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Deepak Bajaj
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Sustainable Built Environment

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Preface

The First International Conference on Sustainable Built Environment (ICSBE), held in Noida, Uttar Pradesh on 23rd–24th February, 2023, is an international conference organized by the RICS School of Built Environment Amity University, Noida, Uttar Pradesh. The conference is aimed at nurturing the study, comprehension and appreciation of the built environment.

The international conference looks to deliver multiple dialogues between academia, policymakers, institutions, industry and society for a push towards a sustainable built environment in the future. The conference aligns with UN- SDG goals and COP- 26 agreements as the countries of the world push towards net zero carbon emissions.

The International Conference on Sustainable Built Environment (ICSBE'23) aims to create a platform for scholars, academics, practitioners and other experts from the society to discuss and deliberate the issues relating to sustainability and resilience in all types of buildings projects, construction projects, operational building and infrastructure projects within urban regions of the world. The ICSBE'23 hopes to add steps towards creating a healthy and net zero built environment for the future generation.

The Built Environment sector is responsible for nearly 40% of carbon emissions and energy consumption, 50% of all extracted materials, 33% of water consumption and 35% of waste generated. The sector has enormous untapped potential to assist in decarbonizing the global economy while addressing the serious climate challenges that the global economy is currently facing. A sustainable built environment considers environmental and socioeconomic challenges such as energy security, resilience, equity, water and waste management, health and well-being. These issues are at the centre of creating sustainable habitats and cities which are equitable and affordable to all sections of society.

The sustainability of green infrastructure and environment is a common thing to be realized without compromising the ability of future generation. It must be done to prevent any adverse impacts on our lives such as air and water pollution, land use and contamination, material depletion, impacts on human health, and climate change. Therefore, it is expected that the incorporation of sustainable development concept in terms of research, product and values will enhance the energy performance of environment development and bring about building sustainability as well as disaster management. The needs should merge with the improvement of global development to create a sophisticated life.

The following are the key themes for the conference.

First Part: Education for Sustainability, Training and Capacity Building

The theme of education for sustainability, training and capacity building within the sustainable built environment reflects a pivotal step towards a greener future. This theme underscores the imperative of equipping current and future professionals with the knowledge and skills required to navigate the complexities of sustainable practices. Education becomes a cornerstone, enabling architects, engineers, urban planners and policymakers to comprehend the intricacies of sustainable design, construction techniques, and integrated systems. Moreover, it emphasizes the need for interdisciplinary collaboration, fostering a holistic understanding of how various elements in the built environment intertwine with ecological considerations. Through comprehensive training and capacity building initiatives, individuals gain the practical expertise necessary to implement innovative solutions, thereby bridging the gap between theoretical knowledge and real-world applications. Workshops, certifications and continuous learning opportunities empower professionals to incorporate sustainable principles into their work, ensuring that sustainable considerations are seamlessly integrated from conceptualization to execution. Additionally, this theme advocates for educational inclusivity, extending knowledge dissemination to diverse communities, thereby promoting a culture of sustainable consciousness at every level of society. Ultimately, education, training and capacity building converge to drive a paradigm shift towards a sustainable built environment, where expertise and awareness intertwine to create transformative change.

Second Part: Sustainable Urban Planning, Housing, Real Estate and Construction Practices

The quest for a sustainable built environment necessitates a transformative approach to urban planning, housing, real estate and construction practices. Sustainable urban planning must prioritize compact, mixed-use communities that minimize sprawl, encourage public transportation and integrate green spaces to mitigate carbon emissions and enhance livability. In tandem, sustainable housing design must embrace energy-efficient materials, passive design principles and renewable energy integration, fostering dwellings that reduce resource consumption while ensuring occupant comfort. Simultaneously, the real estate sector must transition towards eco-friendly certifications, promoting green building standards that validate sustainable practices and attract conscientious investors. Such endeavours are inextricably linked to construction practices that emphasize modular construction, minimized waste and sustainable sourcing of materials, thus redefining the industry's impact on the environment. In amalgamating sustainable urban planning, housing, real estate and construction, a harmonious built environment emerges, one that harmonizes human habitation with the planet's ecological limits.

Third Part: Net Zero Built Environment Agenda, Progression, Opportunities and Challenges

The theme of the Net Zero Built Environment Agenda encapsulates a resolute commitment to achieve carbon neutrality in the construction, operation and maintenance of the built environment. It highlights a trajectory that envisions a future where all aspects of the built environment, from buildings to infrastructure, operate with a net zero carbon footprint. This agenda signifies a profound shift towards renewable energy integration, energy-efficient designs and innovative technologies, propelling the industry towards a sustainable and regenerative path. As this journey unfolds, unprecedented opportunities emerge, such as fostering innovation in green technologies, creating new job markets centred around sustainability and enhancing the resilience of communities against climate change impacts. However, the Net Zero Built Environment Agenda also brings forth a set of formidable challenges. Technical complexities, limited scalability of emerging technologies and financial constraints can impede progress. Regulatory hurdles and varying standards may hinder a harmonized approach across regions. Moreover, achieving net zero aspirations necessitates a deep-seated transformation of established practices, demanding a collective mindset shift and comprehensive stakeholder engagement. Balancing these opportunities and challenges is pivotal, as the agenda's realization holds the key to a sustainable future, wherein the built environment is not just a contributor to planetary well-being but a catalyst for it.

Fourth Part: Climate Change Policy, Legal Framework and Financing

In the pursuit of a sustainable built environment, the convergence of climate change policy, legal frameworks and innovative financing is paramount. As climate concerns intensify, policy initiatives must be crafted to set aggressive emission reduction targets, enforce energy-efficient building codes and encourage the adoption of low-carbon technologies. These policies are fortified by a robust legal foundation that integrates climate resilience into urban planning, mandates disclosure of energy performance and aligns zoning regulations with eco-friendly land use. However, these efforts hinge on innovative financing mechanisms, such as green bonds, public–private partnerships and incentivized programmes, which provide the necessary resources for the development of energy-efficient infrastructure, retrofitting projects and the realization of sustainable urban landscapes. This amalgamation of policy, legal structure and financing prowess constitutes a holistic approach to address climate change within the built environment, fostering a future where sustainability thrives hand in hand with human progress.

Fifth Part: Technology and Innovation in Process and Products

The theme of Technology and Innovation in the Sustainable Built Environment underscores the indispensable role of cutting-edge advancements in reshaping both processes and products within the construction industry. Rapid technological evolution offers a wealth of tools and methodologies that can revolutionize the way buildings and infrastructure are conceived, designed, constructed and operated. From Building Information Modelling (BIM) and prefabrication techniques to smart sensors and data analytics, technology optimizes resource utilization, reduces waste and enhances energy efficiency. Innovation in sustainable materials, like green concrete and recycled steel, further reduces the environmental footprint of construction while fostering resilience against climate impacts. Yet, this theme navigates a dual narrative of promise and caution. The promise lies in harnessing technology's potential to accelerate sustainable progress, from 3D-printed eco-friendly structures to renewable energy-integrated smart cities. However, the challenge lies in equitable access to these innovations across regions and socioeconomic strata. Ethical considerations surrounding data privacy, resource extraction for tech production and the environmental consequences of e-waste must also be navigated. Ultimately, the synergy between technology and sustainability lays the foundation for a built environment that embraces innovation as a cornerstone of its eco-conscious evolution.

We would like to express our gratitude to the reviewers of these manuscripts, who provided constructive criticism and stimulated comments and suggestions to the authors. We are extremely grateful as organizers, technical programme committee and editors, and extend our most sincere thanks to all the participants of the conference. Our sincere gratitude also goes to the Publication Partner Springer Nature for their helpful cooperation during the preparation of the proceeding.

Noida, India — Deepak Bajaj
Newcastle, Australia — Thayaparan Gajendran
Mumbai, India — Sanjay Patil

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Technology and Innovation in Process and Products

About the Editors

Dr. Deepak Bajaj is presently a Professor, Director and Head of Institution at the RICS School of Built Environment, Amity University, Noida, Uttar Pradesh, India. He has been an Adjunct Professor at RICS School of Built Environment since 2016 and regularly mentors and supervises Ph.D. scholars and master's degree students. An industry veteran, Dr. Bajaj has rich and varied industry experience in diverse professional capacities in national and international organizations in real estate and construction sectors. He is Fellow of the Royal Institution of Chartered Surveyors for the past 12 years and chairs the Assessment Panel in India and UK at RICS. Before joining RICS School of Built Environment, he has worked in project management, construction, real estate and facility management sectors of the industry. Dr. Bajaj has pursued his Bachelor of Engineering from Manipal Institute of Technology, India, Master of Construction Management from University of New South Wales, Australia, and holds a Ph.D. from the University of Technology Sydney, Australia. He is passionate about knowledge sharing and has spent the last 35 years working in industry and higher education in the Built Environment sector. He has a diverse technical, business and research background, with a wider experience in consulting, training and academia. He had been an adjunct professor at SKEMA Business School, France, and Chongqing Jianzhu College, Chongqing, China. Dr. Bajaj has been honoured with 'Australian Institute of Building National Excellence Award' in 1999 (Construction Management) and 'Facility Management Association Australia National Excellence Award' for Knowledge Achievement in 2003 (Risk Management). He is author of numerous research publications, guest editor and referee to numerous journals.

Dr. Thayaparan Gajendran is Associate Professor at the College of Engineering, Science and Environment, School of Architecture and Built Environment, University of Newcastle, Australia. Dr. Gajendran's research focuses on the governance of organizations, using cultural analysis lenses, in construction and disaster management. His research is committed to developing evidence-based practices and policies for building resilience at the complex intersections between communities and organizations. He engages in extensive international research collaborations and has published over 150 academic articles. He has held numerous service positions, including Assistant Dean of Education, Program Convener, Faculty of Engineering and Built Environment Ethics Committee Chair, and Acting Head of School. Before joining the University of Newcastle, he worked in the industry as Project Quantity Surveyor and Manager of Projects.

Dr. Sanjay Patil is presently Director and Head of Institution at the RICS School of Built Environment, Amity University, Mumbai, Maharashtra, India. Dr. Govind Patil is a result-oriented professional with 23 years of rich and extensive experience in academics, research and consultancy, strategic planning, curriculum development, academic administration, quality assurance and enhancement with added industry experience in project planning and management, cost planning and budgeting, cost control, resource deployment, and site administration. He is Doctorate in Civil Engineering from NIT, Surathkal, India. His research interest involves construction engineering and management, sustainability, coastal engineering, and artificial intelligence. He published several papers in these areas in reputed international journals and conferences. He has successfully mentored, completed and currently working on funded projects in the area of industrial waste management, sustainability, construction project management of worth INR 20.5 million. He is a reviewer for intentional journals published by Elsevier, Taylor, and Francis & ACI. He is recognized as Outstanding Reviewer by Elsevier. He juried for the most coveted awards for the architecture and building industry such as Construction Week India Awards and 'Construction World Architect & Builder Awards.'

Education for Sustainability, Training and Capacity Building

Automated Framework for Evaluating Sustainability and Resilience in Higher Education Curriculum

Madhuri Kumari, Mamta Mehra, and Dieter Pfoser

1 Introduction

With the advances in technology, sustainable development is gaining great attention. The 2030 agenda for sustainable development [11] motivates us to take transformative steps for shifting the world towards a sustainable and resilient path. The operationalization of sustainability and resilience requires specific skill sets. Looking at the demand of the time, it is imminent that the higher educational institutes (HEIs) need to equip the graduates with required skills.

Sustainability refers to the development of products and services which do not limit the future generations need or ability to acquire the same product and services [2]. The concept can be related to societal, economic, cultural, technological or psychological practices thus qualifying sustainability as social sustainability, economic sustainability, cultural sustainability, technological sustainability and psychological sustainability [5] respectively. Resilience is used to identify products that do not get damaged and deformed easily and can be used for a long time. Resilience is the ability of any system to prepare for facing threats, to absorb impact, to bounce back and adapt to challenges, adversity and stressful situations [7].

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As part of quality education, the fourth sustainable goal of the UN-SDGs, sustainability and resilience related topics should be covered in the university course offerings. The curriculums are the foundation of academic learning and practical experiences in higher education. It is required to include sustainability and resiliency related courses as part of curriculum for a future ready academic framework. In order to develop and design new courses, the reconnaissance of existing curriculum system has to be carried out to understand the current state of course offerings in context of sustainability and resiliency.

With increasing number of universities, institutions and courses across the globe, manual review of the existing system is not feasible. Further, no technology support is available in market for automated review of the course catalogues. Thus, the curriculum review process is manual and very tedious. This provides an opportunity to develop a tool and automate the curriculum review process. Considering the advances in web crawling and data analytics technology, this study proposes an automated framework for evaluating the curriculums of HEIs. This tool can read the contents of course catalogue from the website of universities and further perform data collection and analysis of the courses. As a final outcome, this tool lists the courses in the area of sustainability and resilience and provides insight into the type of the courses. The data collected from the automated system can be further analysed using computational method of text analytics and keyword ontology. The analysis result available from this tool can be used to identify the gap areas and then develop appropriate courses in the area of sustainability and resilience.

2 Literature Review and Research Gap

Many researchers have supported the need for automation of several aspects of education system for getting right input and feedback required for timely improvisation of the system. In a higher educational institute, using of digital technology for automating various educational processes will not only help in achieving a high quality of education but will also help decision makers in monitoring and expediting the changes in HEI as per market demand. At global level, summative assessments are carried out to provide feedback and data on general trends and the state of the education system [10]. Digitalization is much discussed intervention in the education sector. In a study presented by Wright et al. the author has discussed the use of real-time data for adaptive management in education [12]. This study also presents the advantage of such real-time data management system for data-informed decisions helping in teaching and learning experiences. Several works have been carried out in automating the process of the educational institutions. For the past decade, web scraping and web crawling have witnessed application in tasks involving mining the data from internet sources [1, 6, 13]. According to Suhirman et al. [9], the use of data mining or web scraping in education can no longer be considered a new methodology. It is known to be a powerful tool that can render significant results in curriculum design. However, it is a significantly underused methodology in curriculum design research [8]. Automation framework for accreditation of HEI [3], converting the collected data into valuable knowledge, student performance assessment and web-based platform for educational processes are some of the preferred areas by the researchers.

These studies collectively highlight the growing interest in automating the assessment of resilience and sustainability courses offered by universities. They emphasize the benefits of using text analysis, machine learning, and data-driven approaches to streamline the evaluation process and ensure consistent standards for these crucial aspects of higher education.

To assess the performance and benchmark HEIs, ranking and accreditation has an important role to play [5]. Globally there are many recognized ranking and accreditation, and curriculum review forms an integral module of these process. However, there are limited studies or research work on automation of curriculum review due to the inconsistent format of the course catalogue of universities.

Considering the outlined research gap in the above paragraph, there is a scope for developing automation tool that can check and review the course catalogue and provide insights and future course of actions. Through this study, authors have proposed an automated framework for evaluating the curriculums of HEIs for sustainability and resilience. This framework is modular and can be expanded for any future requirements.

3 Study Data Set

This study was supported by Global Council for Science and the Environment (GCSE), USA. The organization of GCSE is a credible source of data and analysis of trends in higher education landscape, especially related to sustainability education and environmental studies. The dataset used in the study was divided into a training dataset and validation dataset. The list of 165 member universities of GCSE as shown in Fig. 1 was considered as training dataset which was used to train and develop the proposed automation framework. A comprehensive list of 2000 universities of USA was used to validate the developed framework.

4 Methodology

The automation framework was developed using four step approach as outlined in Fig. 2. As a first step, the training dataset was thoroughly analysed by visiting the web pages of each of these 165 GCSE member universities. The website of the universities was traversed to find the catalogue page. Thus, the catalogue URLs were listed corresponding to the list of universities. In the second step, the catalogue page was explored to identify the pattern of course information arrangement. This step was critical for framing the strategies and algorithms for scraping the course related

Fig. 1 Training dataset (: Location of Universities)

data from catalogue web page. In the third step, the normalization of web response from catalogue web pages of different universities was done to list down the set of common information available across most of the catalogue information. This information formed the base for the schema designed for the extraction of course related data. As a final step, automated framework was developed using web crawling technologies.

1. **Identify catalogue URLs**: In this stage, the websites of 165 GCSE member universities were traversed to check the placement of course catalogue information and extraction of course catalogue URLs. were explored to understand the placement of course catalogue information. Subsequently, the URLs for accessing the course catalogue were identified. Figure 3 shows the representative data of course catalogue URLs collected in the first stage.

2. **Analyse catalogue page for identifying the patterns**: The presentation and arrangement of course catalogue information on web pages varies across different universities. In general, the course catalogue contains a list of courses which are

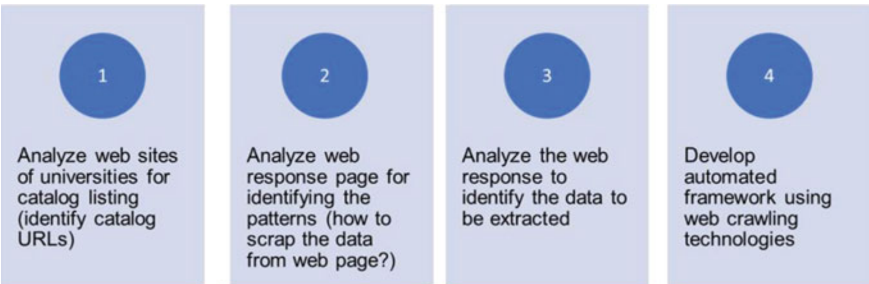


Fig. 2 Methodology

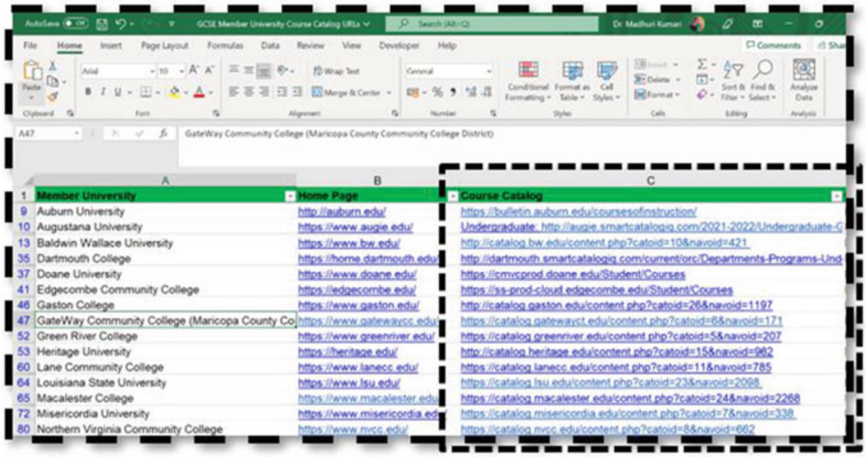


Fig. 3 Identification of course catalogue URLs

either arranged semester wise, UG/PG basis, department wise or presented as a single consolidated list with pagination. To develop web crawler, it is required to identify patterns of information arrangement on webpage. In this stage, an agile approach was used for identification of pattern and sub pattern which evolved as development progressed. In stage 1, the pattern at macro level was identified as table, non-table and pdf as shown in Fig. 4.

In stage 2, the high-level pattern was further nailed down and patterns for accessing details of courses was identified as (a) major divided directory: The courses were listed alphabetically and traversed using menu 'Courses A-Z'. The course name was displayed as hyperlink which on click opens a new page with course details. (b) full listing: All the courses offered by the university are listed on single page with course details presented in tabular format. (c) search-based directory: The subset of courses offered by the university is shown on the web page based on the search criteria. Figure 5 shows stage 2 of pattern identification.

In stage 3, the most common pattern of major divided directory and full course listing was further explored and a micro-level pattern identification was carried out which can form as an input for designing web crawler and parser. The micro-level pattern was identified as (a) major divided directory with details of course opening in new page (b) major divided directory with details of course opening on the same page (c) full course listing with all course information on single page displayed at single click of course catalogue menu. Figure 6 shows stage 3 of pattern identification at micro-level.

