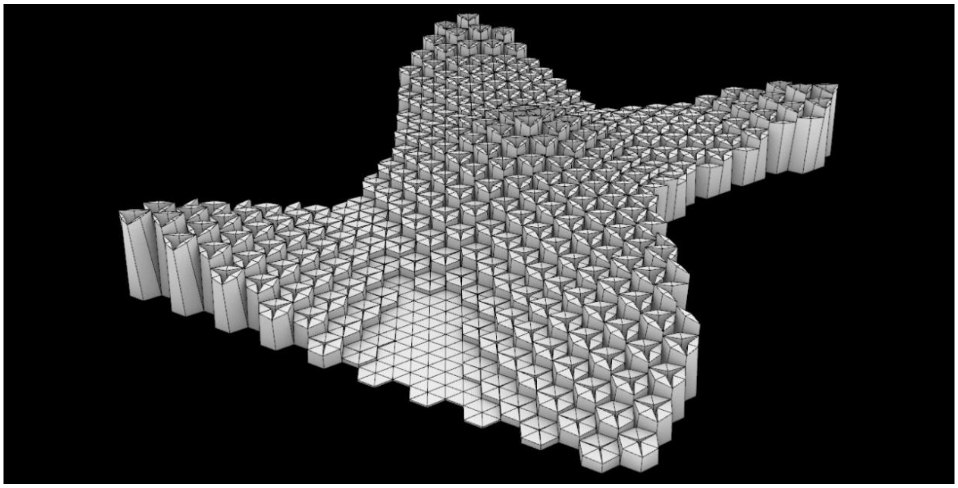

Figure 7: Model developed through a genetic algorithm.
Source: Courtesy of the Author.

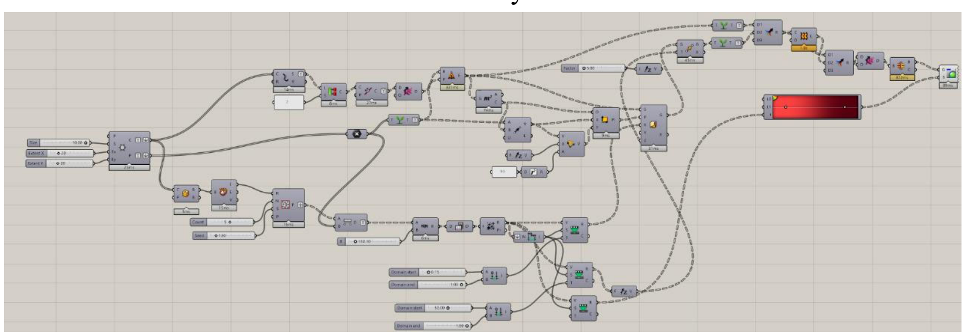

Figure 8: Grasshopper script for genetic algorithm model developed in figure 7.
Source: Courtesy of the Author.

Shape grammars (Pauwels *et al.*, 2015a)(Chakrabarti *et al.*, 2011)
A set of form rules that are applied sequentially to produce a set or design language is called Shape grammars. Shape grammars are generative and both are descriptive. Grammar rules calculate or create the shape of a plan. The rule describes the calculated shape of the design. The symbols directly process the form and do not require translation or interpretation of the symbols. This usually requires user selection after generation and is a means of exploration (Economou, 2000)(Pauwels *et al.*, 2015b).

Lindenmayer System (Bourke, 1991) (Kari, Rozenberg and Salomaa, 1974)
LS are mathematical formulae that produce factual-like shapes that are self-similar and show signs of biological growth. they are algorithm recursions that enables us to create large intricate forms. LS systems have been applied to various design considerations, from straightforward computer graphic patterns to intricate city planning and modeling tasks.

Swarm intelligence (Ahmed and Glasgow, 2012)
Swarm intelligence can be described as the collective behaviors of artificial or natural self-organized and decentralized systems (Aryanpour, 2012). Swarm behaviors of animals inspire swarm intelligence strategies in computer media. Swarm behaviours in nature emerge to enhance food-finding, protection mating, and sufficient energy using abilities of limited-skilled animals when they are individual. There are different words used to express the swarm behaviour of other animals. In architecture, swarm intelligence investigates the role of agency within the generative design process, and architects can benefit from swarm

intelligence for deconstructing modernist tectonic hierarchies. Swarm intelligence is used in architecture in such areas; as visualization, self-organization of multi-agent systems, architecture form design, and urbanism.

Figure 9: Transformation model generated using different AI based tools such as DALL-E, GLIDE and CLIP in each of the above images respectively.
Source:(Shen *et al.*, 2021)

Clip

Inspiration sparks from multiple prompts of the semantics and style that a creator has seen until his creation. He is constantly learning through a multidisciplinary approach later experimenting with ways to merge those studies with his works. Similar to this, we can train the computers to support our design work by employing contrastive models that compute deep learning techniques, self-supervised, task-independent, like CLIP, which stands for Contrastive Language Image Pertaining. In addition to their amazing zero-shot capabilities and ability to produce state-of-the-art outcomes on a variety of vision and language tasks, CLIP embeddings have a number of other desired characteristics (Shen *et al.*, 2021). Research labs like OPENAI, and MIDJOURNEY, are working on products like DALL E2, GLIDE, make a scene, dream by WOMBO, and MIDJOURNEY all work on a similar algorithm of rapidly understanding and comparing multiple data sets to come up with artworks.

In the Figure(9) above, we visually compare unCLIP to various text-conditional image generation models on several captions from MS-COCO. It is noted that unCLIP produces realistic scenes that capture the text prompts. The prompt used here is “a living area with a television and a table”

Furniture-based model

The logic that we propose works on a unit level, keeping all furniture as a base element. Every piece of furniture that is used will have two parameters first one is the area it occupies while at its rest and operation and the second one is the direction of access or operation; both are derived from anthropometric studies. For example, in the case of a chair and a table, both the parameters are analysed and different iterations for spatial arrangements are computed in the given area. This operation is further extended to all the required furniture in the space. Thus, multiple spatial solutions are given for an individual room. if the same principles are applied to other spaces as well a complete design for a module can be obtained. A set of rules can be coded to select the necessitated result.

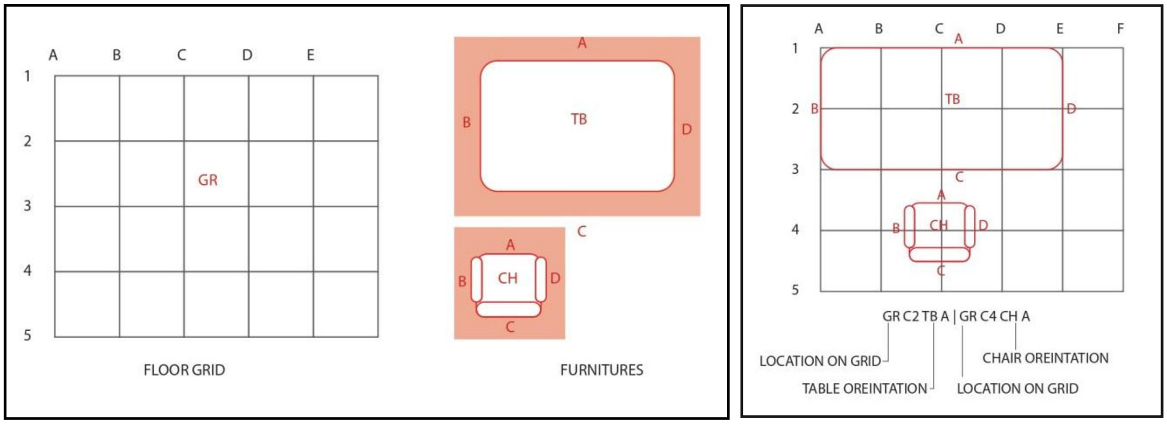

Figure 10: Nomenclatures and Conceptual Spatial arrangement and script.
Source: Courtesy of the Author**.**

TERMINOLOGIES

Zero Shot Capabilities

Zero-shot learning (ZSL) is a problem setup in machine learning, when taking a test, a learner must identify the class to which samples from classes that were not observed during instruction belong. Associating observed and non-observed classes through some type of auxiliary information, which encodes observable distinguishing features of objects, is how zero-shot algorithms typically function. (Xian *et al.*, 2017)
MS COCO (Microsoft Common Objects in Context) is a sizable image dataset with 328,000 pictures of people and common things. You can train machine learning models to identify, classify, and characterize objects using the dataset's annotations. (Microsoft, 2015)