3. **Analyse the web response to identify the data to be extracted**: The course information common across different web response pages was identified. It was found that most web pages render the course catalogue with each course qualified by course title (along with course code), course description and course url that

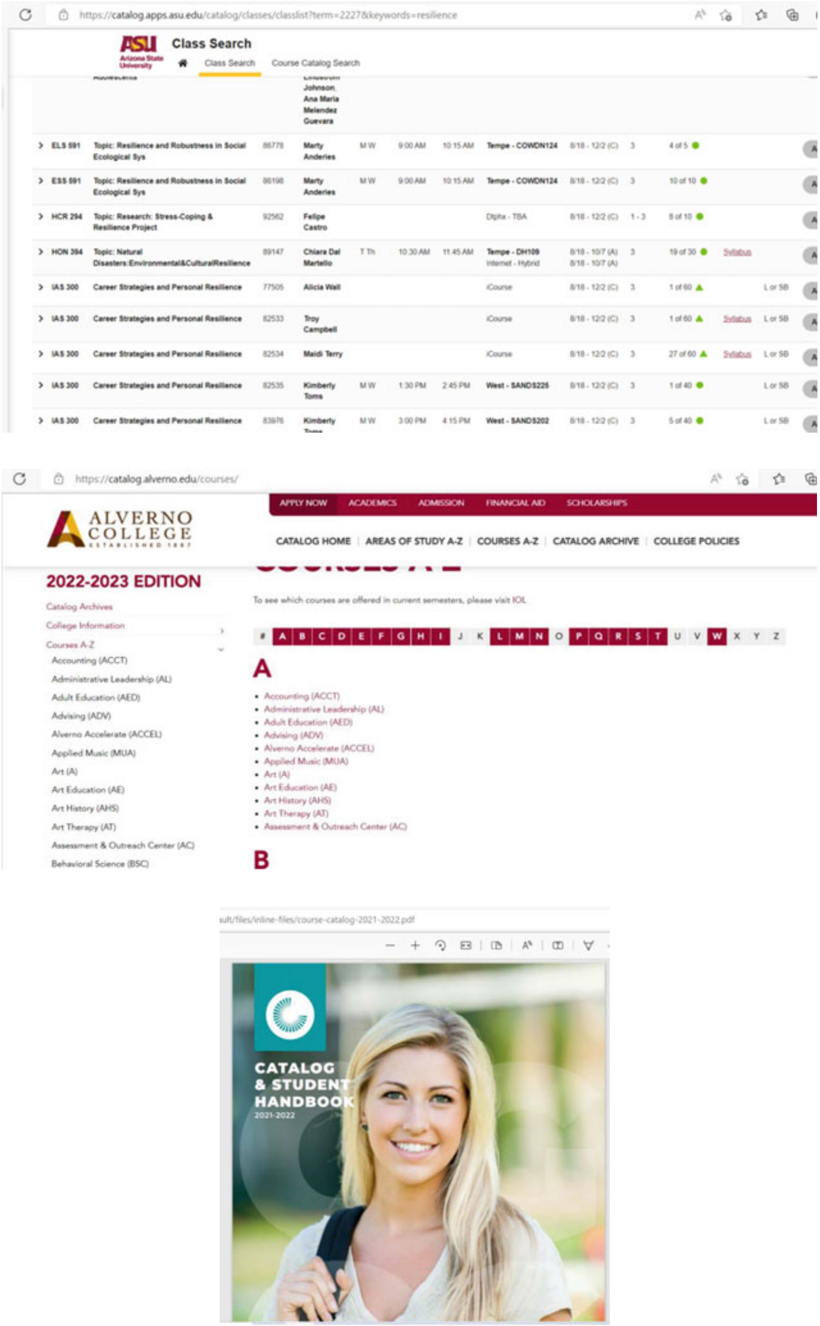


Fig. 4 Stage 1 of pattern identification—macro—**a** Table **b** Non-Table, **c** PDF [14–16]

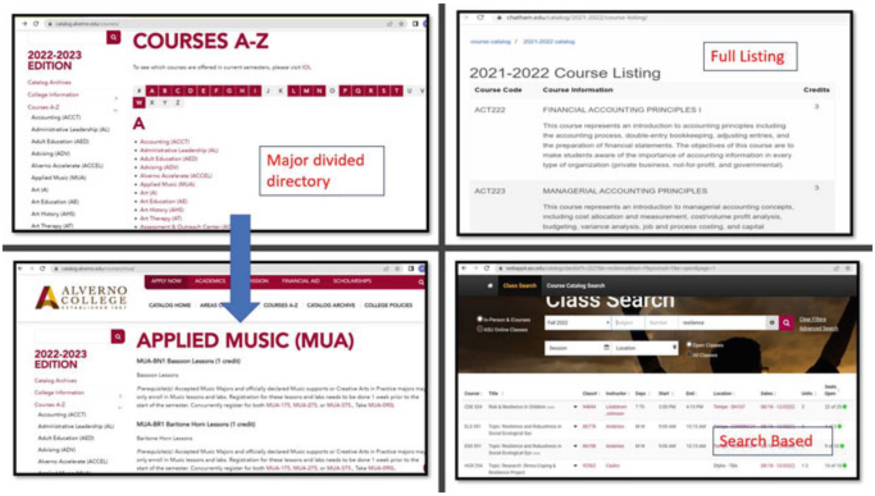


Fig. 5 Stage 2 of pattern identification (macro level—major divided directory, full listing, search-based) [14–16]

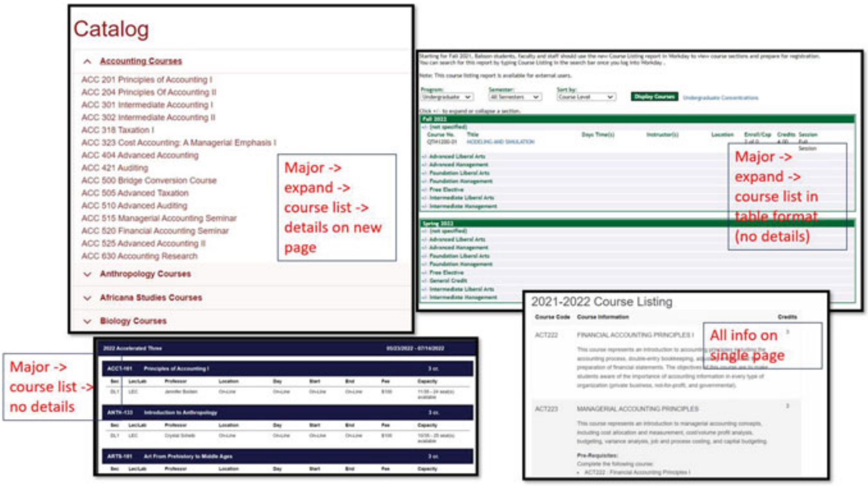


Fig. 6 Stage 3 of pattern identification (micro level—major divided directory with details on new page, major divided directory with inline course details, full course listing) [14–16]

points to course details. Based on the finding the parser was designed to extract course code and course title, course description and course urls (Fig. 7).

4. **Develop automated framework**: An automated web crawler-based framework was developed using open-source technology which can read the contents of course catalogue from the website of universities and further parse the webpage,

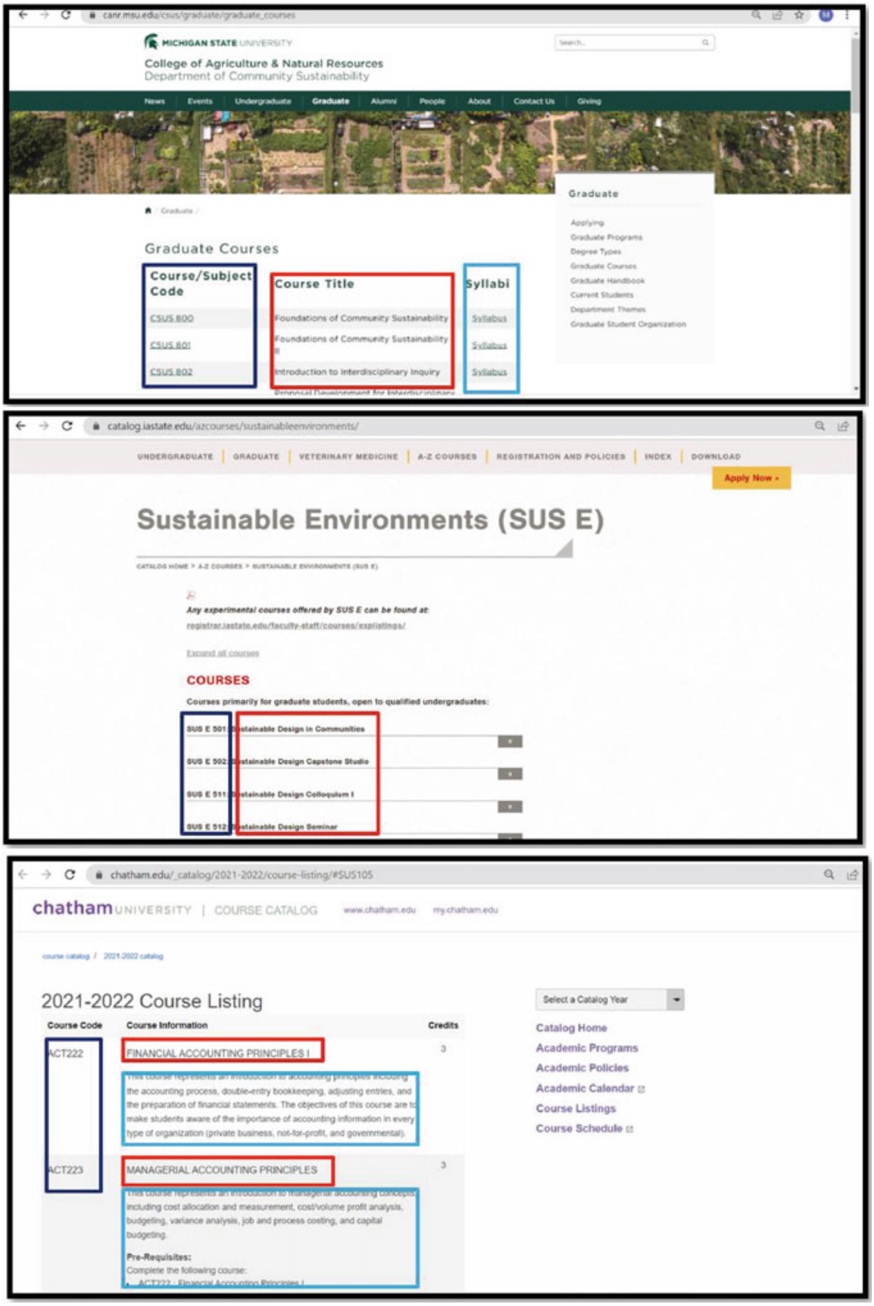


Fig. 7 Common course information across different catalogue pages [14–16]

perform data collection and analysis of the courses. The system was developed for a subset of universities in United States. It was tested using the validation dataset containing the comprehensive list of universities in United States.

5 Automated Framework for Evaluating Sustainability and Resilience in Higher Education Curriculum

The automated framework consists of four important components namely, web driver, web crawler, web response parser and output formatter as shown in Fig. 8. The framework was developed using python. The web driver was responsible for reading the URL of course catalogue and sending the request to the URL. It used selenium library of python. The web crawler was used for collecting the response from the website and storing it offline as a text file. This approach of dumping response in file without parsing was helpful in saving time required for revisit of the website and handle bulky response from the website. The web parser was developed using beautifulsoup library of python. This component was responsible for parsing the web page and extracting the course related information as per designed response schema and storing it in object. The web parser passed on the control to output formatter synchronously. The output formatter prepared JSON object and dumped it in output text file which was then stored offline. The technology stack used for the development of this automated framework is shown in Fig. 9. Google colab was used as the platform to write and execute the python code.

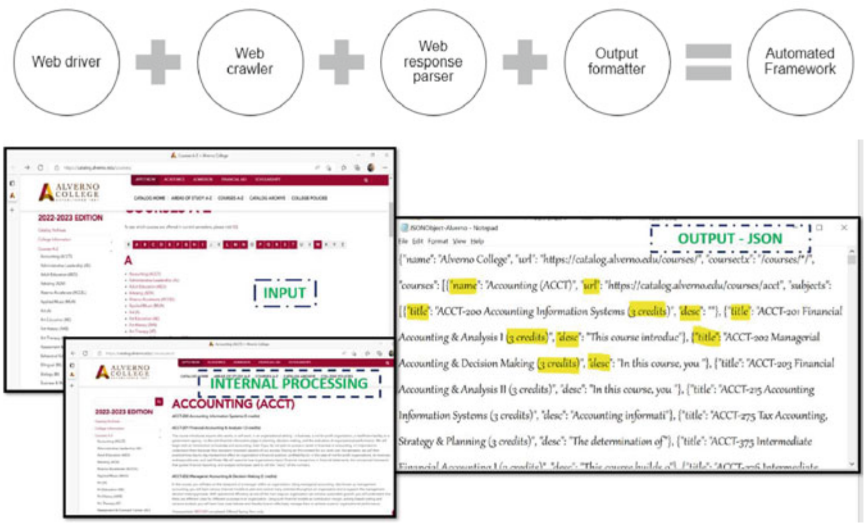


Fig. 8 Automated framework for evaluating sustainability and resilience in higher education curriculum []

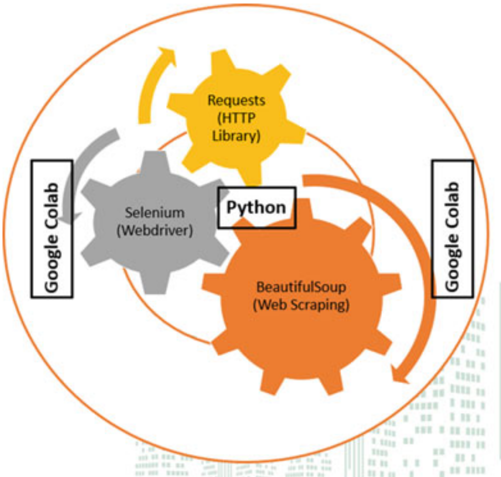


Fig. 9 Technology stack used for developing Automated framework

In summary, this framework takes catalogue URL of a university as input and generates a well formatted file with course information extracted from the course catalogue web page. The output is in popular data-interchange format, JSON which is lightweight, text-based and represents the data as a collection of name/value pairs. It can be easily consumed by any programming language and supports ease of integration.

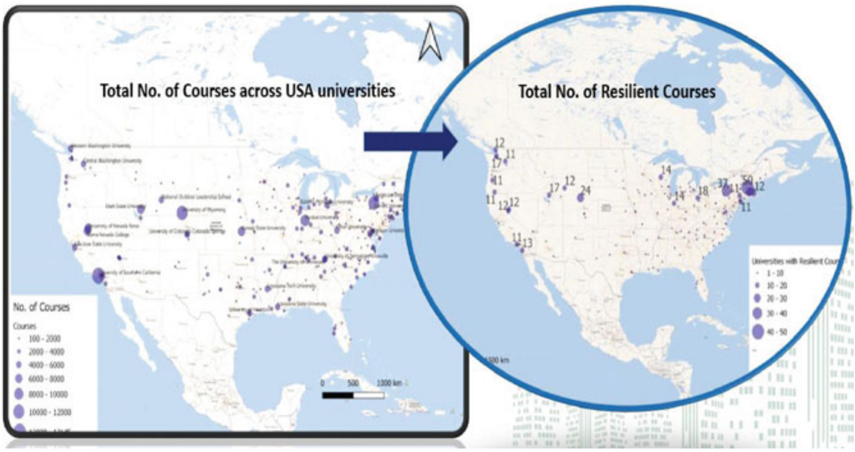
6 Result and Conclusion

The course data collected through the web scraping programme was analysed to understand the integration of sustainability and resilience in the courses being offered across the universities. The data so collected from the automated system was analysed using computational method of text analytics and keyword ontology. Text mining techniques were applied for distilling insights from the collected course data.

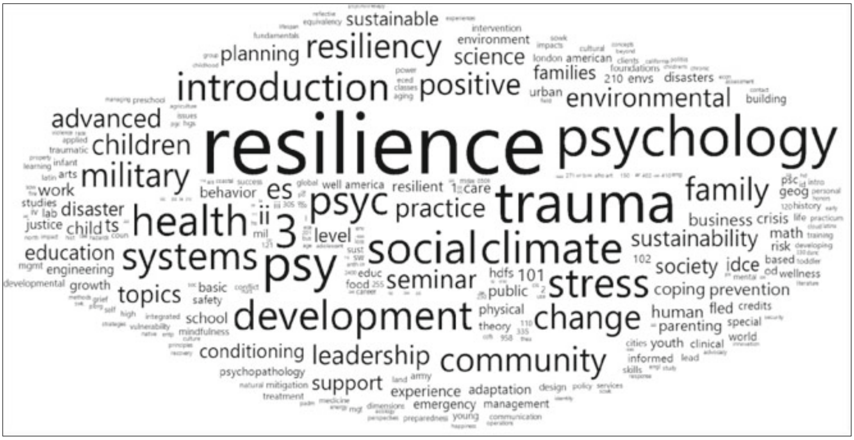
The field of course title and course description were searched for keywords that directly or indirectly indicated the relevance with regard to resilience. The keywords used as a direct indicator were ‘resilient’, ‘resilience’, ‘resiliency’, ‘sustainable’, ‘sustainability’. The keywords used as an indirect indicator were ‘energy’ and ‘climate’. This was followed by analysing the search result further for finding the resilient courses in the area of environment, energy and climate. Word frequency analysis was carried out on the course title and course description field of search results to understand the occurrence of keywords in resilience related courses. The frequency of the words was used to infer the top 5 areas of resilient ready courses. To make semantic analysis more accurate in text mining, collocation analysis using the Bag of Words (BoW) approach was applied. The course title and course description were tokenized using 2-g, 3-g and 4-g to find the occurrence of environment, energy or climate in the courses matching the resilience criteria.

As a final outcome, this tool listed the courses in the area of sustainability and resilience based on the keywords used for searching. The data can be used for getting an insight into the type of the courses as presented in Fig. 10. The top 10 phrases using 2-g, 3-g and 4-g.

The spatial map of resilience courses as in Fig. 10a clearly shows that less number of resilient or sustainability related courses are being offered by the universities across USA. East Coast of USA has better coverage of resilience in the courses as compared to the West Coast of USA. The word cloud of course title having direct mention of resilience or sustainability in the title is plotted in Fig. 10b. It shows that there are varied areas covered as part of resilience education. The top 10 areas include



(a) Spatial representation of total courses versus resilience courses on the map



(b) Word cloud representing the frequency of occurence of different words in the resilience course title

Fig. 10 Spatial map and word cloud for resilience courses psychology, social, climate, health, community, development, environmental, trauma and stress. The word cloud can be supplemented by insights from Table 1 which provide top phrases using 2-g, 3-g and 4-g, indicates that community resilience is most popular course across the university. Climate, weather, food security are also popular resilience subjects. Psychology courses covering trauma and stress resilience are also offered in many of the universities of USA. Resilience in security, risk, system reliability is also covered as course offering in few universities. Though the universities across USA are offering courses related to resilience, still the knowhow of the students in this matter is very limited. This clearly indicates the need for designing and introducing new courses in areas of resilience and sustainability. The courses related to resilience in the field of environment, disaster need to be designed and should be offered in all the universities so that students are aligned to the SDGs.

This outcome can be effectively used to identify the gap and thus preparing the list of courses to be developed and designed for an efficient and future ready curriculum.

Table 1 Top phrases using Bag of Words approach and tokenized using 2-g, 3-g and 4-g

2 words phrase	4 words phrase
Community resilience	Agroecology and resilient communities
Resilient communities	climate change community resilience
Building resilience	Family stress and resilience
Coastal resilience	Stress and resiliency
Community resiliency	Building community environmental resilience
Environmental resilience	Climate and weather resiliency
Resilient cities	Food security and resilient
Resilient systems	Security and resilient communities
Weather resiliency	System reliability and resilience
3 words phrase	
Trauma and resilience	Legacy of resilience
Agroecology and resilient	Reintegration and resilience
Change community resilience	Reliability and resilience
Stress and resilience	Resilience and freedom
Identity and resiliency	Resilience and recovery
Resilience in children	Resiliency and coping
Resiliency in public	Resiliency in meteorology
Risk and resiliency	Resilient communities practicum
Stress and resiliency	Risk to resiliency
Sustainability and resiliency	Security and resilient
Threats and resilience	Skills of resilience
Community environmental resilience	Trauma and resiliency

7 Challenges and Future Scope of Work

The current course offering in various universities is varied, with each college offering different courses under sustainability and resilience. These varied courses need some normalization so that they can be compared and evaluated. It is also important to grade the various courses so that no redundant courses are being offered.

The dynamically changing pages of catalogue presented a challenge during framework development. With new semester and academic session, pointer to catalogue changes. The catalogue URL working today may not be working in future. Also, the web response of the given catalogue URL may change in future. Considering the cases analysed during the development, around 50–65% cases of web response were not generalizable and hence developing a fool proof framework is difficult. In many cases, the university maintains the course catalogue in the form of a pdf copy, parsing of which is not handled as part of our study and forms a limitation for usage of the framework.

Several technological challenges were encountered during development of the framework. Initially, the four components of the framework worked synchronously, and the control serially passed on from one component to another. However, the http request timed out while fetching multiple pages of web response as many web pages of catalogue presented the course list along with pagination. Further, the large size of web response could not be stored in memory and hence the data processing was interrupted. To handle this timeout error, the http request was made asynchronous with increased time lag and the web response was cached in a file. The cached response was advantageous as revisit of web page could be avoided thus saving time.

The developed framework can be extended and generalized in future to cater to higher education institution across the world. Further, the framework is flexible to handle the queries related to finding courses in any domain provided the keyword is defined. This framework can be used for identification of university readiness for subjects beyond sustainability and resilience. Also, there is a scope of increasing the data collection from catalogue for better report generation and handling complex queries. The framework can be considered as a base for incorporating more customization to increase the reach of this framework to recruiters, research institutions and policy makers.