Finch 3d (Finch)

The Swedish construction company BOX Bygg and the architectural firm Wallgren Arkitekter collaborated to create the parametric design tool Finch. Finch is capable of generating detailed floor plans which are adapted to the given site parameters. The parametric design tool allows one to create 2 or 3-dimensional internal house plans which are optimal and considers input data like building regulations of the locality and the size of the building. The program Finch has dual intelligence one is rule-based and the latter one is AI-based. The first set of data which are rule base contains an algorithm that the user is free to modify. It includes parameters like the height of the built form, zoning of spaces, and thickness of the wall. The intent of it is to automate the constantly repeated tasks. The Artificial Intelligence part focuses on generating multiple design iterations and on understanding the end users. Finch also considers factors like daylight, climatic conditions, and elements that influence the architecture. The workflow of the program is in form of a diagrammatic level rather than a descriptive one. For example, FINCH can propose the location of a shaft and then let us know the types of pipes it contains.

Role Of AI in Sustainable Architecture

The adoption of AI in the green building construction sector has the potential to accelerate sustainability initiatives that the sector has been frantically trying to solve. The U.S. General Services Administration (GSA) has outlined six criteria for improving or optimizing through the integration of AI into building sustainable built environments as follows:

- The improvement of indoor air quality.
- Improve facility sustainability factors
- Enhance operational systems management.
- Reduce non-renewable energy usage.

- Protect the environment and conserve water.
- Use environmentally preferable products.

The numerous benefits offered by integrating machine learning technology in construction and design practices are as follows:

1. Energy efficiency: Human comfort is a key while planning. The temperature, quantity of light we are exposed to, and even which electronic gadgets surrounding us are a few of the factors that affect human comfort. Through Intelligent Energy Management System (IEMS), one can assess how much energy and resources are consumed by the building, AI keeps track of these variables. Then, it optimizes resources so that the building may use energy more wisely.
2. Better design: AI gives architects the chance to create buildings that are tailored to each client's sustainability objectives. For instance, expanded models of the structure might show how much light is required. This reduces total energy usage by managing power use for lights.
3. Lower costs: By evaluating variables like project dates, geography, and team member expertise, artificial neural networks can forecast project cost overruns. Using AI technology, possible inefficiencies may be found and addressed early on, saving planners, builders, and owners money in the long run. These AI-generated forecasts play an important role in making the built unit economically sustainable. A major stage in the construction of prefab units is planning and designing thus this technology can be utilized to its full potential.
4. Project planning: Artificial intelligence may increase output yield and streamline projects. From simple tasks like forwarding spam emails to the correct folder, to more complex tasks like scanning construction sites to discover potential setbacks, AI addresses all inefficiencies so the team can remain focused.

AI and green get along great: The need for the construction sector to catch up increases as the globe continues along the path of digitalization. AI has the ability to assist the green building industry in achieving its goal of producing more high-performance, egalitarian, and sustainable structures. AI adoption benefits companies, customers, and the planet all at once. Hence it is indeed time to embrace AI in the future of the building.

CONCLUSION

Prefab construction has been used for a long time and is still an important part of the construction industry. Although the materials used in ancient civilizations have changed significantly or little, they have undergone much scrutiny and experimentation over time. This technique has still survived and continued to be practiced by various stakeholders in the construction industry. Material changes and their implementation are the results of different traditional cultural practices, ethnicity, and climatic conditions. As this construction process is driven by the need to produce faster, smarter, and more sustainable built environments, prefabrication still has and will continue to have new elements and perspectives to explore in the future along with nouvelle AI-based technologies. Artificial intelligence and machine learning tools will be useful in making an architect’s work simpler and faster by analyzing data and generating models that can be more efficient and sustainable. AI can also be called an estimation tool for various aspects while constructing a building. From the study, we also discovered various software and tools like Clip, cellular automation, Glide, Midjourney, Swarm intelligence, etc that can be coherently applied in designing and building construction. Furthermore, a few topologically optimized models have been experimented with and generated using a visual programming language tool like grasshopper that runs within the Rhinoceros 3D, a computer-aided design application. These optimized surfaces or structures help in saving material, reducing the dead load, and improvizes on the aesthetics of the structure. Innumerable permutation combinations can be made for single or multiple prefabricated units with the help of machine learning and visual programming tools.

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DIGITALLY FABRICATED SETTLEMENTS FOR THE INTERNALLY DISPLACED IN THE PORT CITY OF ADEN, YEMEN

Jabin Biju Thomas[1], Madhumathi A.[2]

[1] Student, School of Architecture (VSPARC), VIT, Vellore, Tamil Nadu, India; jabin.thomas09@gmail.com
[2] Professor, School of Architecture (VSPARC), VIT, Vellore, Tamil Nadu, India; madhumathi.a@vit.ac.in

ABSTRACT

Yemen has been a victim of civil unrest since late 2014, hundreds of thousands have lost their lives in its aftermath and the country deprived of its natural resources and infrastructure. The paper explores the avenues digital fabrication and prefabrication opens up for the internally displaced population of Yemen, as a long term alternative to the emergency camp approach, and aid in building a sustainable and resilient community. Given the constraints of on-site construction in this particular context, digital fabrication holds a lot of potential.

Merely providing the displaced population with a roof over their heads will not suffice, as it is also crucial to revert from this cycle of violence and poverty, to eventually make them self-reliant and independent again. Principles like incremental construction and democratization of the technology will ensure the involvement of the community, subsequently providing them with a platform to express themselves, with art and design as a medium. The design approach places emphasis on the holistic development, not just rehabilitation, of the displaced community.

Keywords: Digital Fabrication, Incremental Construction, Democratized Technology, Self-Sustainable, Holistic Development.

INTRODUCTION

The war in Yemen, between the Abdrabbuh Mansur Hadi and the Houthi armed movement, along with their supporters and allies, has claimed around 230,000 lives according to the United Nations (2020). Amongst this tally, 130,000 deaths were due to indirect causes such as lack of food, health services and infrastructure. The project focuses on the Internally Displaced Persons (IDPs) population, who are often more vulnerable as they are more likely than refugees to stay near or get stranded in conflict zones, caught in the crossfire and at risk of being used as pawns, targets, or human shields by the belligerents. Yemen currently has the fourth largest IDPs population in the world (about 4 million people), of which more than 1.5 million are children. 3D Printing (3DP) holds the potential to provide long term alternatives to the emergency camps that is quick, efficient and cost-effective. Democratizing the technology will help the people design/cater to their own needs and requirements over time.

Drawbacks of the Emergency Camp Approach

According to an internal UNHCR report (2004), the average lifespan of the emergency camps or settlements is 17 years, and this number has been drastically rising over the years. Due to the lack of proper infrastructure and amenities, these camps turn into grounds for violent crimes and virulent diseases. The visual and existential monotony also needs to be combated with the aid of design and planning.

Understanding Yemen

Yemen's economic growth, job creation, and labour productivity have all been hampered by decades of political instability and cyclical military conflict. Prior to the ongoing conflict, majority of the country's working population was involved in unskilled labour, such as farming or were informally employed in small businesses. It is essential to identify the needs and opportunities the context presents to cater to the needs of the displaced population and help them develop holistically.

The Agricultural Sector

Yemen's agriculture industry accounted for nearly a third of the country's employment, but the farmers have been compelled to flee their lands as a result of a variety of circumstances, including closeness to the conflict – since continued security prevents the private sector from investing in farmers – as well as increased prices for fuel and irrigation, along with the persistent shortages of commodities that are crucial in the production of food. Agribusinesses relied mainly on the government for finance prior to the conflict; but, in the midst of the ongoing conflict and economic crisis, the government has not made any provisions to help alleviate the expenses and shortages associated with the conflict. While some farmers have turned to alternative sources, such as solar energy, to complement their energy demands, the vast majority cannot afford to do so due to financial constraints. In Yemen, the Food and Agriculture Organization of the United Nations (FAO) offered agricultural support to about 600,000 farmers during the 2017 fiscal year (Sana'a Center For Strategic Studies, 2018).

The Fishing Industry

The selected site of Aden is a coastal region and fish along Yemen's coast are plentiful. One Development Champion familiar with Yemen's fishing industry estimated the Yemeni fishers land between 180,000-220,000 tons of fish per year. Much of the fishing is artisanal to this day, using traditional methods, thus even moderate training and equipment upgrades hold the potential to substantially increase the sector's economic potential. The international community can teach skills and provide their expertise to the current fishermen and youth. Besides training fishermen to use modern equipment, training units can teach skills that are essential throughout all stages of the value chain: cold storage, support team, transport, marketing, and sales (Sana'a Center For Strategic Studies, 2018).