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References

1. Adelola MA, Adewale OS, Iwasokun GB (2016) Graph theoretic and genetic algorithm-basedmodel for web content mining. Int J Comput Sci 13(6):68–75.https://doi.org/10.20943/01201606.6875
2. Aminpour P, Gray S, Richardson R, Singer A, Castro-Diaz L, Schaefer M, Chikowore NR (2019) Perspectives of scholars on the nature of sustainability: a survey study. Int J Sustain Higher Education
3. Alhiyafi J, Abuaqel I (2018) An Automated System for Collection and Analysis of ABET Curriculum Requirements. International Conference on Computational Science and Computational Intelligence (CSCI), pp 663–666. https://doi.org/10.1109/CSCI46756.2018.00133
4. Di Fabio A, Kenny ME (2018) Connectedness to Nature, Personality Traits and Empathy from a Sustainability Perspective. Curr Psychol 1–12. https://doi.org/10.1007/s12144-018-0031-4
5. Fernandes JO, Singh B (2022) Accreditation and ranking of higher education institutions (HEIs): review, observations and recommendations for the Indian higher education system. The TQM Journal 34(5):1013–1038. https://doi.org/10.1108/TQM-04-2021-0115
6. Kimmons R (2017) Open to all? Nationwide evaluation of higher-priority web accessibility-considerations among higher education websites. Journal of Computing in HigherEducation 29(3):434–450. https://doi.org/10.1007/s12528-017-9151-3
7. Marchese D, Reynolds E, Matthew B, Morgan H, Clark SS, Linkov I (2018) Resilience and sustainability: Similarities and differences in environmental management applications. Science of The Total Environment, Vol 613–614, 1275–1283, ISSN 0048–9697. https://doi.org/10.1016/j.scitotenv.2017.09.086.
8. Moretti A, González-Brenes JP, McKnight K (2014) Data-driven curriculum design: Mining theweb to make better teaching decisions. Proceedings of the 7th International Conference onEducational Data Mining (EDM 2014). Retrieved from https://files.eric.ed.gov/fulltext/ED558339.pdf
9. Suhirman S, Herawan T, Chiroma H, Zain JM (2014) Data mining for educationdecision support: A review. Int J Emerg Technol Learn 9(6):4–19
10. World Bank, UNICEF & UNESCO (2020). The state of the global education crisis: a path to recovery. https://www.unicef.org/media/111621/file/%20The%20State%20of%20the%20Global%20Education%20Crisis.pdf%20.pdf
11. https://sdgs.un.org/2030agenda
12. Wright E, Osborne S, Aggarwal M (2022) Digital tools for real-time data collection in education, The Brookings Institution. https://www.brookings.edu/essay/digital-tools-for-real-time-data-collection-in-education/
13. Raicu I (2019) Financial banking dataset for supervised machine learning classification. Informatica Economica, 23(1), 37–49. https://doi.org/10.12948/issn14531305/23.1.2019.04
14. https://www.canr.msu.edu/
15. https://catalog.iastate.edu/azcourses/sustainableenvironments/
16. https://chatham.edu/_catalog/2021-2022/course-listing/#SUS105

Monitoring Occupant Preferences for Daylight Levels in Indian Homes: A Case of Ahmedabad

Minu Agarwal, Swetha AB, and Atisha Jain

1 Introduction

1.1 Overview

Daylighting is one of the critical ingredients for human health. To encourage the use of daylight and enhance indoor environment quality, Leadership in Energy and Environmental Design (LEED) prescribes up to three points, and the WELL building standard prescribes up to two optimizations through simulation and a prescriptive approach. However, availing the full daylight depends upon home design, location, content, weather, occupant behavior, and visual and thermal comfort.

Growing urban density and air pollution reduce daylight availability inside homes, resulting the need for artificial ventilation and lighting systems. Daylight significantly impacts natural body functions and is considered central to our well-being as it influences our circadian rhythm, which further impacts our sleep cycle, energy and alertness, mood, and other essential functions for our health and well-being.

Considering that people spend substantial period of the day indoors, sufficient daylight access in buildings has become a public health issue. At the same time, cross-modal research shows that people in warm environments may prefer low light levels to enhance their overall comfort. Improper daylight access has been linked to breast cancer, type-2 diabetes, and prostate cancer that have reached epidemic levels in many countries. The occupants without a good source of overall lighting

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environment can have a subsequent impact on health. The sunlight and vitamin-D have been associated with reduced risk for many chronic illnesses, including cancer and cancer mortality [10]. It is shown that there is a 30 to 50% reduction in risk for developing breast and prostate cancer by either increasing vitamin D or increasing sun exposure [9]. Studies show that daylight has been linked with better mood, less tiredness, and reduced eye strain.

While daylight ensures many health benefits, occupants may experience barriers in using it effectively at all times. Electric lighting is often used to supplement daylight in homes. In 2011, The Indian Bureau of Energy Efficiency stated that the end-use-energy consumption break-up in the Indian residential sector was 28% of energy use in lighting, 34% in fans, and 13% in refrigeration systems [14].

1.2 Research Goals

1. To measure and report the average daylight levels maintained in the Indian residences by their respective occupants.
2. To estimate the gap between the daylight access availed by the occupant and the ideal daylight access of the residence as per the design.

This study also reveals the extent of trade-offs that occupants have to make for their daylight access and the occupant's comfort in their living rooms.

The study shall be limited to the living rooms of residential buildings in Ahmedabad, considering the most used space in residence during day time.

2 Literature Review

The literature review is divided into three major parts. First, to understand the occupant behavior in residential buildings. Second, to understand the factors determining the occupant to curtail the daylight access in the residences. Third, to understand the importance of vertical illuminance in everyday life.

2.1 Impact of Occupant Behavior on Residential Buildings

Building energy certification versus user satisfaction with the indoor environment: Findings from a multi-site post-occupancy evaluation (POE) in Switzerland. This paper presents a thorough and detailed method for generating occupancy data for offices using on time-use data by surveying method. The study adopts the survey methodology to understand the occupants' daily activities. The presented approach generates statistical occupancy time series data at ten-minute intervals, taking into account weekdays and weekends by building transaction probability matrices from the source data and using these to generate synthetic data series. The model indicates the number of occupants active within a house at a given time to model the sharing of energy use. As a result, the model generates detailed occupancy patterns in time series, intended to be used in energy simulations and to track a space's active and passive users [17].

Occupancy and occupant activity drivers of energy consumption in residential buildings—This paper addresses one of the uncharted area occupant behavior and its co-relationship with the load profiles through plug loads and end-use energy demand. Three residential units of the same floor plans were chosen in an apartment to investigate Occupancy and occupant activity drivers of energy consumption. The methodology is based on a data-driven framework which is monitored for an entire year in these 3 residential units. Occupants have much control over their indoor environment. A long-term data collection declines each household's weekend and weekday behavior based on the occupancy profile. Knowing the occupancy profile of a particular house can help in knowing the high energy consumptions period throughout the day. This paper states, "The impact of reducing peak demand and achieving flatten load profiles for each household can become tangible on large scales." This paper clearly shows that occupancy profiles and behavior play a significant role in energy consumption, and it changes for every household [1].

Residential electric lighting use during daytime: A field study in Swedish multi-dwelling buildings—This paper explores how occupants' behavior in a residential building is affected by the characteristics of the rooms, specifically focusing on their electrical lighting usage. The study aims to understand how room features influence how people interact with lighting systems in the building.

This paper investigates the effect of room function and orientation on daytime electric lighting use in dwellings and the role of room design. The study was conducted in six multi-dwelling residences in the kitchen, the living room, and the bedroom in Sweden. The study adopts the methodology of a questionnaire survey with responses on electric lighting using a seven-point Likert scale, a preliminary study to understand the effect of orientation, geometry, and function on occupant behavior diversity and statistical analysis was performed to verify whether there is a relation between daytime electric lighting and the room function, room orientation or both. The findings of this study show that lighting usage in a built space depends upon occupancy patterns and design features like room orientation and window orientation [5].

2.2 Daylight-Related Trade-Offs Made by Occupants

Privacy and daylight: Evaluating the acceptance of daylighting traditional devices in contemporary residential houses in Bahrain—The need to curtail daylight by an occupant in a residence depends upon various reasons like visual

Table 1 Understanding the correlation of the factors determining the occupant to curtail the daylight access

FACTORS / REASONS	Glare-Visual discomfort	Heat (Direct sunlight)	Privacy	Noise
Ventilation	*	*	*	✓
Daylight	✓	✓	✓	*
View	✓	✓	✓	*
Direct Sunlight	✓	✓	✓	*

Legend

✓	Trade-off
*	Plausible but no papers found

Source Author's Computation

comfort (glare), noise, privacy, direct sunlight, etc. In Bahrain architecture, the trade-off on the daylight is also based on cultural considerations of privacy.

This paper presents the Trade-off is done between daylight access and visual privacy. A cross-sectional survey with 15 close-ended questions was used to measure visual privacy and daylight issues in Bahraini homes. In this study, all questionnaire surveys showed that 92.07% of people considered daylight important and 95% of respondents considered visual privacy to be important. Moreover, 30.29% of people considered priority to the need for visual privacy over the need for daylight in the space. The results show that religious beliefs and cultural factors also play a significant role in visual privacy. Even though people were aware of the conflict between the need for visual privacy and daylight availability in their houses, they were ready to trade off the light levels for visual privacy.

Daylight and view through residential windows: effects on well-being—[20] states that direct sunlight provides light and warmth, and conversely, direct sunlight and a bright sky can also cause visual discomfort for the elderly. A set of open-ended questions were developed to understand the visual performance, spatial appearance, discomfort, stress and restoration, and circadian regulation. The results state that openings must be modifiable to exclude direct sunlight when required for privacy and discomfort, and views contribute to the health and well-being of human eyes.

3 Overview of the Daylight-Related Trade-Offs Made by Occupants

3.1 Importance of Vertical Illuminance

Vertical illuminance is an indicator for the brightness of vertical surfaces such as walls which form a large part of an occupant's field of view. Thus, brightness of walls is seen as the missing link between existing daylight standards (horizontal illuminance-based) and user evaluations and satisfaction with daylight levels [16]. Its primary purpose is to make spatial proportions, spatial experience, and immediate visual tasks visible. The light on the vertical plane significantly influences the impression of brightness. The perception of brightness is greatly influenced by the light on the vertical plane. Therefore, a space where people move, or work should be illuminated.

3.2 Literature Gaps and Methods Used in Earlier Studies

Daylighting in residences in the urban environment is a relatively uncharted area of study. Only a few studies are showing the impact of daylighting in residential spaces, with the influence of surrounding contexts of obstructions and shading devices [11].

In earlier daylighting studies, Horizontal illuminance has been taken as the parameter to evaluate daylight access in the horizontal work plane. In this study, Vertical illuminance was taken as the parameter to access the illumination because it is evaluated by its visual task when we enter a space. Hence in this study, vertical illumination was measured in point in time.

This study focuses on vertical illuminance with a data set collected over a week and with the seasonal change at various residences.

4 Research Methodology

A field study was conducted in the living room of eleven residences to assess daylight access by measuring the vertical illuminance of the living room. In the field study, vertical illuminance was measured at a point in time [4]. The sensor point was decided based on the thumb rules to measure the maintained daylight in the house. After the field study, a simulation-based study was conducted for the same house to understand the potential/theoretical daylight access in the living room using LightStanza—a cloud-based simulation tool.

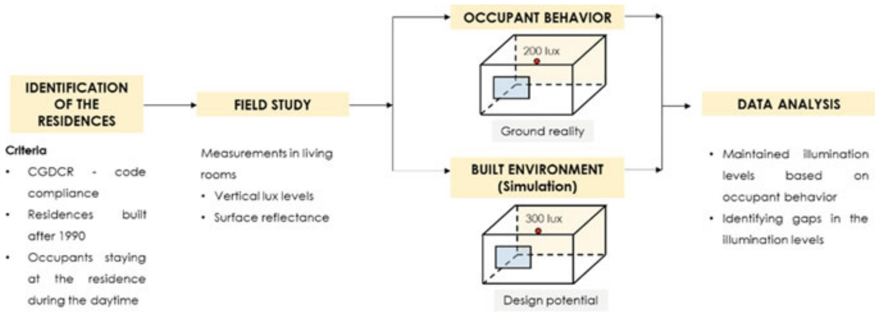


Fig. 1 Overview of methodology. *Source* Author's Computation

4.1 Selection Criteria of Residences

In this study, eleven residences were selected based on the following criteria. Where the residence should compile under the Comprehensive General Development Control Regulations Gujarat (CGDCR) code compliance residence, the living room should have a minimum of 10% of the floor area of the residence, and the window-to-wall ratio should have a minimum of 15%. All the residences should be built after 1990, and an occupant should reside at the residence during the daytime from sunrise to sunset. These criteria were formulated to select consistent houses for the data without any bias in the residences (Fig. 1).

4.2 Selection of Logger

Onset MX1104 hobo logger has been used to measure vertical illuminance in homes. The FOV (180) measures 0 to 167,731 lux with an accuracy of ±10%, typical for direct sunlight and flexibility time steps starting from 1-second intervals. Also, the range of wavelength of light that this can measure. Capable of measuring daylight and artificial light sources commonly used in homes.

4.3 Protocol for Placement of the Sensors

Placement of the sensors follows specific thumb rules for all the residences,

- HOBO logger measuring daylight lux levels to be placed at 1.2 m from the ground.
- HOBO logger measuring daylight lux levels should be placed at the darkest or farthest wall with direct light of sight to the window and the sky visible through the window.

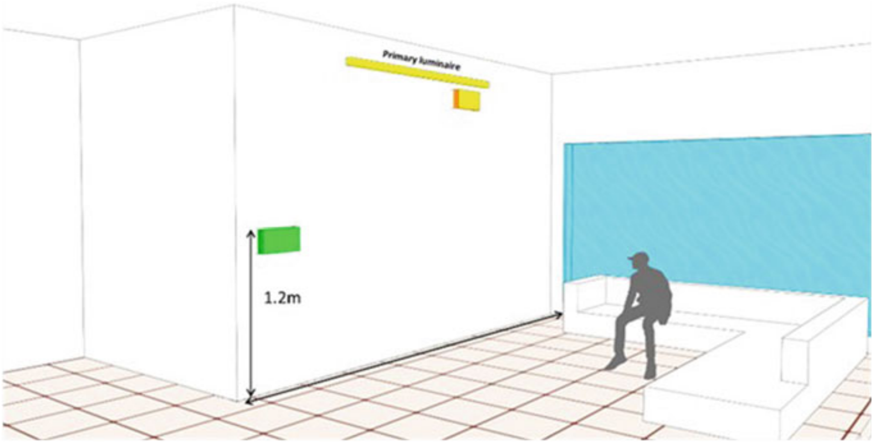


Fig. 2 Protocol for placement of the sensors. (Green marker indicates the daylight sensor, orange marker indicates the sensor below the primary luminaire, and yellow indicates the Primary luminaire). *Source* Author's Computation

- To monitor the usage of the luminaires, a second HOBO logger should be placed below the primary and if needed a third HOBO logger to be placed under the secondary luminaire (Fig. 2).

4.4 The Procedure of the Field Study

See Fig. 3.

- Vertical illuminance would be measured using HOBO Loggers—lux meters in the living room of residences at the height of 1.2 m for obtaining a point in time data at an interval of fifteen minutes for one week.
- The location, time of conducting the experiment, site context, orientation of the building, and other room level and building level observation as per Table 2 must be recorded
- The data of the residences are quantified based on the window wall area

4.5 Observations at Room Level and Building Level

The observations in Table 2 were taken to better understand the occupant behavior in the house.

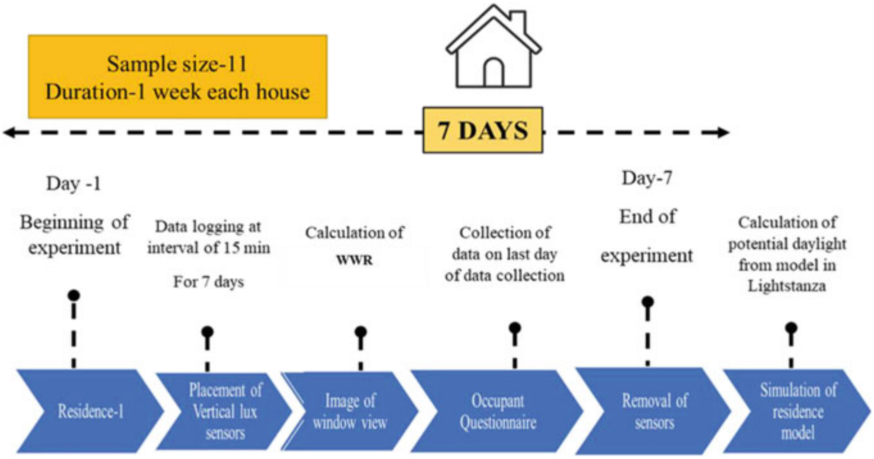


Fig. 3 Procedure for monitoring daylight. *Source* Author's Computation

Table 2 Building and room level observations

	Observations
Room level details	• Obstructions near the window opening • Window shading (Curtains/blinds) type and color • Distance from window to the position of the logger • surface reflectance of the materials (door, wall, curtain, furniture, floor) • Visible light transmittance (VLT) of the glazing • Dimensions of the living room • Dimensions and orientation of the openings • Building floor level • Number of luminaires and their light contribution to the room
Building level details	• Obstruction in front of the building • Vegetation surrounding the building • Outdoor sky conditions

Source Author's Computation

4.6 Simulation Study

The indoor conditions and data collected from the field study was used for modeling one of the residences. Model characteristics were defined based on IES LM-83–12 to reflect likely inputs while assessing daylight performance for standards such as the LEED rating system. The model was simulated using Light Stanza to calculate the vertical illumination of the living room to get potential daylight Illumination.

4.7 Methods for Data Analysis

Through the field study we obtained the vertical daylight illuminance for seven to fourteen days at fifteen minutes intervals. The raw data collected from the field study were analyzed to derive the maintained daylight by deducting the contribution of the electrical light during its usage (Fig. 4).

In quantitative measurement, a field study was conducted to record the vertical daylight illuminance for seven to fourteen days at fifteen minutes intervals. The raw data collected from the field study were analyzed to derive the maintained daylight by deducting the contribution of the electrical light during its usage.

Similarly, a simulation-based study was also conducted in the first house using the observations and the data collected from the field study. Daylight penetration in the axis of the sensor placed during the field study (on-site) was checked to understand the stability of the point of data collection. In the simulation, the theoretical daylight potential of the house was found through which the gap of daylight access. From the gap, the occupant behavior was identified.

In qualitative measurements, a questionnaire survey was conducted to understand the relevance and occupancy behavior with the room and daylight.

Using both quantitative and qualitative measurements, the vertical illuminance was quantified through the Window-Wall-Ratio (WWR).

5 Results

From the data collected from the eleven homes in the field study, the data were analyzed at point in time at 15-min intervals from sunrise till sunset at each home to find the maintained daylight levels in their house (Fig. 5 and Table 3).

Table 4 shows the description of the houses. Houses 1 and 2 were monitored in the same week. Similarly, Houses 3 and 4 are identical houses that were monitored in the same week. All the houses were monitored in the living rooms.