Empowering the People

The strategies should be centred on finding pre-existing local potential and supporting it to expand and prosper, due to the fact that the Yemeni are mercantile by nature, instead of implementing foreign economic models into the Yemeni sphere of influence. There are several ways to achieve this including; the utilization of local potential by investing in training programmes that improve local business practices and sharing of knowledge that stimulates local innovation, as well as technological infrastructure that boosts productivity and efficiency. These could prove to be powerful catalysts for a thriving economic climate, producing jobs while also propelling rapid social advancement.

CASE STUDIES

Numerous live case studies were explored and inferences made, that would aid in the process of designing with 3DP in a low-resource setting (LRS) like Yemen's. The case studies were selected based on parameters or principles that could be incorporated into the design.

Table 1: Case studies - comparative analysis
Source: Author

Case Study	Material Used	Mode of Construction	Area Constructed (sq.m)	Inferences
Villa Verde Housing by ELEMENTAL	Timber frames supported on concrete foundations, clad internally in 10mm gypsum board were used predominantly.	Analogue	57 (85 after extensions)	The concept of incrementality and community engagement, which provides the residents with the freedom to expand their homes based on their needs or financial stability.
3D Printed Community in Nacajuca, Mexico by ICON	Lavacrete, an advanced material blend of concrete, created by ICON, has been used for the walls.	3DP	≈ 50 (500 sq.ft)	This case study is an example of how 3DP can provide affordable and compact solutions in a LRS to address the housing crisis that the world is currently facing.
Tecla by WASP & Mario Cucinella Architects	Clay and fibers from rice husk were major components used for the construction of the walls.	3DP	≈ 60	An instance of 3DP with the use of locally procured materials, ensuring sustainability and factors like zero carbon emission.
3D Printed House in IIT-Madras by Tvasta	A Portland cement based mix was used for 3DP.	3DP	≈ 58 (600 sq.ft)	Aspects like local context and involvement of small startups in the enhancement of the technology and its use were explored.
Traditional architecture in Yemen	Sun-dried mud blocks and timber are predominantly used in parts of Yemen.	Analogue	--	The study was vital in understanding the context of Yemen, and the appropriate construction techniques that are to be used.
Shelter project by QRCS	Brick walls, stone slab, tarpaulin and straw roof were utilized for coastal regions.	Analogue	≈ 50	Crucial in understanding the humanitarian projects in Yemen's context and their drawbacks.

3DP WITH EARTHEN MATERIALS

Traditional Yemeni architecture predominantly uses mud bricks or burnt clay bricks, widely used in the old cities of Shibam and Sana'a for multi-storey structures. Earthen construction techniques reflect the local abilities and material availability, and are well adjusted to the severe climatic condition of Yemen (Sultan, 2008). Houses built with mud or brick of over 500 mm thickness display excellent thermal insulation properties and help retain the heat in order to cool the interiors at night.

Buildings that have been constructed using modern techniques have proved to be unsuitable for the climatic context of Yemen, as the reinforced concrete buildings with concrete block walls do not provide sufficient thermal inertia, offering minimal thermal comfort which in turn makes them heavily reliant on artificial cooling. A survey conducted by Sultan and Kajewski also discovered that imported materials and building waste were significant factors that contributed to high construction costs (Sultan, 2008). Since, earthen construction techniques have been deemed the most appropriate for Yemen's context, we can examine why 3DP with earthen materials is a viable alternative;

Cost-Effective
3DP essentially helps reduce labour costs, which amount to 55% of total construction cost in industrial countries. In terms of labour required during the production of components, 3DP requires only one person to load the materials (mixture of soil, straw and water) into the printer and to control the graphical interface. To assemble the building using the printed components it requires only two unskilled persons to move, lift and assemble the components and the time required will depend on the size of the building along with the fixture of external elements (Russell, 2015). It is also important to note that the cost of construction using 3DP remains constant with the increase in complexity of the form, whereas it increases for traditional methods of construction.

Ease
Housing for the displaced populations generally comprises of tents or other temporary alternatives which need to be replaced quite often, but for this project we are looking at more permanent / long term solutions. Therefore, the ease of deployment, is an important factor. Unlike traditional construction methods, the reliance on 2D technical drawings to execute the construction on-site is very minimal, as printers utilize the 3-dimensional model provided to its graphical interface for defining the building. On-site customization of the 3D models gives users the freedom to design, essentially exercising democratization of the technology.

Speed of Construction
The process of construction can be broken down into four main sections; the extraction of raw materials, the preparation and production of materials, the production of the walls and the time taken for the walls to set, these are the factors that contribute to the time taken for the construction of a project. 3DP is considerably the quickest alternative in comparison to concrete, fired clay bricks and other earthen techniques.

Accuracy
The accuracy provided via the use of Computer Numerical Control (CNC) utilized by 3DP is another benefit over other construction methods as it ensures the buildings can be built without errors. Human errors can result in longer construction periods, higher material and labour costs, all of which can be avoided by using 3DP technology.

Sustainability
3DP is one of the most sustainable techniques we have at our disposal, given that it is very efficient, there is no wastage of material, reduces energy consumption and carbon footprint, amongst many other advantages.

Freedom of form

3DP opens up an avenue to execute forms that would be considered complex for traditional techniques. It is possible to print parametric forms or complicated structures with pinpoint accuracy. For example, curved wall edges can be printed with very minimal / no wastage of material.

Safety

The construction industry is known to be quite dangerous, causing numerous deaths every year. Using 3DP we can almost completely eradicate injuries or deaths on-site. There are certain limitations to the technology since 3DP is still in its infancy, there is a lack of building codes, height restrictions and the high initial investment for the printer. It is only possible to print the walls using the technology, as experts continue to explore alternatives for other elements such as roofing. But the pros outweigh the cons, and the technology holds a lot of intrinsic value in this context regardless.

DESIGN DETERMINANTS

There were several factors considered before venturing into the design aspect of the project such as, the demography it caters to, guidelines provided by organizations like the UNHCR and the site study. Following that, the development of the project was divided into phases to ensure a holistic growth.

Phase Distribution

The project, due to its complexity was divided into various phases to ensure that the needs of the IDPs are addressed. Abraham Maslow's 'hierarchy of needs' provided a framework to create a phase by phase distribution for the settlement, which is as described below.

Phase 1 - Addressing the basic needs

Time period : Initial 3-6 months
Construction of the 3D printed shelters (PHU), with basic safety and security considerations for the clusters.
The development of the primary healthcare centre.
Water trucking will be utilized to provide for the basic water needs of the people.
Mobile / common sanitation facilities will be provided (as per UNHCR guidelines).
Food supply and distribution points will be allocated on site to cater to the needs of the people.
Shelter for the livestock and storage of other commodities will be provided.

Phase 2a - Addressing the psychological needs

Time period : Within 6-18 months
Construction of the living quarters for the vulnerable, which will be a predominantly pre-fabricated structure, assembled on-site with the assistance of the existing residents.
Developing the agricultural and fishing infrastructure, which are promising industries, in order to ensure the IDPs become financial independent.
Construction of the community kitchen for the residents of the living quarters.
Development of private / individual sanitation facilities for the 3D printed housing units.
Development of the water supply systems - sanitation, drinking and irrigation. (eg: solar powered pumps for boreholes)

Phase 2b - Addressing the psychological needs and developing the settlement further

Time period : Within 6-18 months
Construction of the educational complex and its associated facilities.
Construction of the religious complex and its associated facilities.
Building a well defined road network.
Integration of community gardens, sports and recreational facilities into the settlement.

Phase 3 - Achieving self-sufficiency and sustainability
Time period : Within 18-36 months
Integration of market spaces, essentially providing the residents with a platform to grow financially.
Development of community spaces for various festivities and events.
The incorporation of facilities like desalination plant and other off-grid services.

The social, economical and environmental factors that will determine the design have been mentioned in Figure 1.