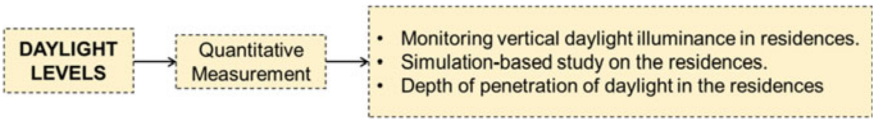


Fig. 4 Methods used for daylight analysis. *Source* Author's Computation

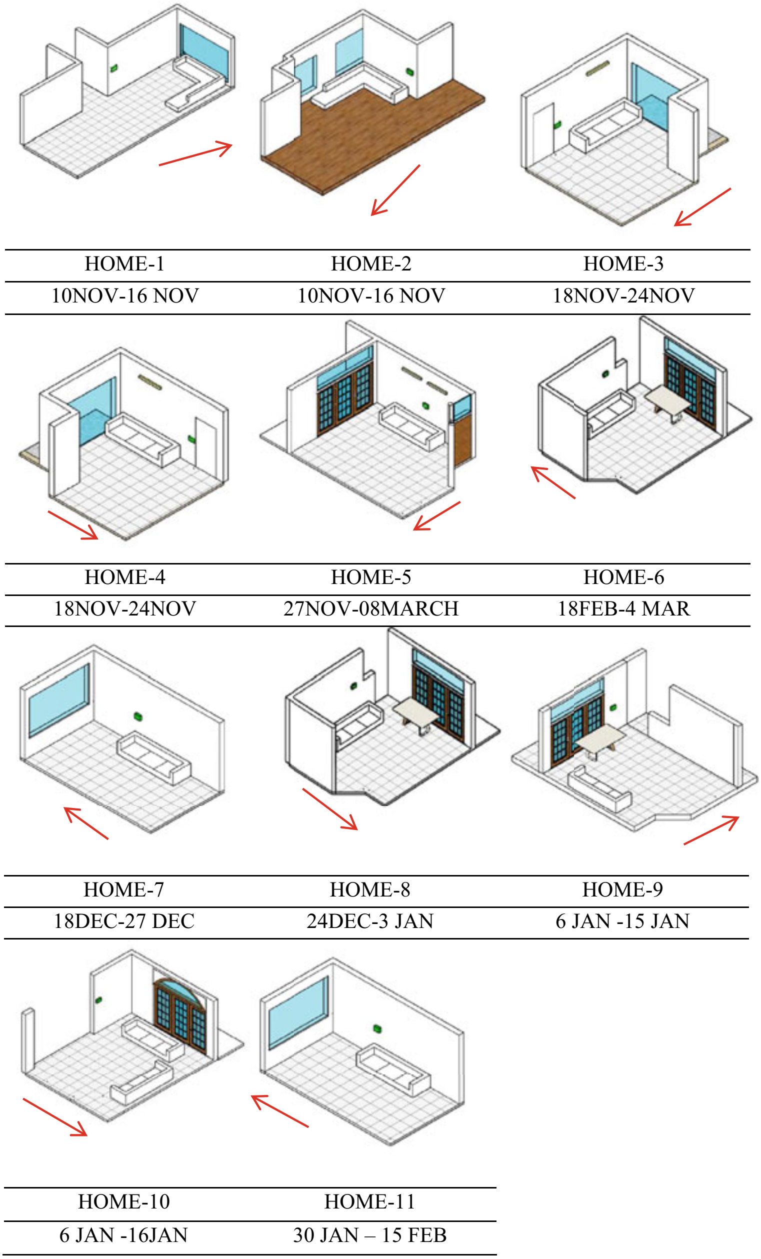


Fig. 5 All homes illustration and point of the sensor (Green marker indicates the location of daylight sensor. Red arrow indicates north). *Source* Author's Computation

Table 3 Description of the houses

	Floor	Orientation of the opening	No. of Openings through which sky is visible	WWR ratio (%)
House 1	Tenth	North West and South East	1	56
House 2	Tenth	South East	2	41
House 3	Fifth	South	1	63
House 4	Fifth	South	1	63
House 5	Ground	East	3	35
House 6	Ground	East	3	35
House 7	First	North	1	55
House 8	Ground	West	3	40
House 9	Ground	West	3	35
House 10	Ground	West	3	40%
House 11	Second	North	1	55

Source Author's Computation

Table 4 Parameters for the study

Parameters	Data
Area of study	Living Room
Time of study	Sunrise to sunset
No of Occupants	5
Window orientation	North–West and South East
Distance from the window to the point of data measurement	4.5 m
WWR (%)	56.00%

5.1 Average Daylight Levels Maintained in Living Rooms

The examined house was classified into three categories based on the maintained daylight levels, daylight deprived house—low light levels (0–50 lx peak daylight level), well-lit house—moderate light levels (50–100 lx peak daylight level), and well daylight-maintained house—high daylight levels (more than 100 lx peak daylight level) (Figs. 6 and 7).

From these three categories, we further hypothesize that daylight deprived homes have significantly less trade-offs that can be done by occupants as the peak daylight levels are less than 50 lx. Hence, to understand the trade-off done by occupants from theoretical daylight access to the observed on-site daylight access—one house from well daylit house was further investigated by computer-based simulation (Fig. 8).

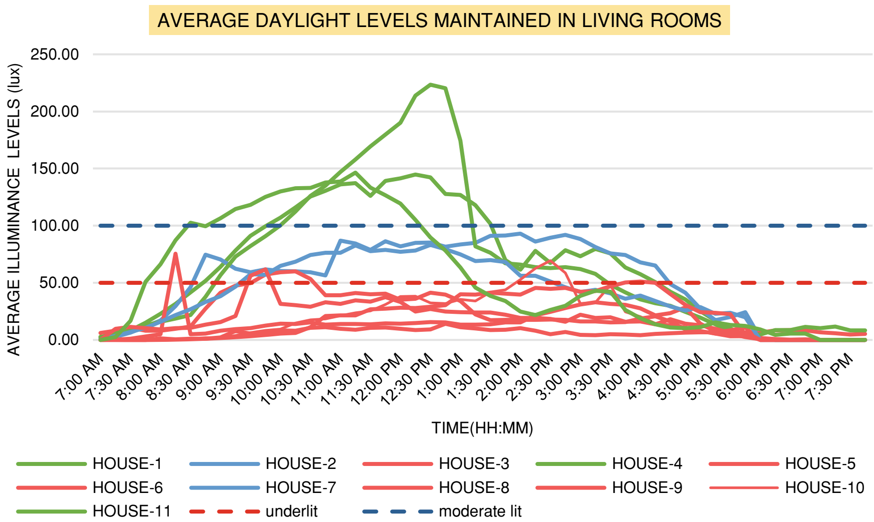
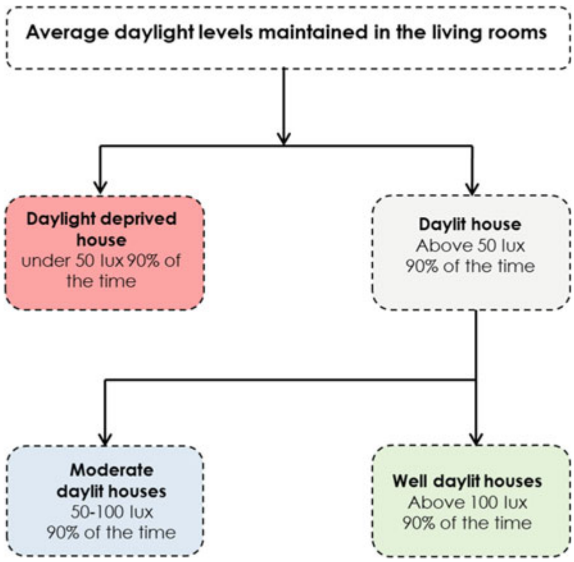


Fig. 6 Average daylight levels maintained in the living rooms. This figure shows over averages over a week for every 15 min. (Red lines indicate homes that are under 50 lx 90% of the time—Daylight deprived home, blue lines indicate homes that are between 50–100 lx 90% of the time—Well Daylight-maintained home, green lines indicate homes that are above100 lux 90% of the time—Well Daylit home. *Source* Author's Computation

Fig. 7 Classification of the houses based on the average maintained daylight levels in the living rooms. *Source* Author's Computation



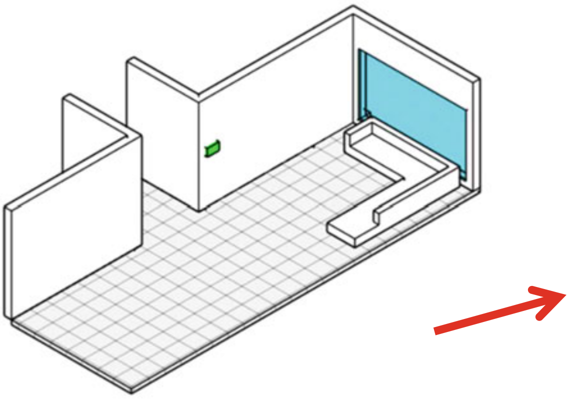


Fig. 8 Home-1_Well daylight-maintained homes (Green marker indicates the location of daylight sensor. Red arrow indicates north). *Source* Author's Computation

6 Case Study—Well Daylight-maintained Homes: To Estimate the Gap Between the Daylight Access Availed by the Occupant and the Ideal Daylight Access of the Residence as per the Design

Usage of curtains/blinds in the living area—From Fig. 9, Based on the activity and time usage of the living room. The living room was majorly used during the daytime and evening and partially during the afternoon. From this residence's living area was concluded to be the most commonly used space throughout the day (Fig. 10).

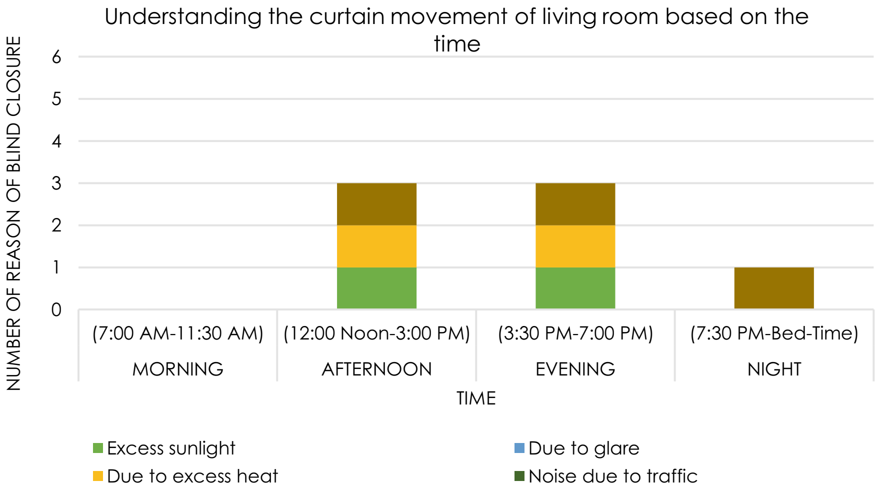


Fig. 9 Understanding the curtain movement of living room based on the time. *Source* Author's Computation

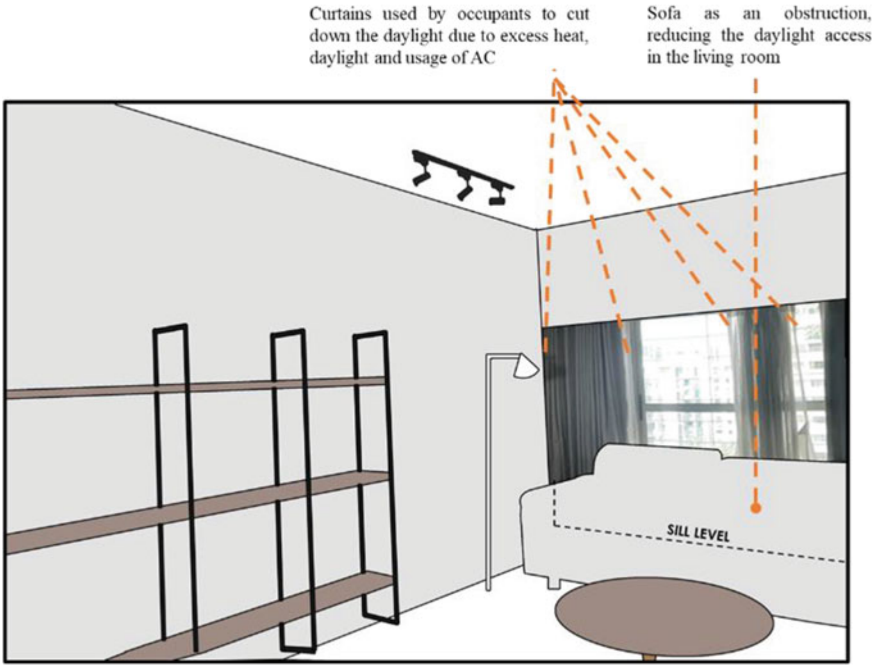


Fig. 10 Understanding the obstruction in the daylight access and reasons to curtail the daylight access by the occupant. *Source* Author's Computation

6.1 Understanding the Obstruction in the Daylight Access and Reasons to Curtail the Daylight Access by the Occupant

Simulation study: Results generated from the LightStanza simulations were then analyzed for the distribution of daylight. From the simulation model, a vertical grid was laid in the sensor point's axis to understand the sensor point's stability in November to understand the sensor point's stability through daylight access (Fig. 11).

Understanding the stability in the point of sensor based on seasons—From the simulation model, a vertical grid was laid in the axis of the sensor point to understand the stability of the sensor point through daylight access (Fig. 12).

From Fig. 13, the shift in the illuminance values on the sensor point was less than 10% (9th point) in November. From Fig. 13, it was concluded that the logger was placed in one of the most stable points in the living room that does not have an impact from the weather change. Hence, when the weather conditions remain steady, any day-to-day change in the illuminance levels was most likely due to the occupant's behavior.

Relation between average daylight levels maintained in the home and the usage of artificial light in November. From Fig. 14, the average maintained daylight levels

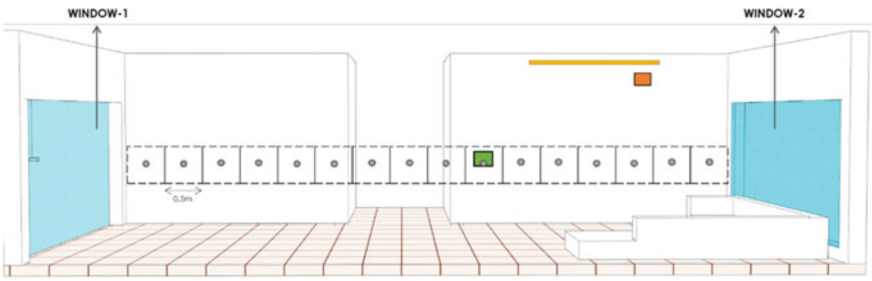


Fig. 11 Schematic representation of points of penetration of the daylight in the axis of the daylight sensor. (Green marker indicates the daylight sensor-on-site, the orange marker indicates the sensor be the low primary luminaire-on-site, and, yellow indicates the Primary luminaire, the grey marker inside the square box indicates the sensor points in simulation). *Source* Author's Computation)

Fig. 12 Renders from light stanza (Left image shows window-1, right image shows window-2). See Fig. 11 for window orientation *Source* Author's Computation

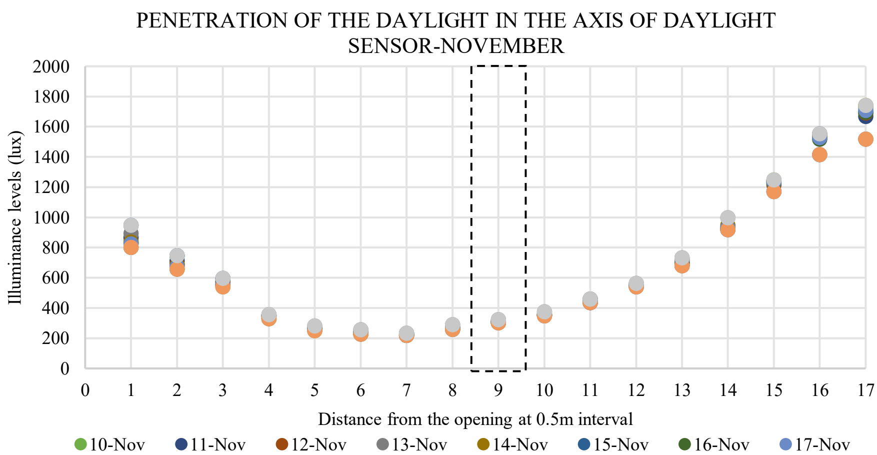


Fig. 13 Penetration of the daylight in the axis of daylight sensor-November. *Source* Author's Computation

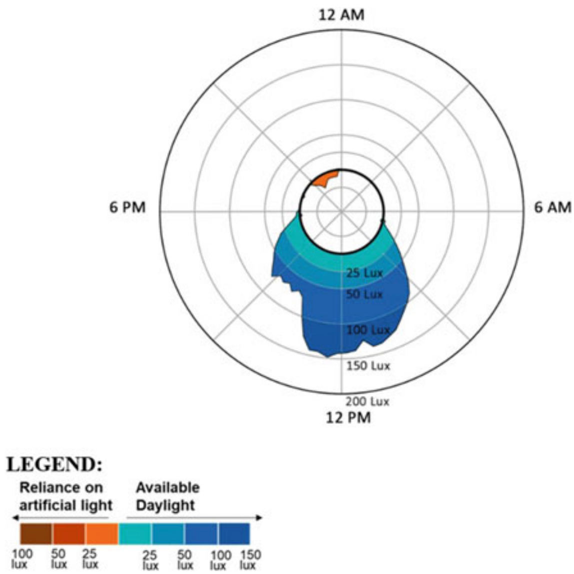


Fig. 14 Relation between average daylight levels maintained in the home and the usage of artificial light. *Source* Author's Computation

in the afternoon reached a peak of less than 150 lx levels. Hence this residence was considered a well daylit home. In this residence, artificial light usage was observed only at night after sunset. These factors suggested that the occupants might have been satisfied with the daylight access in the living room. Hence, they might not rely on artificial light during the daytime.

Hourly daylight illuminance levels maintained at each hour—From Fig. 14, in winter, during the morning and evening, the gap between maximum and minimum daylight illumination throughout the week was less than 20%. However, in the afternoon, the gap between maximum and minimum daylight throughout the week was 75%. Hence, the occupant actively used the curtains during the afternoon to curtail the excess heat and sunlight. From the above factors, daylight illumination levels were reduced in the afternoon (Fig. 15).

6.2 The Observed Gap Between Theoretical Design Potential and Observed Daylight Levels

Figure 16, a lower shift in ideal daylight and maintained daylight was observed in November. There was a gap of 84.99% from theoretical design potential to the on-site observed daylight levels (without curtains/blinds).

Both weather differences (simulated versus real conditions) and occupant behavior contribute to the observed gap in the daylight access (potential versus real). However, field study results were compared from one day to another and this helped isolate the impact of the occupant behavior—during the afternoon and evening (12 noon to

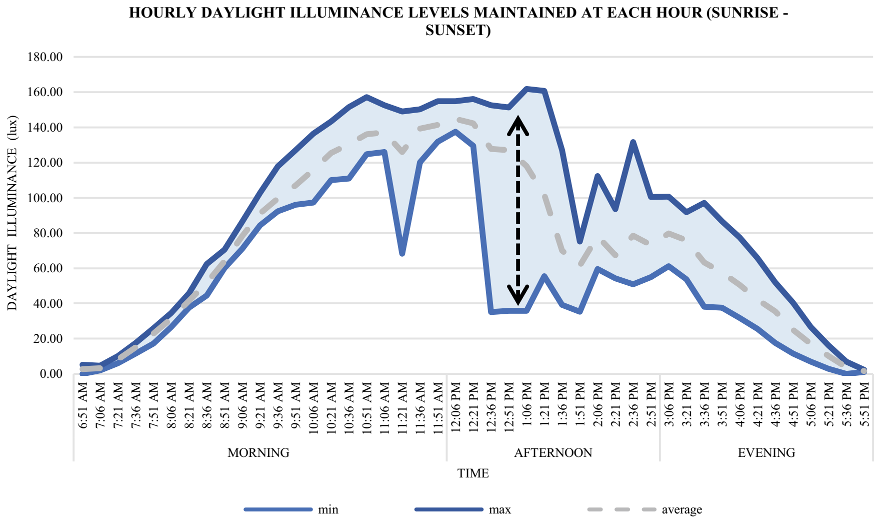


Fig. 15 Daily Daylight illumination levels from sunrise to sunset-November. *Source* Author's Computation

7 PM), curtains were used by the occupants (see Fig. 15) resulting in reduction of daylight access in the living room. In the survey it maybe noted that for the week for which the home was observed, in the field study during the daytime, the home satisfies UDI but not LEED threshold.

The ideal daylight potential without an active shading device through simulation does not include the occupant behavior that satisfies both UDI and LEED threshold theoretically but not on actual field conditions.

Through this, it can be inferred that the occupant has been trading off the daylight levels in the home throughout the day in summer to maintain thermal and visual comfort in the living room.

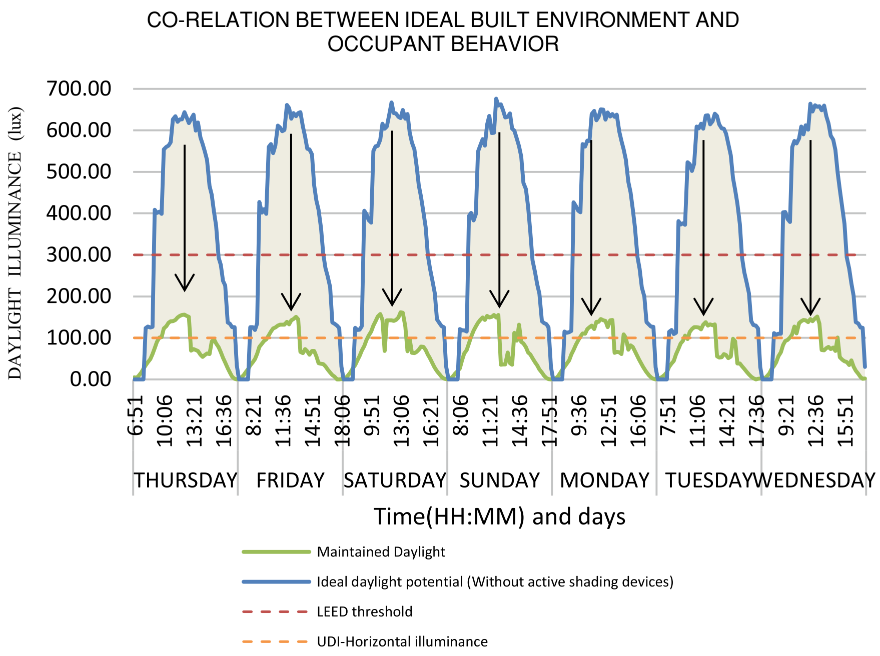


Fig. 16 Relation between built environment and occupant behavior. *Source* Author's Computation

7 Conclusion

The above study was conducted for eleven houses in an experimental and simulation approach to identify the gap between theoretical design potential of the home and observed daylight levels.

- In the best lit homes that were found (above 100 lx 90% of the time), nearly no artificial lighting was used during daytime in homes.
- In moderately well daylight-maintained homes (between 50–100 lx 90% of the time)—daylight was partial to nearly full day usage of artificial lighting.
- Well Daylit homes: In November, there was a gap of 84.99% from theoretical design potential to the on-site observed daylight levels.

There has been a trade-off in the daylight levels at the homes by occupants' activities (knowingly or unknowingly). At each house, occupants have been maintaining daylight levels based on their preferences and comfort levels (visual and thermal comfort). Occupants do have to trade off between daylight access and other competing conditions like sun control and glare to maintain thermal and visual comfort. More holistic design can improve daylight access.

8 Limitations and Future Scope

Monitoring and evaluating real-world case studies are time-consuming, costly, and challenging. The presence of occupants was understood using a questionnaire survey and lighting usage in the living room from the collected data. However, in the case of passive users, it does not assure the usage of the space. Occupancy sensors could have given better control over the living room usage-associated behavior.

Understanding occupant behaviors in residential is highly challenging due to privacy, ethical restrictions, diversity in activities, and the willingness of occupants to participate.

Overall, Research in this area can help to improve daylight design in residences. Long-term research can help analyze and understand the gap between theoretical and on-site data based on occupant behavior with consideration. By understanding the gap from the occupant behavior, this data can further help designers and architects to include effective design decisions from the initial design helping the occupants reduce their reliance on artificial lighting during the day.

References

1. Akbari S, Haghighat F (2021) Occupancy and occupant activity drivers of energy consumption in residential buildings. 250:111303. https://doi.org/10.1016/j.enbuild.2021.111303
2. Aljawder HM, El-Wakeel H (2020) Privacy Vs. Daylight: Evaluating the Acceptance of Daylighting Traditional Devices in Contemporary Residential Houses in Bahrain. 15, 5. https://doi.org/10.18280/IJSDP.150508
3. Bajaj S, Jain S (2018) Impact of Day Lighting in Residential Building: A Case Study of Indore. India 1(10):253–255
4. Bardhan R, Debnath R (2016) Towards daylight inclusive bye-law: Daylight as an energy saving route for affordable housing in India. 34, 1–9. https://doi.org/10.1016/j.esd.2016.06.005.
5. Bournas I, Dubois M-C (2020) Residential electric lighting use during daytime: A field study in Swedish multi-dwelling buildings. 180. https://doi.org/10.1016/J.BUILDENV.2020.106977
6. Dabe TJ, Adane VS (2020) Evaluation of Daylight Parameters on the Basis Simulation Model for the Tropical Climate. 03, 02, 22–28. https://doi.org/10.30564/jaeser.v3i2.598
7. Debnath R, Bardhan R (2016) Daylight Performance of a Naturally Ventilated Building as Parameter for Energy Management. 90. https://doi.org/10.1016/J.EGYPRO.2016.11.205
8. Dogan, T., Park, Y.C.: A New Framework for Residential Daylight Performance Evaluation. Presented at the Presented at the Proceedings of the 15th IBPSA Conference, San Francisco, CA, USA, August 7–9 (2017)
9. Donkena KV, Young CYF (2011) Vitamin D, Sunlight and Prostate Cancer Risk. https://doi.org/10.4061/2011/281863
10. Holick, MF (2014) Cancer, sunlight and vitamin D. 1, 4, 179–186 (2014). https://doi.org/10.1016/j.jcte.2014.10.001
11. Gujar S, Deshmukh A (2022) Methodology for visual comfort analysis in intermediate open spaces of residential areas, case study: Nagpur. India 1–18. https://doi.org/10.1080/17452007.2022.2125490
12. Jakubiec JA et al (2019) Subjective and Measured Evidence for Residential Lighting Metrics in the Tropics. Presented at the Proceedings of the 16th IBPSA Conference, Rome, Italy. https://doi.org/10.26868/25222708.2019.210898.

13. Kaja N (2017) An Overview of Energy Sector in India
14. Khandelwal R et al (2020) Case Study: India's First Net-Zero Energy Building- Indira Paryavaran Bhavan. Int J Sci Technol Res 9(11):353–357
15. Mousavi SM et al (2018) Impact of furniture layout on indoor daylighting performance in existing residential buildings in Malaysia. 5, 1. https://doi.org/10.15627/JD.2018.1
16. Nezamdoost A, Van Den Wymelenberg K (2017) Revisiting the Daylit Area: Examining Daylighting Performance Using Subjective Human Evaluations and Simulated Compliance with the LEED Version 4 Daylight Credit. 13, 2 https://doi.org/10.1080/15502724.2016.1250011
17. Pastore L, Andersen M (2019) Building energy certification versus user satisfaction with the indoor environment: Findings from a multi-site post-occupancy evaluation (POE) in Switzerland. 150. https://doi.org/10.1016/J.BUILDENV.2019.01.001
18. Richardson I et al (2008) A high-resolution domestic building occupancy model for energy demand simulations. 40:8. https://doi.org/10.1016/J.ENBUILD.2008.02.006
19. Sunger V, Vaidya P (2019) Evaluation of Daylight Performance of the New Workshop Building at CEPT University, Ahmedabad. Presented at the Proceedings of the 16th IBPSA Conference. https://doi.org/10.26868/25222708.2019.210912
20. Veitch JA et al (2013) Daylight and View through Residential Windows: Effects on Well-being

Sustainable Urban Habitat Through Integrated C&D Waste Management in India: Challenges and Prospects

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1 Background and Motivation

In recent times, many attempts have been made all around the world to implement the idea of sustainability in all possible aspects. Infrastructure creation, following the agriculture sector find the 2nd place in Indian economy and employment generation. Infrastructure creation including housing demands construction materials. Furthermore, one of the most significant contributors of solid waste is construction activity. Construction and demolition (C&D) waste and other inert materials form 1/3rd of the Municipal Solid Waste (MSW) [1, 2]. The unavailability of adequate disposal sites, scientific mechanisms, enforcement mechanisms for C&D waste disposal has resulted in their unscientific disposal in the landfills, in and around water bodies, and other open spaces [3]. This unscientific disposal of C&D waste is a growing problem. However, it has tremendous potential, yet to be utilized in a rightful manner in the production of construction materials, specifically masonry products and thereby promote sustainability and circularity in construction [4–7].

There are numerous challenges to scientifically manage and thereby utilize C&D waste (CDW). The absence of precise knowledge on its quantity and composition of C&D waste; its consideration and collection as a part of MSW; absence of enforceable framework for collection and scientific disposal of CDW; some legal aspects

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and engineering challenges; ultimately the acceptability of the products manufactured utilizing CDW to achieve sustainability and promote circularity in construction remain some of the pivotal aspects.

'Every problem has a solution', provided the problem is identified and defined. A solution to any problem is possible, when the extent of the challenge is quantified—which remains the core of issues related to CDW management in India. The absence of precise knowledge of the quality (composition) and quantity of CDW generation, a reliable data source to keep track of the generation, and scientific disposal hinders solutions to CDW management. India alone is not isolated in this regard. Countries like Sweden and Brazil where CDW types are categorized in various groups also face similar challenges [1]. The scientific definition of CDW and its constituents vary and remain fundamental challenges across several places.

CDW in India is not dealt with independently, but it is considered as a part of MSW [1]. CDW and MSW bear similarity in terms of their state of matter (solid) and their nature (being 'wastes'). The MSW may consist of biodegradable, hazardous, medical, domestic waste, etc. On the contrary, CDW is randomized, clustered and its reuse/recycle potential is distinct. MSW management involves material recovery through recycling and energy recovery by incineration as an energy source. The generation of CDW is through construction, demolition, repair, and/or rehabilitation and its composition consists of non-hazardous inert materials viz., plastics, metals, wood, concrete, masonry, excavated materials like soil/rocks, etc. In 2012, the Ministry of Urban Development (MoUD) recommended that CDW recycling facilities be established in all towns and cities having population above one million people. However, the recommendation remains on paper, which highlights the issues related to the absence of enforceable framework (technical and legal) for scientific collection and disposal (utilization) remains a challenge!

The least desirable option is landfill, whereas reducing CDW output is the most desired. The 3Rs—Reduce, Reuse, and Recycle, remain in order of importance in terms of sustainability. Figure 1 shows the CDWM hierarchy.

The demand for construction materials, especially the aggregates (fine and coarse) have peaked. The cost of extraction has increased multiple fold over the years. Adding to this unscientific disposal of inert materials like CDW has put a lot of pressure on

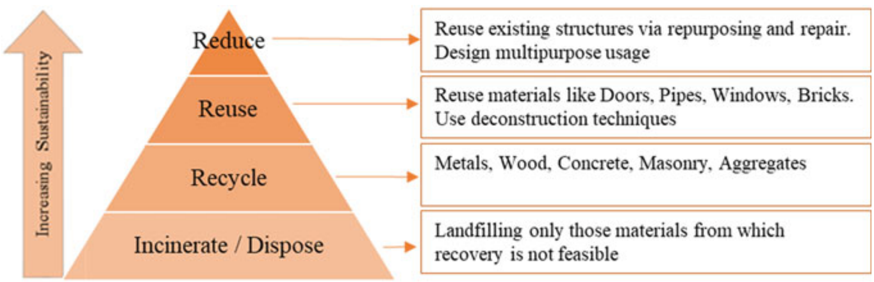

Fig. 1 C&D Waste Management hierarchy *(Graphic Source: Authors)*

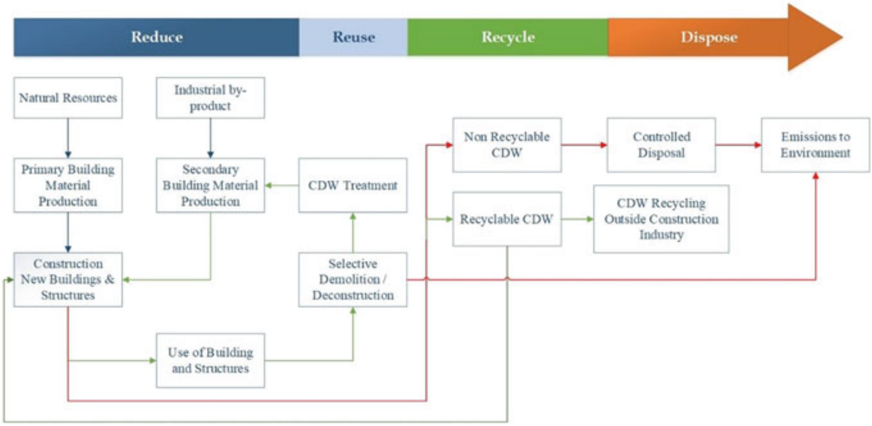

Fig. 2 CDWM close loop solution *(Graphic Source: Authors)*

environmental and sustainability aspects. In addition, studies over time have exhibited these (CDW) along with industrial by-products and other marginal materials have high potential to be utilized in construction [4–8]. While the precise data is not available; the recovery potential for older buildings may range from 25% to as high as 75% [9]. The close loop technique for efficient CDW management proposed through this study is shown in Fig. 2.

The adoption of circularity in construction is very appealing. It is environmentally, economically, and socially progressive and promotes sustainability. The economic impulses are opportunities for recycling industry, promoting circular economy (CE): through investments, business avenues, and employment generation; reduced end-of-life costs; conservation of natural resources and reduced carbon emissions; lower construction cost and carbon factors; reduced pollution levels, etc.

2 Objective, Scope, and Methodology

The primary objective of the study was to identify the practical constrains, challenges, legal aspects related to existing policies and framework, and prospects of utilizing construction and demolition wastes in India in general and particularly in urban scenario with the background of recyclable and/or recovery potential in major developed economies.

The scope of the current article includes but not limited to identifying challenges specific to C&D waste, its composition, primary source of generation, its quantitative aspects in various major cities in India, a case study related to the quality and composition in a major city like Bengaluru and Mysuru, CDW utilization policies and regulations. The research also attempts to identify and highlight the existing

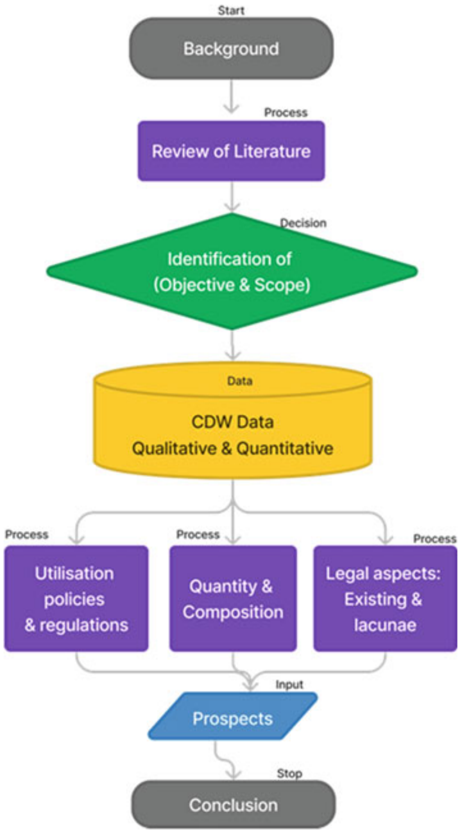

Fig. 3 Graphical presentation of methodology of research *(Graphic Source: Authors)*

policies and lacunae in legal aspects and collaborate it with technical data to put them to effective utilization in the development of recycled construction materials.

The content of the current research is a part of a larger goal in the direction of attaining Net zero targets in built environment and urban habitat through ***Circularity in construction*** promoting ***Circular Economic*** models.

The methodology adopted in carrying out the current research and in the preparation of the manuscript is presented graphically through Fig. 3.

3 Construction and Demolition Waste

The share of waste generated through construction activity and its source is quite different from that of the quantity and composition of waste generated from a demolition activity and both differ over repair/rehabilitation waste. Though the exact share of each is not available, the contribution from each section varies significantly. Through

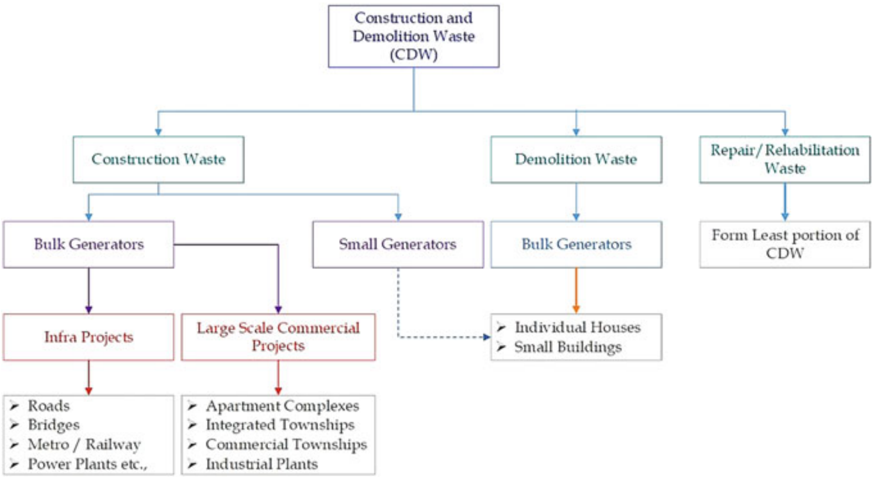

Fig. 4 Bulk and small generators of C&D Waste *(Graphic Source: Authors)*

Fig. 4 an attempt has been made to categorize various sources and types of generators of C&D waste in each of the three categories viz., construction, demolition, and repair/rehabilitation.

4 C&D Waste: Quantitative Aspect

The quantities of CDW are estimated with different methodology by different countries globally and at times they are linked to MSW. However, the developed countries generate twice as much MSW as developing countries [1]. The share of CDW in MSW forms about 61% in Germany and about 42% in some Asian countries [1]. According to a Ministry of Environment and Forests (MoEF) 2008 report, India generates approximately 0.573 million metric tonnes (MMT) of MSW per day, translating to roughly 210 MMT annually and 175 kg/per person, given that the country's population at the time was over 1.20 billion [1].

4.1 Global Scenario

As per the estimates, globally 3 billion tonnes of CDW are generated annually [10] and has currently reached a stage wherein techniques for treating recovered aggregates on-site become necessary. A chart presenting the global CDW recovery against per capita generation for various countries was reported by Gálvez-Martos et.al, using a graph through their research [11]. As per this study, Austria has the greatest recycling and waste collection rates among European nations, South Korea among Asian countries, and Germany has one of the highest per capita generators with one of the maximum recovery rates among large generators and for obvious reasons the recovery rate in developing countries like India, China, Brazil, etc., has been considerably low [11]. Among these, undoubtedly China was not only the largest contributor of C&D waste generation in absolute numbers, but it is also one of substantial contributors in terms of per capita CDW generation. Recovery and recycling help to reduce embodied carbon emission, achieve net zero emission targets, and help promote circular economy and circularity in construction. This will also help in improving recovery rate in end-of-life stage of life cycle analysis (LCA).

Figure 5 presents the CDW generation of some of the prominent countries across the globe. China, India, US, France, Germany, UK, etc., are some of the major contributors [1, 10, 17]. The mechanism to record the CDW generations across various countries remains sketchy, and unlike environmental product declaration (EPD) of global warming potential (GWP) is not standardized and remains grossly under-reported. In this context, the actual generation may be much higher than these estimates. Apart from a handful of countries like New Zealand and South Korea where the recycling potential is about 98%, most of the large generators viz China and India, hardly recycle/recover, and ultimately ends up in landfills. The primary data related to the quantity of CDW generation for various countries was compiled through sources [1, 10, 17], and the observations recorded were shown through graph (Fig. 5).

Although the composition of CDW is not readily available in most countries, it is interesting to note that concrete, masonry, and soil/stones make up most of its

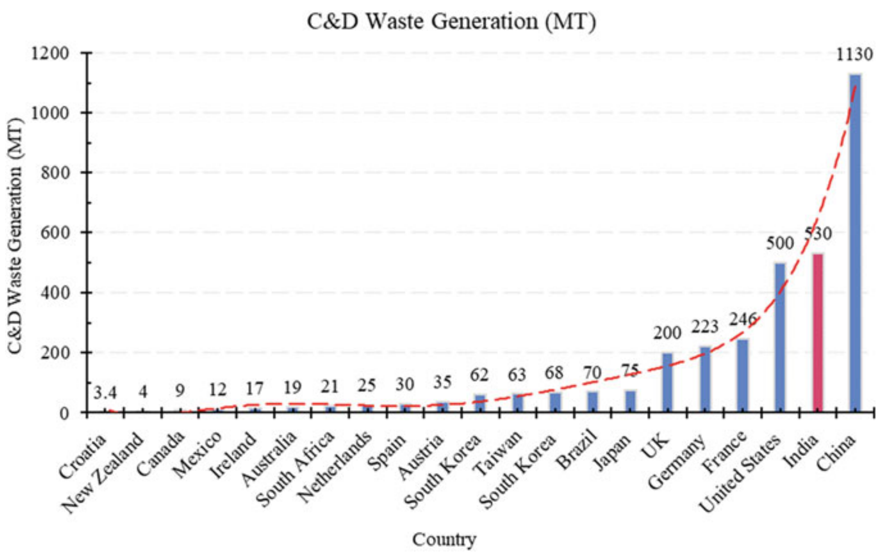

Fig. 5 Estimate of CDW generation (major countries) *(Graph: Authors)*

constituents. The lack of specific data is another challenge. On the contrary, if a situation is presented wherein the availability of adequate amounts of qualitative data might help improve recovery/recycle rate, aid circularity in construction, and so on. Data is the backbone to develop any project.

4.2 Indian Scenario

The average share of CDW in MSW for India is about one third, as per the estimates of few Government agencies [1]. In the metro city of Chennai, it's about 36% [12] and as high as 50% in some of the important Indian cities [13]. As a proportion, with these numbers, the CDW in India can be approximated to be over 70 million tonnes annually. The same studies, however, dispute these numbers and provide an estimate of between 10 and 12 million tonnes [1]. Another estimate by Rathi et.al gives out the figure of 716 MT [14] and for the year 2013, the Centre for Science and Environment (CSE) in New Delhi estimated that CDW produced by buildings alone was 530 MT [15]. This value with the inclusion of mining, industrial, and agricultural by-products stands at 960 MT [16]. Several studies have also estimated data relating to CDW generation in India. However, the challenges related to disconnect in various estimates remain and emphasize on a collective mechanism for reliable data collection.

Based on various studies carried out across the country [1, 12–15, 17, 25], a list of prominent cities was chosen and estimates of CDW were recorded and presented in Fig. 6. NCR (National Capital Region) remains the largest generator of CDW, followed by Bengaluru and two metros viz., Chennai and Mumbai. A detailed analysis was carried out for Bengaluru (2020) to understand the quantity and composition of CDW. Ahmedabad, Delhi (NCR), and Chennai are some of the prominent cities where recycling plants are available as of 2020. Attempts are being made currently to incorporate such practices in many other major cities in India. However, at the consumer end, the identification of CDW generation site, scientific collection, transportation of debris to a specific location for further processing has remained a primary challenge along with its awareness among the general public of availability of such infrastructure for meaningful use.

Several studies [1, 17, 26] were referred to understand the methodology and assessing the quantity of CDW as reported in those studies. A comparative analysis was carried out and values are reported through Fig. 7. The analysis presented an interesting fact. Discrepancies existed not only in the overall estimation of CDW generation nationally, but also in various studies carried out in Bengaluru. Considering the range of values which is put out by various sources, 2700 TPD was found to be a reasonable value.