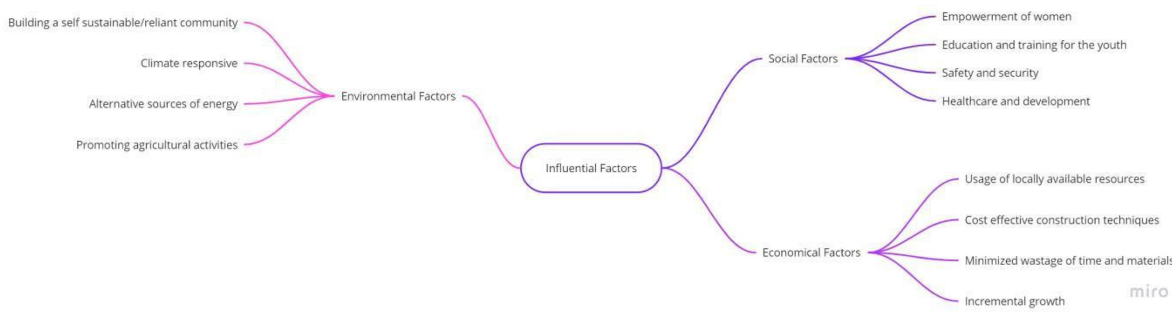

Figure 1. Factors that will influence the design
Source: Author

DESIGN OF THE HOUSING UNITS

The Permanent Housing Unit (PHU) clusters have been planned to accommodate 480 residents in 12 clusters. Each household is given a plot of 100 sq.m, of which 50 sq.m will be constructed in the initial phase. Each unit can accommodate about 5 residents, it consists of a living room, two bedrooms and a kitchen. Common drinking and sanitation facilities will be provided initially, as recommended by the UNHCR guidelines. Water trucking will be used to replenish the underground water tank on a weekly basis. The residents are given the freedom to expand their homes or construct private facilities as the need arises or once they attain financial stability.

The site - Aden, is a coastal region and the external walls are provided as 500 mm thick, to meet the thermal insulation requirements. Semi-circular openings and earthen domes have been used, amidst other elements like *Mashrabiyas*, to provide passive cooling strategies that employ traditional elements in order to create an indigenous environment for the displaced population. The colonnaded corridor enhances privacy and reduces direct sunlight on the structures.

Figure 2. Rendered views of the residential areas
Source: Author

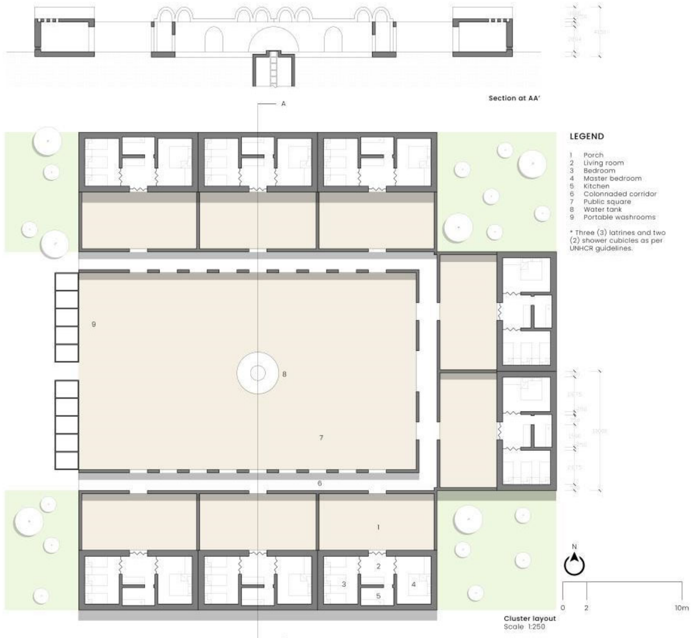

Figure 3. Cluster layout for the PHUs
Source: Author

The concept of incrementality has been explored, the possible iterations that the residents could come up with have been depicted below in Figure 4. They can construct rent-able units adjacent to their homes for example; extended bedrooms, kitchens or bathrooms, even shelters for their poultry and livestock. Backyard gardens or *Al-Bustan* can also be incorporated into the design to tackle the severe climatic conditions. Democratizing the technology and engaging the community from the initial phase onwards will play a pivotal role in the development of the settlement.