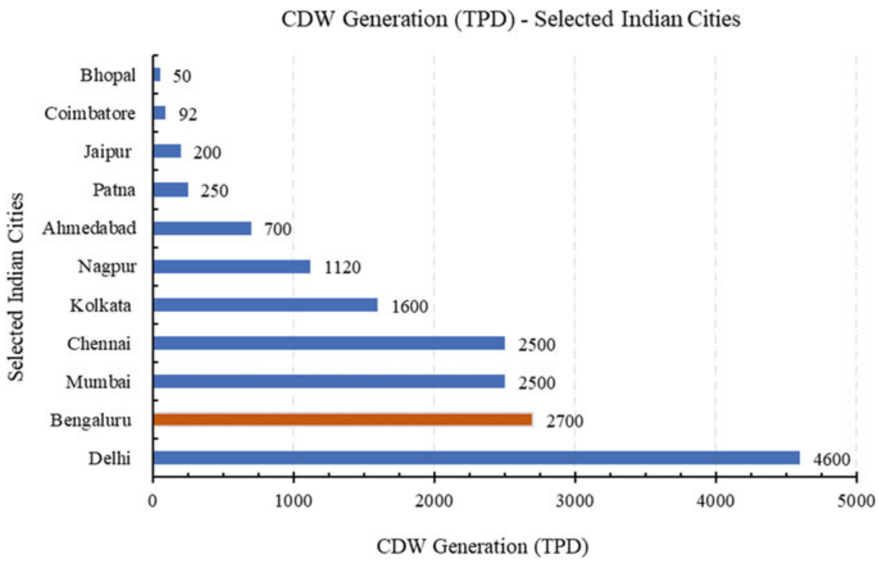

Fig. 6 CDW data for selected Indian cities *(Graph: Authors)*

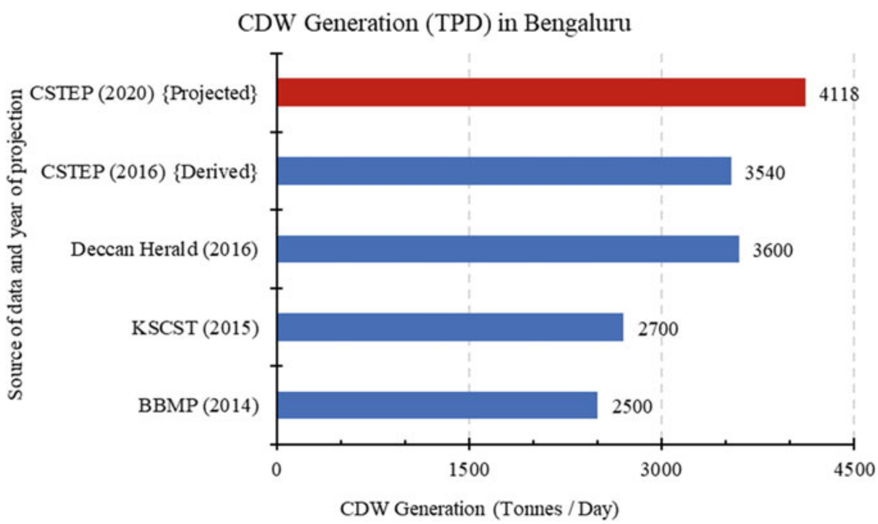

Fig. 7 Estimates of CDW generation in Bengaluru (various studies) *(Graph: Authors)*

5 C&D Waste: Quality and Composition

The other most important aspect related to CDW generation is the data related to its composition as this represents the qualitative aspect. Most researchers, and/or Government agencies, fail to address this as an important parameter. The recovery rate and circularity potential of CDW is determined by the qualitative aspect as much as the quantitative aspect, i.e., composition of CDW. In this regard, several studies were referred to understand the composition for different cities in India and abroad.

For various reasons single and two storied masonry structures are paving way for framed multi storey structures. The floor area ratio, cost of land within the urban environment, more occupancy per unit area, etc., are some of the reasons. The other aspect of a masonry structure is the lower strength to weight ratio of a typical masonry structure (<30%) [17]. Approximately 80% of the population in the Indian subcontinent find their shelter in a masonry structure. Millions of such units are being deconstructed to make way for larger multi-storied structures, generating large amounts of demolished brick masonry waste (DBMW) [17]. Merely less than one fifth of CDW is being reused or utilized, while the rest is being dumped unscientifically in landfills. This contrasts with the nearly 90% recovery ratio for a train engine which is made up of thousands of complex components which also happens to be one of the largest locomotives in the transportation sector. This underlines the importance of adopting circularity in construction through recovery, recuse, and utilization of CDW as a resource over discarding it as a waste in landfills leading to environmental degradation and more carbon emissions.

Though the composition of CDW across the continents differs, its overall generation pattern remains alike. The primary constituents may be considered broadly under various categories, viz., Earth (excavated and processed soil), concrete, wall material (masonry), metals (primarily steel and aluminum), wood, and others (polymers, ceramics, etc.). A comprehensive investigation was carried out to understand the composition of CDW generated in cities of Bengaluru and Mysuru as a part of the current study. Some of the published literatures [9, 12, 17] were also referred to understanding the composition in some countries through Table 1.

The studies on CDW composition of developed countries including Germany, Spain, and several others, interestingly reported to have masonry debris as a larger share. There is also no disparity in the situation in Indian cities. Detailed studies carried out in cities of Chennai and Coimbatore also reported demolished masonry waste as their primary constituent in their CDW debris, constituting at least nearly 30 and 49% respectively. A thorough experimental investigation was carried out in the cities of Bengaluru and Mysuru, regarding the composition of C&D waste. Similar data was also collected from ILFS recycling plant in Delhi, which is India's one of the largest C&D waste recycling facilities. The outcome of the detailed analysis is interesting. The share of masonry debris was 53–56% in Bengaluru and Mysuru. The value was 50% for the IL&FS Delhi plant. The reported values of Delhi were recorded at the IL&FS plant at the time of processing C&D waste and thus is of prime importance. The share of DBMW in average composition of CDW in India

Table 1 CDW composition in different countries *(Data Compilation: Authors)*

Sl No	Composition of CDW (%)	Germany	Iraq	Spain	Victoria (Australia)
1	Soil/Sand, Gravel	–	8	9	24
2	Masonry/Bricks	59.4	40	54	14
3	Concrete	25.5	52	12	53
4	Bitumen	–	–	5	6
5	Metals	1.1	–	2.5	–
6	Wood	13.4	–	4	–
7	Others	0.6	–	13.5	3
	Data Source	[1]	[18]	[19]	[20]

was found to be just over 43%. Overall, the combined share of soil (excavated and processed) and masonry waste in CDW is over 73% and even at a global scale, it constitutes over 2/3rd of total debris, which constitutes a very large quantity.

Figure 8 shows the composition of C&D waste in Chennai. Ram et. al has reported the composition of CDW in Chennai landfill through their study on estimate of CDW [12].

Figure 9 shows the composition of CDW for Coimbatore (2015). The primary data related to the composition was first reported by GIZ [27].

Figure 10 shows the composition of C&D waste in IL&FS plant in NCR (Delhi) along with the Bengaluru and Mysuru (2020). The primary data related to IL&FS was reported by Ali [28] and the data related to Bengaluru and Mysuru was estimated through a thorough investigation over period of few months.

Figure 11 shows the average composition of construction and demolition wastes in India. The value arrived at by averaging the values of different materials for various cities in India as reported in the previous sections and graphical representations.

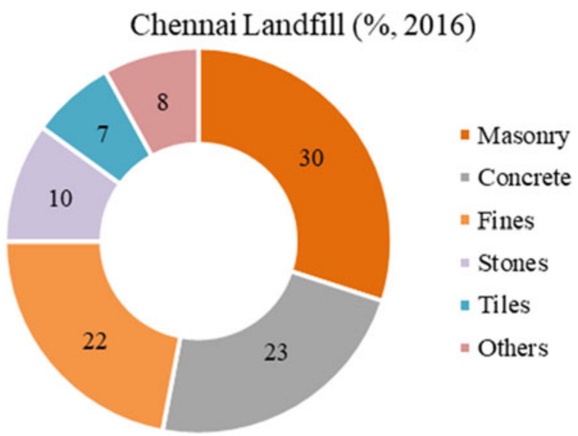

Fig. 8 Composition of CDW—Chennai (2016) *(Source: Graph – Authors; Primary data—V. G Ram et. al* [12]*)*

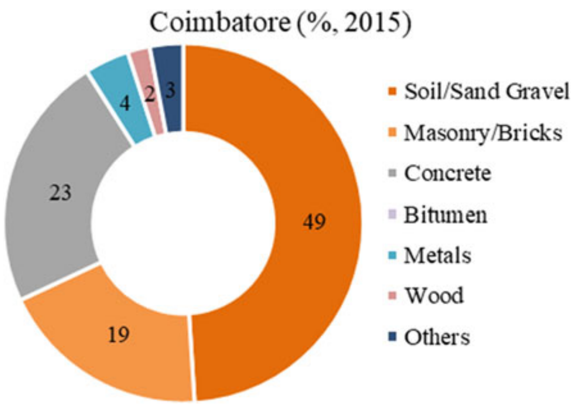

Fig. 9 Composition of CDW—Coimbatore (2015) *(Source: Graph - Authors; Primary Data: GIZ* [27]*)*

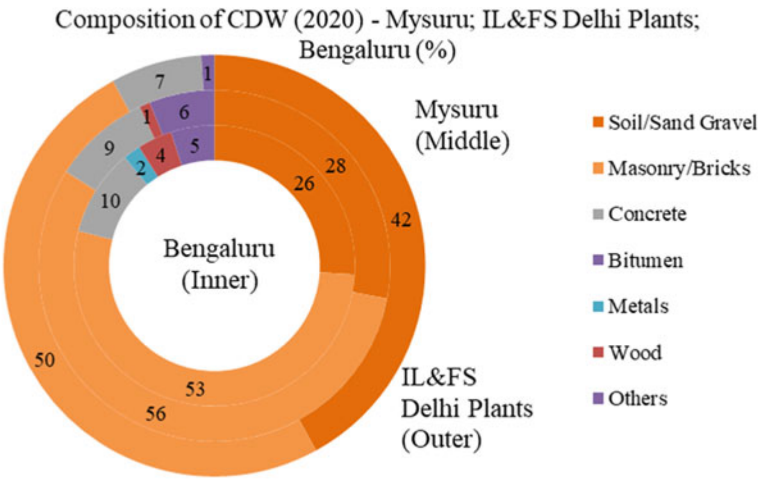

Fig. 10 CDW composition (2020)—IL&FS Delhi Plant, Mysuru and Bengaluru *(Source: Graph - Authors; Data on IL&FS Plant – S. Ali* [28]*; Data on Bengaluru & Mysuru: Author)*

6 CDW Waste Utilization Policies and Regulations

Various agencies and departments have been working on regulations, recommendations, and policies to utilize CDW in construction. The Construction and Demolition Waste Management (CDWM) Rules (2016), Niti Ayog, Central Public Works Department (CPWD), Central Pollution Control Board (CPCB), Smart City Mission, Building Materials Technology Promotion Council (BMTPC), National Building Code (NBC), Bureau of Indian Standards (BIS), and other have been in the forefront of actively promoting utilization of C&D waste in construction in a possible form.

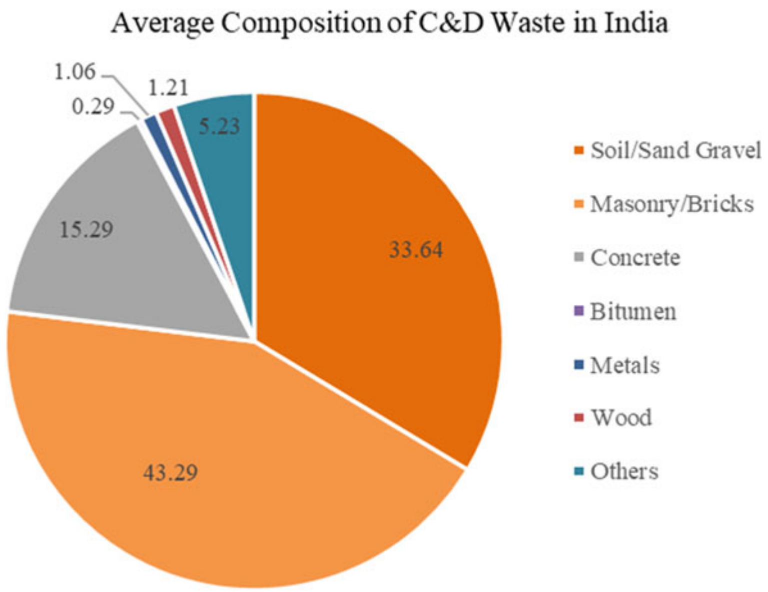

Fig. 11 CDW composition in India (Average) *(Graph – Authors)*

However, still a lot needs to be covered to effectively realize and unlock the potential of CDW management.

CPWD has issued guidelines with sustainability index and materials, and recommendations to reuse and recycle CDW in projects. CPCB has identified and notified thrust areas and roadmaps under NBC. BMTPC is in the forefront of promoting various building products, specifically recycled products. BIS through IS 383: 2016 has allowed the use of Recycled Concrete Aggregate (RCA), Recycled Aggregate (RA) in fine and coarse form is allowed to be used in lean concrete (100%) and up to 20% in reinforced concrete. However, primary lacuna is that the masonry debris which forms the major component still needs regulatory backing to be used in construction products in general and in masonry blocks/bricks in general.

7 Legal Aspects: Existing Policies and Lacunae

The concept of sustainable development, first developed during the UN Conference on Human Environment, in Stockholm (1971), [21] and subsequently by the Brundtland commission in 1987, was finally materialized in the Earth Summit in Rio de Janeiro (1972) [22]. The concept was defined as the development which meets the needs of the present without compromising the ability of the future generations to meet their own needs [23].

India, being a part of this convention, is obligated under the 12th goal of sustainable development [24] to adopt methods that foster sustainability while developing the infrastructure of the country. Moreover, the courts have recognized the need to incorporate methods of infrastructural development that preserve the ecology. With this in mind, a comprehensive policy, Construction and Demolition Waste Management (CDWM) Rules (2016), was legislated to ensure proper disposal and reuse of C&D waste [25].

The CDWM lays down a broad framework outlining the duties of various authorities involved in the process of recycling C&D waste. This includes the duties of waste generators wherein they are obligated to store and transfer C&D waste to recycling facilities; as well as local authorities and State Pollution Control Board (SPCB), who are mandated to enforce the rules. Further, in accordance with Sub-Rule 10 (1)(a) of the CDWM, the Central Pollution Control Board (CPCB) enacted the guidelines on Environmental Management of C&D Waste.

Nonetheless, there are certain patent lacunae within the provisions of the act, thereby making it ineffective in totality. The act albeit requires the generators to pay for processing and transporting the C&D waste after having segregated it, also requires them to pay for its storage at the recycling facility [25]. The enactment lacks provisions which would require the local authority to ensure that the C&D waste is disposed in accordance with the provisions of the act [25].

While unproblematic in a utopian world each fulfills their respective duty, the lack of a distinct enforcement mechanism leaves the act toothless. For instance, in the city of Bengaluru, Karnataka, there currently exists one C&D processing unit at Chikkajala which can process up to 1,000 tonnes of C&D waste/day. However, the city produces a total of 2500–3000 tonnes of waste/day [26]. Thus, the money that ought to be expended on storage for extended periods of time discourages the generator from following the mandated procedure.

Moreover, an individual, after getting their disposal plans approved by the local authority, can continue to illegally dump the waste in an unauthorized area without any consequence. To that end, in Kavith Shankar v. Bruhat Bengaluru Mahanagara Palike (BBMP), the High Court of Karnataka observed that the local Municipal Corporation had failed to follow the rules laid down under Solid Waste Management Rules, 2016 as well as the CDWM Rules, 2016 and was found to have dumped all categories of waste in unauthorized areas—thus, failing to act as the 'watch-dog' that it was supposed to.

The reforms that could be incorporated to cover these loopholes will be suggested in the next section of the paper, however, the reforms suggested by the authors are based on the observations made in the previous parts of the paper.

7.1 Recommendations

The primary problem that currently persists in the disposal mechanism is the shortage of facilities to process the waste generated daily. Constructing a myriad of processing units would not only hasten up the process but would also indirectly reduce the space that would be required for storing the waste.

Secondly, the problem entailing illegal dumping can be solved by ensuring that permission for constructing a building is granted only after the individual seeking permission for the same provides proof of depositing the demolition waste at the approved site. Since relevant permissions are granted through websites tailored for the same, the entire process itself can be simplified by shifting the entire process online. Additionally, by designating disposal areas for each builder and ensuring that the vehicle carrying the C&D waste reaches the designated area, the identified lacunae may be filled. Thus, where, individual fails to deposit this waste at the allocated site, the permission for constructing the new structure would not be permitted thereby compelling the individual to adhere to the guidelines laid down under the rules of 2016.

8 Prospects

Figure 12 presents a step wise methodology for effective scientific solution for collection, utilization, and disposal of construction and demolition waste for an urban center. The process covers demotion/deconstruction phase, collection centers are different levels, processing centers and their functioning, material production phases, and construction phase where in the produced recycled products are being utilized. This not only helps in developing a sustainable habitat, but also presents an opportunity for developing efficient models for scientific disposal of CDW. In addition, this offers to develop a built environment with reduced embodied emissions which is instrumental to achieve ambitions *'Net Zero Emission'* targets.

9 Future Scope

The current study primarily focuses on summarizing factual data related to quantity, quality, and composition of C&D waste in India. Also attempts to qualitatively identify, quantify, and articulate primary challenges and prospects for effective integrated management of C&D waste specifically in urban habitat.

Going forward, the study can be extended to formulate and incorporate the policies to ensure and adopt recycling or repurposing C&D wastes in India to ensure 'Circularity' in construction to a maximum extent as currently it accounts to less than one percent. This further facilitates in promoting 'Circular Economy' (CE) in construction and thereby creating a plethora of new opportunities. Cost and Carbon Accounting (decarbonization) may be promoted and incentivized to facilitate the efforts of decarbonization in construction and thereby ensure sustainable urban habitat through effective management of C&D wastes and thus contribute to reduced

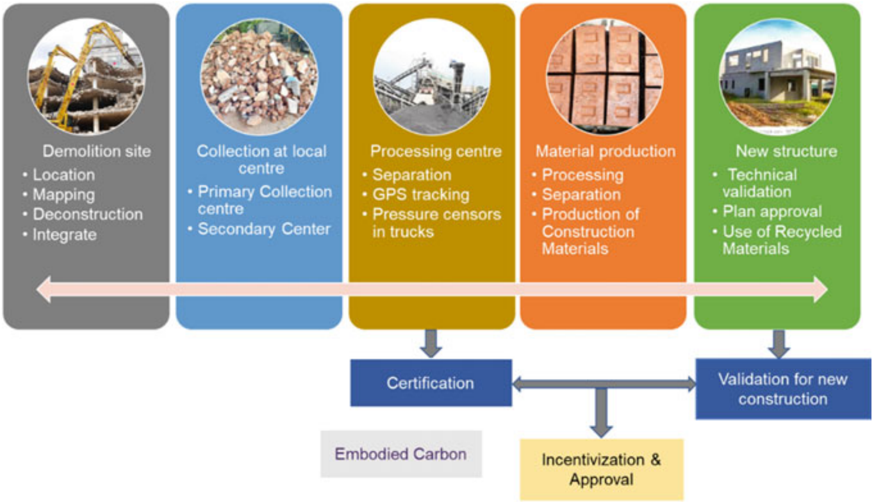

Fig. 12 Proposed C&D Waste—Management Framework (Source: Authors)

Carbon emissions, which is contributory for achieving ambitious *net zero emission* (NZE) targets.

10 Conclusion

The important conclusions of this article have been summarized in this section and are as follows:

(a) The unavailability of reliable qualitative and quantitative data on C&D waste in India in general and specifically in major urban centers.

C&D waste in general and DBMW with excavated natural soil forms the major portion of CDW not only in major cities, but also across India and in most nation across the globe. Furthermore, it has huge potential to be used as a resource in the preparation of construction material with minimum or no processing.

(b) Attempt has been made to categorize various sources and types of generators of C&D waste in each of the three categories viz., construction, demolition, and repair/rehabilitation and among them small and bulk generators are designated.
(c) The composition and quantity estimates of C&D wastes concerned to global and Indian scenarios are presented and major observations were highlighted.
(d) The legal aspects of the existing policies concerned to C&D waste management in India and its lacunae were identified and technological solutions are proposed to overcome them through efficient utilization and disposal.

In addition, the major portion of C&D waste can be potentially utilized, in the production of soil-based materials like stabilized adobe blocks (SAB), stabilized mud blocks (SMB), controlled low strength material (CLSM), masonry mortar, stabilized mud concrete (SMC), rammed earth, etc. With minimal use of binders, these products possess a huge potential not only to provide an alternative to conventional materials in the form of recycled construction materials but also an effective mass for carbon capture and sink, thus help in decarbonization of the construction sector. It also presents an opportunity to produce similar materials using alternative binders in place of conventionally used materials namely cement and lime, which are carbon intensive.

References

1. ICI – Guidelines (2015) Recycling, Use and Management of C&D Wastes, Indian Concrete Institute, Chennai
2. Joshi AM, Raghunath S, Mangala K, Kaup J (2018) Stabilized Adobe using Demolished Brick Masonry Waste, in National Seminar on Emerging Building Materials and Construction Technologies, New Delhi. https://doi.org/10.13140/RG.2.2.24096.84481
3. Abhishek M, Joshi AM (2022) A Case Study on Estimation and Composition of Construction and Demolition Waste in Bengaluru. In: Sustainability Trends and Challenges in Civil Engineering, Lecture Notes in Civil Engineering, vol. 162, L. Nandagiri, M. C. Narasimhan, S. Marathe and S. V. Dinesh, Eds., Springer Nature Singapore, 2022. https://doi.org/10.1007/978-981-16-2826-9_66
4. Joshi AM, Basutkar SM, Ahmed MI, Keshava M, Raghunath S, Jagadish K (2019) Performance of Stabilized Adobe Blocks Prepared Using Construction and Demolition Waste. J Building Pathol Rehabili vol. 4, no. 13. https://doi.org/10.1007/s41024-019-0052-x
5. Joshi, A.M., S.M. Basutkar, M. Keshava, S. Raghunath and K. Jagadish, “Performance of Masonry Units Prepared Using Construction and Demolition Waste as Fine Aggregates,” in 10th International Masonry Conference (IMC), Milan, 2018. DOI: https://doi.org/10.13140/RG.2.2.22838.55364
6. Joshi, A.M., S. M. Basutkar and K. Jagadish, “Stabilized Mud Concrete for Sustainable Construction,” in Sustainable Materials in Building Construction, vol. 11, Springer, Cham, 2020, pp. 135–147. DOI: https://doi.org/10.1007/978-3-030-46800-2_6
7. Sequeira, V.L., Joshi, A.M., Kerekoppa, M.D., Bharadwaj, N., “Physical and microstructural properties of Construction and Demolition Waste based masonry units,” in 3rd International Conference on Innovative Technologies for Clean and Sustainable Development, Chandigarh, 2020. DOI https://doi.org/10.1007/978-3-030-51485-3_27
8. A. Nagaraj, Joshi, A.M., S. Girish, and N. Bharadwaj, “An Experimental Study in Developing Self-compacting Concrete as per IS: 10262 (2019) by Utilising the Marginal Materials as Fines,” Indian Concrete Journal, vol. 95, no. 5, pp. 41 - 50, 2021. DOI: https://icjonline.com/explore_journals/2021/05
9. M. R. Ponnada and K. P. Lalitha, “Construction and Demolition Waste Management – A Review,” International Journal of Advanced Science and Technology, vol. 84, pp. 19–46, 30 11 2015. DOI: https://doi.org/10.14257/ijast.2015.84.03
10. ZEBAU GmbH, “Construction and Demolition Waste Management in Germany,” TuTech Innovation GmbH, Hamburg, 2006.
11. J.-L. Gálvez-Martos and I.-R. Istrate, “Construction and demolition waste management,” in Advances in Construction and Demolition Waste Recycling, F. Pacheco-Torgal, Y. Ding, F. Colangelo, R. Tuladhar and A. Koutamanis, Eds., Woodhead Publishing, 2020, pp. 51–68. https://doi.org/10.1016/B978-0-12-819055-5.00004-8

12. Ram VG, Kalidindi SN (2017) Estimation of construction and demolition waste using waste generation rates in Chennai, India. Waste Manage Res 35(6):1–8. https://doi.org/10.1177/0734242X17693297
13. S. Spies, “3R in Construction and Demolition Waste (CDW) - Potentials and Constraints,” 2009. https://www.env.go.jp/recycle/3r/en/forum_asia/results/pdf/20091111/06.pdf
14. V. Rathi, P. Phulwari, A. R. Sekhar and S. Maity, “Application of Construction and Demolition Wastes in production of Building Materials,” in International Seminar on Emerging Building Materials and Construction Technologies, New Delhi, 2016.
15. S. Gupta and R. K. Malik, “The Impact of C and D Waste on Indian Environment: A Critical Review,” Civil Engineering Research Journal, vol. 5, no. 2, pp. 57 - 63, 25 5 2018. DOI:https://doi.org/10.19080/CERJ.2018.05.555658
16. A. Pappu, M. Saxena and S. R. Asolekar, “Solid wastes generation in India and their recycling potential in building materials,” Building and Environment, vol. 42, no. 6, pp. 2311–2320, 6 2007. https://doi.org/10.1016/j.buildenv.2006.04.015
17. Joshi, A.M., “Studies on Strength and Elastic Properties of Masonry Products Using C&D Waste,” PhD Thesis, Visvesvaraya Technological University, Belagavi, 2020. DOI: https://doi.org/10.13140/RG.2.2.32359.78243
18. N.A. Abdulla, “Effect of recycled coarse aggregate type on concrete,” Journal of Materials in Civil Engineering, vol. 27, no. 10, 1 10 2015. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001247
19. M. Del Río Merino, P. I. Gracia and I. S. W. Azevedo, “Sustainable construction: Construction and demolition waste reconsidered,” Waste Management and Research, vol. 28, no. 2, pp. 118–129, 2 2010. https://doi.org/10.1177/0734242X09103841
20. Hyder Consulting, Encycle Consulting & Sustainable Resource Solutions, “MANAGEMENT OF CONSTRUCTION AND DEMOLITION WASTE IN AUSTRALIA,” Hyder Consulting Pty Ltd, Melbourne, 2011.
21. UN General Assembly, “United Nations Conference on the Human Environment,” UN General Assembly, 15 December 1972.
22. World Commission on Environment and Development, “Brundtland G. H., Our Common Future,” 1987. [Online]. Available: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf. [Accessed 27 December 2020].
23. The United Nations Conference on Environment and Development, “Rio Declaration on Environment and Development,” 14 June 1992. [Online]. Available: https://www.cbd.int/doc/ref/rio-declaration.shtml. [Accessed 27 December 2020].
24. The United Nations (2019) The Sustainable Development Goals Report. The United Nations, New York
25. Central Pollution Control Board, “Environmental Management of Construction and Demolition (C&D) Wastes,” CPCB, Ministry of Environment, Forests & Climate Change, New Delhi, 2017.
26. Special Correspondent, “BBMP notification on dumping of construction and demolition waste soon,” The Hindu, 15 November 2019. [Online]. Available: https://www.thehindu.com/news/cities/bangalore/bbmp-notification-on-dumping-of-construction-and-demolition-waste-soon/article29986368.ece.
27. Development Alternatives, “Resource Efficiency in the Indian Construction Sector,” Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, New Delhi, 2015.
28. Ali S (2020) Construction Demolition Waste Recycling. SRM Institute of Science and Technology, Chennai

Transformation Toward Net Zero Built Environment—Indian Scenario: Challenges and Opportunities

Ashwin M. Joshi, N. Anbumaninathan, and Vishal Shah

1 Introduction

In the preindustrial era, carbon flew among air, vegetation, land, and oceans and remained balanced. With the increased levels of industrialization, carbon flew majorly in the form of oxides of carbon, primarily due to burning fossil fuels. This has made a significant contribution to 'carbon in atmosphere'. Figure 1 shows the pictorial presentation of the flow of carbon in the preindustrial and industrial eras.

Every year it is estimated that more than 50 billion tonnes of carbon dioxide is emitted to the environment globally. Cumulatively, till 2021 the overall worldwide carbon emissions from fossil fuels and industries alone (without considering land use change) stands at staggering 1.70 trillion tones of which more than half is contributed by Europe and the United States [1]. The share of India and China stands at 54 and 238 billion tonnes, respectively [1]. The high levels of carbon and greenhouse gas (GHG) emissions have caused considerable damage to the earth's atmosphere as compared to the preindustrial era. As per 2018 data, India stands fourth after China, the United States, and Europe as a top emitter of GHG. Among the overall carbon emissions, the buildings and built environment are responsible for nearly 38% of global carbon emissions [2] and currently nearly 30% of this is embodied carbon emissions and the rest is operational carbon.

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in Civil Engineering 451, https://doi.org/10.1007/978-981-99-8842-6_4

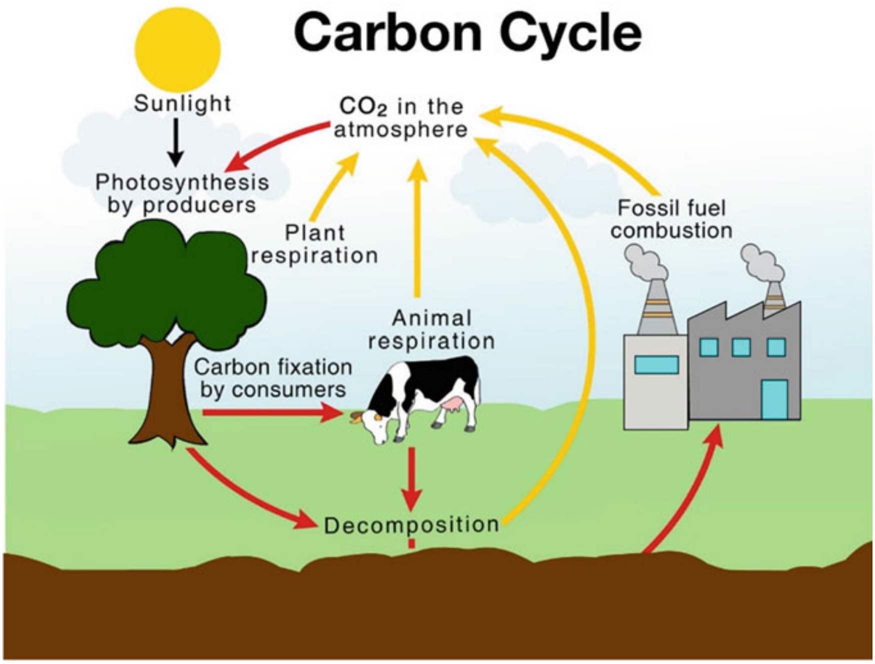

Fig. 1 Pictorial representation of carbon cycle

The carbon concentration in environment is generally recorded through atmospheric carbon-di-oxide (CO_2) concentrations assessed and reported in parts per million (ppm) as its unit of measurement. The CO_2 concentrations in the atmosphere remained stable in the range of 270–285 parts per million (ppm) for thousands of years until the industrial era (eighteenth century) and have been rising since then [3]. As per recent estimates, it has already reached 420 ppm in 2023 and is expected to be about 430–450 ppm when the temperature will increase by 1.5–2 °C. The global atmospheric CO_2 concentration over decades is presented in Fig. 2.

In order to reduce further environmental degradation due to carbon emissions and fight climate change, the United Nations Framework Convention on Climate Change (UNFCCC) in its twenty-first session of Conference of the Parties (COP 21), in 2015 accepted the recommendation of Intergovernmental Panel on Climate Change (IPCC) to limit global warming to 1.5–2 °C, above the preindustrial levels [4]. Since then, about 92% of the global GDP, 88% of global emissions, and nearly 85% of population are now covered by commitments to achieve net zero, thanks to pledges from major countries as a part of the commitment for action on climate change [5]. Achieving the carbon emission targets is important, as even a half a degree increase in temperature increase between 1.5 and 2 °C, shall have a cascading and catastrophic effect on the global population, environment, and its wellbeing. It is estimated such a situation is 2.6 times worse for the global population being exposed to extreme heat; 10 times

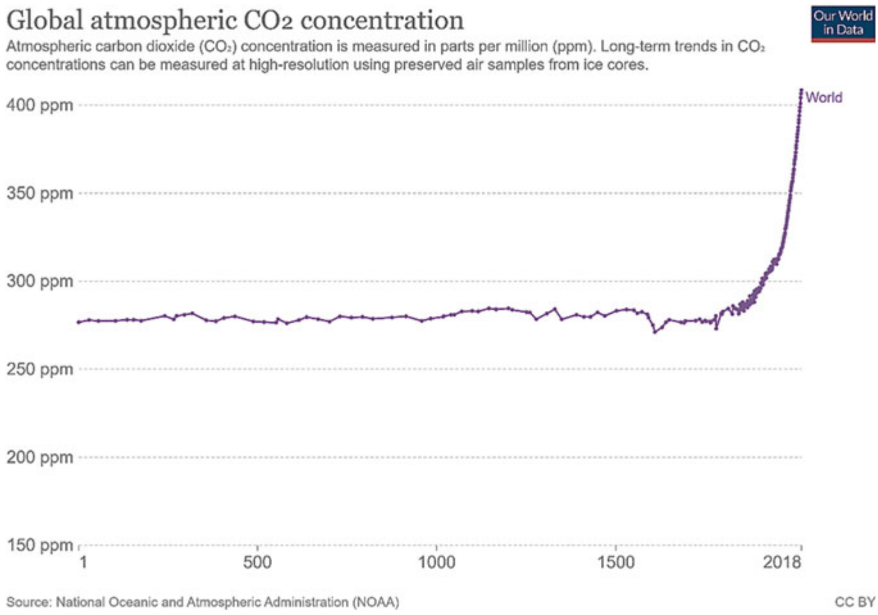

Fig. 2 Global atmospheric CO_2 concentration [15]

impactful for sea ice-free Arctic; an increase in sea level by 0.46 m by 2100 to name a few [6]. The changes observed in global temperature over time (1960–2100) have been modeled and the responses are reported in the IPCC report [6].

In the report, the graph shows observed global temperature change and modeled responses. It is imperative to adopt measures for faster CO_2 reductions to achieve higher probability of limiting warming to 1.5 °C where in the case of inaction from hereon may result in increased global temperatures to the tune of limiting value by 2040, which may result in catastrophic consequences as discussed. While timely and effective action from hereon may result in an optimistic scenario of reaching net zero emissions in 2055. It is interesting to note, the observed monthly global mean surface temperature has already peaked at 1.5 °C above preindustrial era levels once in 2017 before reducing thereon. This further justifies the immediate need to act, deliver, and thus bend the curve of CO_2 emissions downward in this decade to ensure a smooth transition toward net zero targets [6].

The overall cumulative carbon emissions till 2021 for the world stand at 1.70 trillion tons, for Europe 531.94 billion tons, followed by the United States and China (416.90 and 237.88 billion tons), whereas that of India remain about 54.40 billion tons [3]. Currently India stands at fourth position behind China, the US, and the EU in net greenhouse gas (GHG) emissions whereas second in terms of carbon intensity per GDP only behind China [7].

2 Review of Literature

A portion of the literature and data has been discussed in the previous section through introduction. There is an urgent need to address the issues related to climate change; some scientists articulate the current situation as climate emergency over climate change. In addition, the other parameters related to the need of the study viz., carbon emissions, net zero targets, and India's commitment to it are discussed with some detail in this section.

2.1 Carbon Emissions

As per the United Nations Environment Programme (UNEP) report, the highest ever CO_2 emissions and final energy was recorded from the building sector (2019) [2]. The report further indicates the CO_2 emissions from building operations at 10 $GtCO_2$, which is about 28% of total global energy-related carbon emissions and with the inclusion of building construction the value increases to 38%, forming the largest chunk of global carbon emissions, this value surpasses the transportation (23%) and other industry (32%) [2]. Figure 3 shows the share of final energy and emissions for 2019.

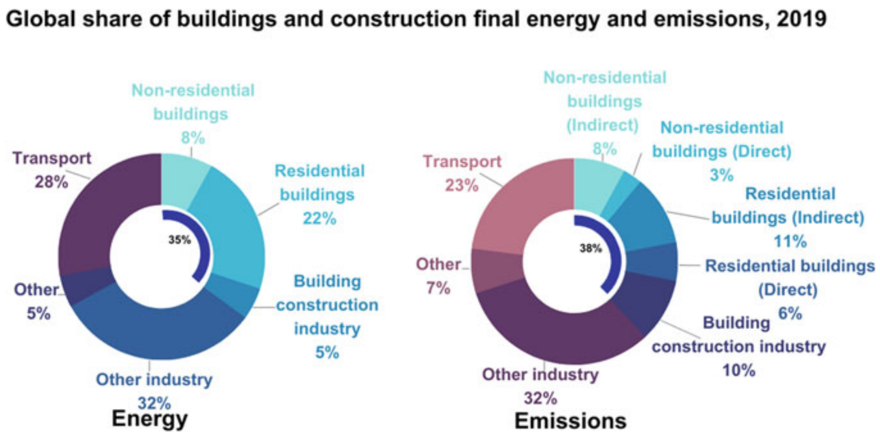

Fig. 3 Global share of buildings and construction final energy and emissions, 2019 [2]

2.2 Built Environment

'Built environment' is a broad notion that encompasses everything that has been constructed by mankind to support human activities. Buildings and all civic infrastructure, amenities, and other physical features of a particular place (geographical area) are all included in this definition. It must be remembered, in most cases, the built environment is evaluated based on its aesthetic quality, comfort, etc. It is important to note the built environment currently contributes nearly 40% of the greenhouse gas (GHG) emissions [2]. However, to mitigate the climate change challenges, it must be decarbonized, and net zero emissions must be met by 2050 to avoid catastrophic outcomes as discussed in previous sections. India's commitment in this regard has been discussed in the following section.

2.3 Net Zero Targets

The concept of Net Zero refers to 'the balance between the amount of greenhouse gas (GHG) that's produced and the amount that's removed from the atmosphere'.

Energy and climate intelligence unit [8] provides the details of targets and status of Net Zero Targets for various countries across the world. While the majority of the developed countries including the US and the UK have the year 2050 as their target year. Other developing countries, which are also significant carbon emitters viz., China and Russia, have 2060 as their target year and India has set 2070 for net zero emissions. Interestingly, some of the small-sized countries like Bhutan, Madagascar, Cambodia, Benin, etc., have already achieved net zero emissions due [8]. Overall, 140 countries, constituting about 88% of global emissions have expressed their commitments to net zero as of November 2022.

2.4 India's Commitment

India has updated its NDC (Nationally Determined Contribution) and communicated it to the United Nations Framework Convention on Climate Change (UNFCCC) in the name of 'Panchamrit', and 'LIFE—Lifestyle for Environment', has provided a roadmap to achieve net zero emissions by 2070 [9]. As per this vision document, India targets to meet 50% of energy requirement by renewables, with current figures stand at about 40%, and aims non-fossil energy capacity of 500 GW by 2030. A 45% reduction in carbon emission intensity is targeted by 2030 in comparison to 2005 levels. An additional carbon sink of 2.5–3 billion tonnes is also planned. Indian Railways, which is one of the world's largest railway networks, targets net zero by 2030 which is expected to reduce 60 Mn tons of carbon annually. In addition, solar mission, FAME, LED mission, and National Green Hydrogen Policy are expected to contribute significantly toward achieving net zero targets.

3 Objective, Scope, and Methodology

The primary objective of the current article is to identify the macro level challenges, chart out a roadmap, and identify enablers specific to the civil engineering industry in the path to achieve net zero targets in a built environment centered around the India scenario. The scope of the study was confined to identifying the macro level parameters related to barriers (constrains), and enablers specific to decarbonization, circularity, and other digital infrastructure enablers which shall influence in a major way to achieve objectives. A graphical presentation of the methodology adopted in the current study is shown in Fig. 4.

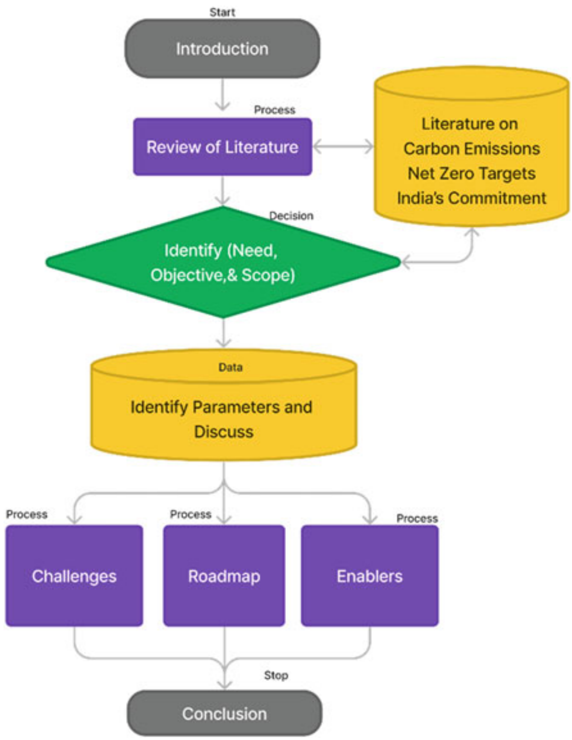

Fig. 4 Graphical presentation of the methodology adopted in the current study

4 Challenges

Though the never before optimistic environment has created a sense of positive atmosphere toward achieving net zero emissions, a wide specter of challenges remains and requires undeterred attention and resolve. After a careful review of data and its analysis, certain macro level parameters were identified. In this section, an attempt had been made to list and discuss those identified objective macro level challenges which might pave the way for achieving net zero targets.