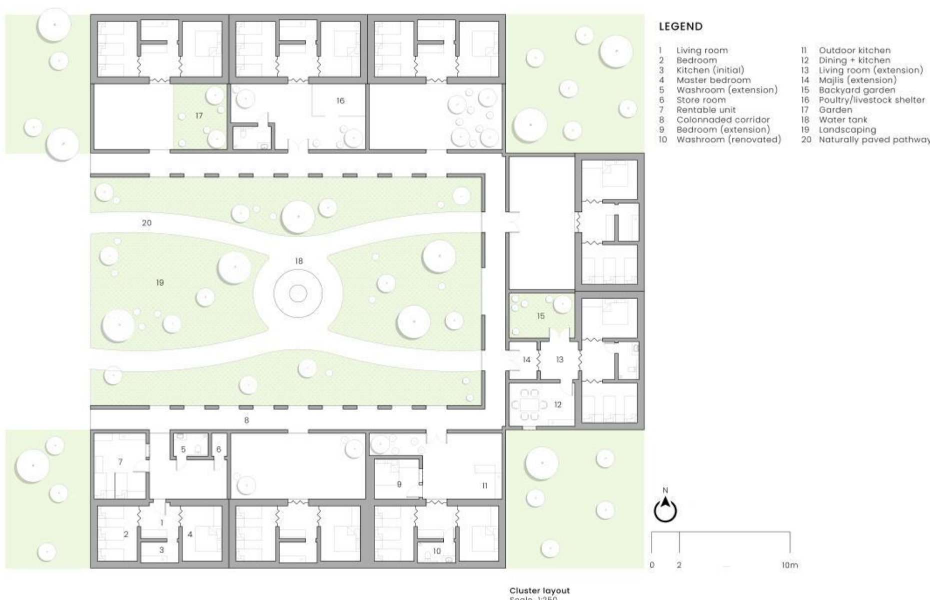

Figure 4. Possible iterations for the PHUs cluster
Source: Author

The construction details for the 3DP housing units are as displayed below (Figure 5), the pattern followed by the printer to print the walls, the voids, display how material wastage can be minimized using the technology. The joinery details display how the pre-fabricated roof can be assembled on-site.

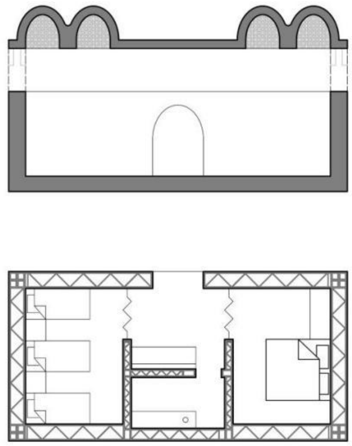

Figure 5. Construction details for the PHUs
Source: Author

The various techniques that will be implemented for the construction of the PHUs have been shown in Figure 6. Since 3DP technology is in its infancy, we are limited to printing the walls only, therefore, the roofing will be pre-fabricated and assembled on-site while the flooring will be laid manually, with the assistance of the IDPs.

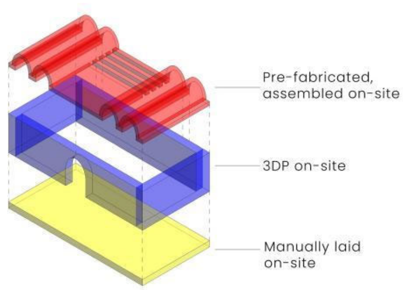

Figure 6. Construction techniques used for the PHU
Source: Author

The master plan depicts the approach taken towards creating a settlement that is resilient and caters to the holistic development of the IDPs (Figure 7). A central node connects the settlement to the centre of Aden. Amenities like the primary health center, masjid, educational facilities and recreational activities have been placed in close proximity to the residential units to make them easily accessible. The design aims to reduce the reliance of the community on vehicular transportation, by attempting to make the settlement walk-able.

Figure 7. Master Plan
Source: Author

The market spaces and social squares have been planned along the transit, potentially capable of turning the settlement into an urban hub in the near future. Land has been allocated for future development in order to cater to the growing demand and IDP population. Democratization of the technology will ascertain the development of the settlements and its facilities over time.

NOMENCLATURE

3DP	3-Dimensional Printing
IDPs	Internally Displaced Persons
LRS	Low-Resource Setting
PHU	Permanent Housing Unit

CONCLUSION

The study attempts to design a settlement for the IDPs in Yemen that caters to the holistic development of the people, whose growth and development have been hindered over the years by the civil conflict. Using 3DP as an aid, the study tries to highlight the potential the technology holds to create an indigenous environment and provide a platform for the displaced population to grow as a resilient and self-reliant community. Alternately, providing solutions to the emergency camp approach that is being utilized to provide temporary solutions for such a demography around the world.

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Dr. Shaila BANTANUR
Conference Chair
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