(a) **Data**: The availability of data, resources, and their integration has remained one of the primary challenges to overcome. Any issue can have a solution only when the qualitative and quantitative aspects of the issue are modeled and understood. The availability of primary input in the form of factual data on carbon emissions and their sources has been a long-standing issue and requires an immediate resolution. Without this the path of decarbonization in the direction of achieving net zero emissions remains a challenge.

(b) **Identifying Primary Contributors**: The availability of substantial reliable 'data' shall resolve the issue of identifying primary contributors to a significant extent. For example, in a built environment; cement, concrete, steel, and other metals in addition to finishes and fit outs remain significant contributors to the embodied carbon of a construction project. To give a perspective, in a case study, for one of the past retail projects, the embodied carbon emission values for material and civil works constituted about 58% and the interior constituted about 17%, together constitutes three-fourth of total emissions.

The active and passive systems to achieve efficiency in terms of building design and operation are also important. The contribution of operational carbon to the total carbon emission is also significant. A substantial progress has been achieved in reducing operational carbon emissions, and with further technological advancements and with green energy supply, it is expected, the share of operational carbon to reduce to 10% of the total carbon emissions from the present 70% by 2050. Thus, it is imperative to identify primary contributors to develop sustainable solutions.

In India, the concrete sectoral targets, trajectories, short-term and long-term milestones, and trackers are lacking. Also, India being the world's third-largest emitter of GHG has a heavy dependence on conventional sources of energy and fossil fuels. The ambitious move toward green hydrogen/urea has provided an environment of optimism in the direction to achieve net zero transitions.

(c) **Funding**: Undoubtedly, the 'Funding': cost of decarbonization is the 'biggest challenge' to overcome. As per ASPI (Asia Society Policy Institute) report, in order to achieve India's net zero targets by 2070, an overall investment requirement of USD 10.1 trillion starting now was approximated [10]. This is expected to boost the Indian economy by 4.7% above the projected baseline growth by 2036 in GDP terms translating worth of USD 370 billion (approx.). Also, the transition is projected to generate 15 million jobs by 2047 beyond the baseline scenario [10]. In case if the target is advanced to 2050, the requirement of capital increases by a whopping 35%

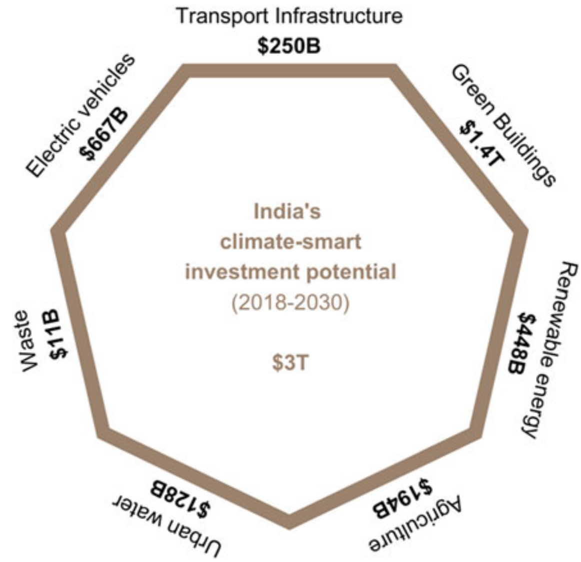

Fig. 5 India's climate-smart investment potential [11]

to USD 13.5 trillion dollars as per this ASPI report. Another estimate by IFC (International Finance Corporation) places India's climate-smart investment potential at above USD 3 trillion for just over a decade between 2018 and 2030 [11]. Out of this, about USD 1.4 trillion is required for sustainable habitat in the form of green buildings. Figure 5 shows the breakup for India's climate-smart investment potential (2018–2030). The access and mobilization of funding for net zero transformation was extensively debated and discussed and was the primary agenda of the recently concluded 27th session of UNFCCC (COP 27) in Egypt [12].

(d) **Technology Transfer**: To achieve ambitious targets apart from investment requirements, research and innovation, technology transfer and many transformative initiatives are required to improve efficiency and to bring down the cost of transformation.

(e) **Pace of Global Decarbonization**: In the present world of globalization, the influence of economy, climate, environment, carbon, etc., in a particular region is not completely isolated from each other; rather they are interdependent to a certain extent. Thus, the pace of global decarbonization will certainly impact the efforts and transition toward net zero of a particular country and/or continent. PWC report on Net Zero Economy Index 2022 [7] provides interesting data on the rate of global decarbonization in terms of a parameter viz., 'global carbon intensity' (GCI). GCI fell by an average of 1.4% per year between 2000 and 2021; and in 2021 this value was a mere one-third, i.e., 0.5%. To limit global warming to 1.5 °C of the preindustrial levels, a reduction of 77% in carbon intensity is required in this decade alone. The annual decarbonization rate of about 6.3% is necessary to limit global warming to a limit of 2.0 °C and a whopping 15.2% rate of reduction is desirable

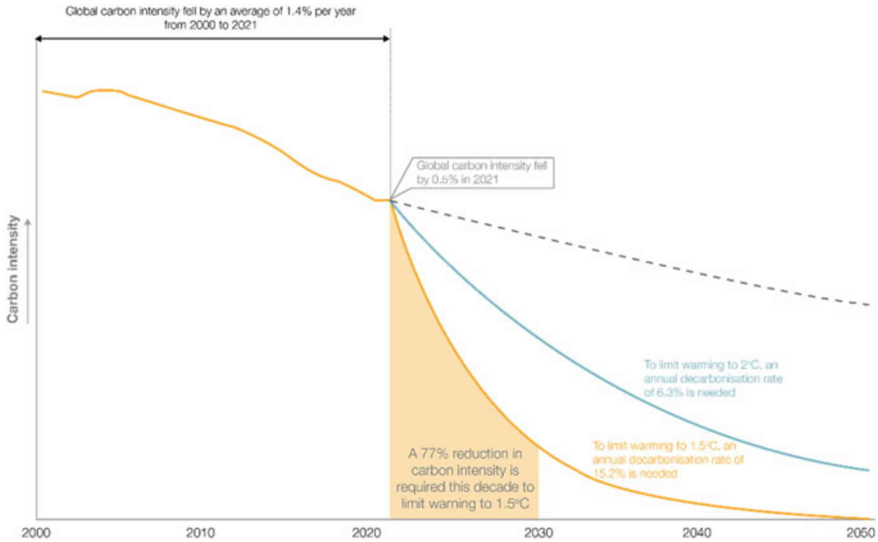

Fig. 6 Carbon intensity versus timeline, PWC report 2022 [7]

to limit the temperature increase under 1.5 °C, which is about 11 times the global average achieved for past two decades. Figure 6 shows the graph of carbon intensity against projected timeline to achieve net zero transition by 2050. The data and the parametric study were initially conducted and reported in PWC report on Net Zero Economy Index—2022 [7]. Based on the reported data, certain important metrics of the study reported were referred and the graphic showing carbon intensity over time was reproduced and presented through Fig. 6 in this section.

(f) **Geopolitical and Economic Environment**: Global pandemic and conflict in the Eurasian region have worsened the global economic situation like never seen before, and changing the world order has led to a 'fragile' outlook. This shall have its effects on investments, transition, technology, and net zero ambitions for not only to the Indian subcontinent but in majority of the regions and has remained one of the contributors to existing challenges for the transition.

(g) **One Goal—Many Paths**: Each country and sector are forced to take an objective and subjective route to effectively achieve net zero transitions. Under these circumstances, the divergent paths require convergence to achieve specific goals and the path leading to such an entity remains a challenge.

(h) **Collaboration Not Competition**: Businesses and investors must lead toward 'triple i's—innovate, invest, and implement'. This requires collaboration and not competition. This collaboration should exist in various levels between businesses, investors, and end users at national and global level platforms.

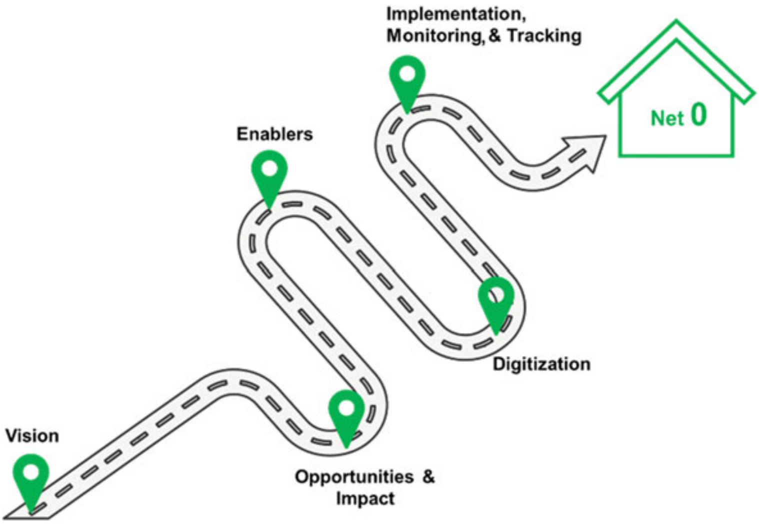

Fig. 7 Proposed roadmap to achieve net zero transition

5 Roadmap

An effective and efficient roadmap for each sector and sub-sector needs to be established at all levels with short-term, medium-term, and long-term objectives. Figure 7 shows birds eye view of a functioning roadmap to achieve net zero transition in the built environment. The various parameters presented through the graphics include vision, opportunities and impact, enablers, digitalization, implementation monitoring and tracking. In the subsequent sections, the importance of enablers viz., circularity, decarbonization metrics, and digitalization has been discussed in detail.

6 Enablers

Several enablers exist and several others have potential to be developed as enablers and facilitate an effective transition toward net zero environment. There is no one-size-fits-all solution to the challenges of environment and sustainability. A multi-pronged in various aspects shall enable us to achieve ambitious net zero targets. An example of cement production may be considered. This also happens to be one of the most carbon-intensive sectors in construction and built environment. To enable the net zero goals the combination of factors viz., efficiency in design and construction, efficient concrete production, optimal cement/binder content, optimal clinker content, efficient and renewable energy and electricity, Carbon Capture Utilization & Storage (CCUS), and recarbonization through carbon sink are to be adopted.

The current model of infinite extracting of resources specifically to develop the built environment does not work and it's a failed model; the resources are in fact finite. The rate of consumption of natural resources is nearly 1.7 times the rate at which nature (earth) can replenish. Therefore, the current system requires a fundamental shift from the conventional profit-based system to a more inclusive, collaborative, and reformative sustainable system. This also requires us to move away from a profit-based GPD focused economy to a planet and society-based approach; individualistic to a collaborative system; extractive to regenerative approach; and short-term to a long-term approach. These approaches are the combination of subjective and objective methods and active and passive methods. The investment and investment enablers, educating and motivating stakeholders through workshops and other engagement practices, digitization, and regular audits on carbon analysis and reporting are some of the other most important enablers to be seriously considered and adopted in practices. Carbon reporting of a construction project and/or built environment, soon becomes one of the primary requirements like a cost or a design plan as the current structure of embodied carbon vs operational carbon share of ratio is expected to move on from the current ratio of 30:70 (in 2020) to 90:10 by 2050 [13]. This is significant as per the United Nations environmental program report of 2017, about *230 billion square meters of new construction will be carried out by 2060* [14]. Which results in demand for sustainable construction materials and clean energy.

6.1 Circularity and Its Importance

In the path of sustainability, currently the industry has reached a tipping point. Minor tweaks to the business-as-usual approach to a conventional system of linear economy are not enough but a fundamental, system level change to create a resilient, collaborative construction sector is the need of the hour. Currently, we have stretched the limits of what our ecosystems can handle in terms of waste and pollution, and we are currently overshooting several planetary boundaries, such as the carbon limit. In future, the onus is on mankind to ensure the economic and built environment are intertwined with society and the environment, and they coexist in harmony with earth's finite resources. To ensure this, it is important to ensure the enablers of circularity are embedded into the construction life cycle. Some of them are:

- Early engagement and collective collaboration
- Access to secondary materials market; design principles for circular economy
- Green Contracts: expanding the customary contracts and leases to include wider legally binding sustainability aspects
- Regulate policy legislations and taxes toward adopting sustainable practices in construction and built environment
- Green Financing: Banks and financing lending institutions must leverage scale and reach to push businesses to stimulate and shift to circular from linear practices

- Analytics: Consistent benchmarking and target measurements through metrics to drive sustainable and circular practices
- Awareness: Educate practitioners and decision-makers and empower them with necessary knowledge on circularity and sustainability.

The practice of circular economy finds an important place in the transformation of the built environment toward net zero targets and sustainable construction practices.

6.2 Decarbonization: Metrics and Analytics

Facilitating businesses and industry to record, measure, and analyze progress by having a consistent set of metrics in place; benchmarking and target setting to drive sustainability efforts through decarbonization principles. All stakeholders must work toward a standard reporting format and data to enable consistent and comparable reporting structure. Project promoters, architects, engineers, and consultants must collect and report carbon-related metrics for projects and manufacturers ought to do the same for their products. Stakeholders and manufacturers must also work toward increasing transparency in data through central freely accessible databases and quantify the benefits of implementing sustainable practices through carbon reports. The regular metrics of recording, calculating, and reporting of carbon data most certainly facilitate to bring in matured social behavior, mindset shift in consumption behavior, and high consumption mindsets; may push occupants toward low-resource lifestyles; fair distribution; and use of finite resources. In a business perspective, transparent disclosure of data related to reduced carbon footprint of a project may also attract above average income group; help improve average per capita revenue of projects; and facilitate to bridge the gap of cost of decarbonizing the built environment in particular and construction as a whole.

Decarbonization efforts also present and economic opportunity for reliance on regenerative, renewable, and inclusive resource flows; potential for creation of sustainable market opportunities eco-design, secondary material, and circularity market; and facilitate transition beyond GDP-focused economy to a sustainability-centric market.

Embodied carbon calculations involve arriving at data related to material quantity and multiplying it with embodied carbon factors for each material type category to arrive at total embodied carbon values. Globally accepted practice through ISO standards records the embodied carbon data through kgCO2e per unit of measurement of the component in consideration and summed up finally to report the total mass of carbon emissions.

6.3 Other Enablers

Carbon labeling and labeling life cycle impacts of construction materials, similarly in lines of nutrition labeling of a food product may become a norm in coming days. The environment product declarations (EPDs) of construction material are one step in this direction. This helps carbon estimation of materials, products, and projects. Material passports offer a tool to gather data on construction products and materials, linked to an accessible database. This provides proof of source and origin, with clarity on existing materials, repair, and restoration, and detailed info to obtain the confidence of consumers in a secondary materials market. With detailed information on the composition of a building prior to its deconstruction, a material passport can be a potential source of data for material reuse and enable circularity as it provides insights into the availability of potential materials. The 'track and trace' aspect is vital for buildings to be designed based on the availability of materials in the secondary market through potential re-use and/or re-purposed use. In addition to these enablers, as a part of futuristic approach, it is essential to establish the infra support for the principles of circularity; carbon database, metrics, and calculations; material passport; carbon inventory; post-occupancy responsibility; green financing; informed and objective decision-making; secondary market access; supporting supply chain and measure, monitor, and reporting is essential to ensure sustainable habitat. Figure 8 presents the graphical representation of futuristic approach to sustainable habitat. It is equally important *to digitally integrate* the essential enablers listed in this section through a digitally *interoperable platform* along with technical data with respect to the costing, planning, engineering analysis and design, and execution to ensure sustainable habitat.

7 Conclusions

The built environment is an intricate ecosystem made up of established procedures, dependency on conventional materials and methods, and interdependent supply chains. It is difficult to modify this system to suit the demands of resolving our present challenges due to its intricacy. Furthermore, the way things are done now is supported by existing infrastructure, whereas conflicting and divergent future ideas may make it difficult to choose the best course of action. Therefore, the transition to net zero built environment demands a fundamental system level change, adaptability, inter and intra industry collaboration. The resolve involves adopting a roadmap consisting of identifying opportunities and impacts, identifying challenges, and resolving them through systemic enablers. Adopt and integrate digitization tools to enable decarbonization through data collection, analysis, and standardized format of reporting. Circular economy and circularity; embodied energy calculation, reporting, and decarbonization methods; material passports and similar integrated digital tools and platforms to adopt 'track and trace' method to design built environment forms the essential pillars

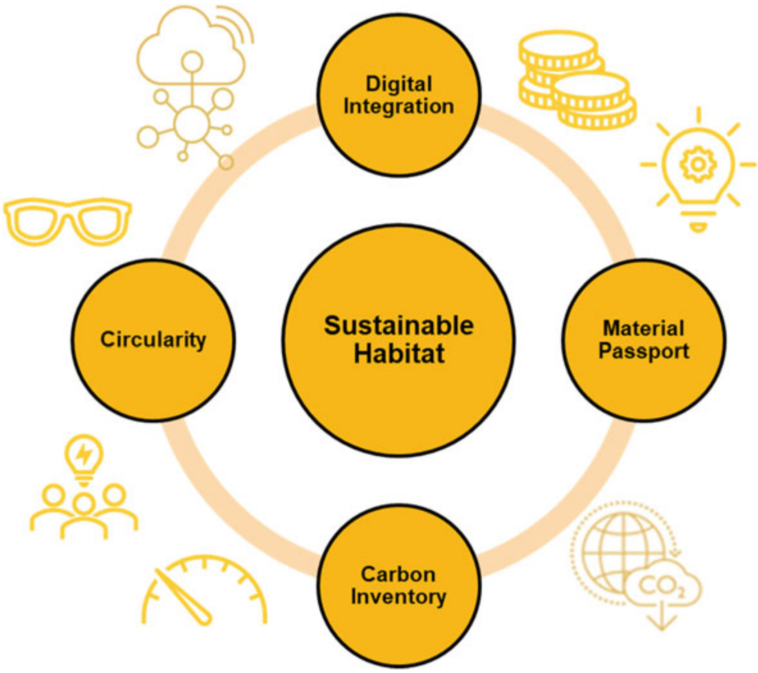

Fig. 8 Graphical representation of futuristic approach to sustainable habitat

of futuristic approaches in transformation toward net zero built environment in India. In addition, a robust system of recording, analyzing, calculating, and reporting carbon emission data through environment product declarations (EPDs) or similar instrument is an important aspect especially in Indian context, as such data is currently not available to the desired extent. The path to a net zero built environment poses several challenges to comply and the potential opportunities to explore, exploit, and grow.

References

1. Friedlingstein P, O'Sullivan M, Jones WM, Andrew RM, Gregor L, Hauck J, et al (2021)Our world in data—CO_2 emissions, [Online]. Available: https://ourworldindata.org/co2-emissions
2. United Nation Environment Programme (2020) 2020 Global status report for buildings and construction: towards a zero-emission, efficient and resilient buildings and construction sector. UNEP, Nairobi
3. Ritchie H, Rosado P (2020)CO_2 and greenhouse gas emissions, OurWorldInData.org, [Online]. Available: https://ourworldindata.org/co2-and-greenhouse-gas-emissions
4. COP21: The key points of the Paris Agreement, Ministry of Europe and Foreign Affairs, France, December 2020, [Online]. Available: https://www.diplomatie.gouv.fr/en/french-foreign-policy/climate-and-environment/the-fight-against-climate-change/2015-paris-climate-conference-cop21/cop21-the-paris-agreement-in-four-key-points/. Accessed Jan 2023

5. Net Zero Tracker, 10 March 2023, [Online]. Available: https://zerotracker.net/. Accessed 10 March 2023
6. Masson-Delmotte V, Zhai P, Pörtner DRO, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy L, Maycock T, Tignor M, Waterfield T (2022) Global warming of 1.5 °C IPCC special report on impacts of global warming of 1.5 °C above pre-industrial levels in context of strengthening response to climate change, sustainable development, and efforts to eradicate poverty. Cambridge University Press, Cambridge, UK and New York, NY, USA
7. Pricewaterhouse Coopers (2022) Net Zero Economy Index 2022. PWC LLP, UK
8. Energy and Climate Intelligence Unit, Net Zero Scorecard, [Online]. Available: https://eciu.net/netzerotracker. Accessed 23 March 2023
9. Cabinet, Release ID: 1847812 - PIB, [Online]. Available: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812. Accessed 24 March 2023
10. Bui H, Kőműves Z, Chewpreecha U, Gutzianas I, Stenning J (2022) Getting India to net zero: a report of the high-level policy commission on getting Asia to net zero. The Asia Society Policy Institute, New York
11. International Finance Corporation (2017) Climate investment opportunities in South Asia. International Finance Corporation, World Bank Group, Washington D C
12. Conference of the Parties—Twenty-seventh session, United Nation Climate Change—COP 27, Sharm el-Sheikh, 2022
13. Apel F, Boland B, Motte Hdl, Moore A, Reiter S, Sjödin E (2022) Basic materials practice: accelerating green growth in the built environment. McKinsey and Company
14. UNEP Press release on Energy, As buildings and construction sector grows, time running out to cut energy use and meet Paris climate goals, UN Environment Programme, 11 December 2017, [Online]. Available: https://www.unep.org/news-and-stories/press-release/buildings-and-construction-sector-grows-time-running-out-cut-energy. Accessed 20 March 2023
15. Ritchie H, Roser M, Rosado P, Our world data, Global Change Data Lab, August 2022. [Online]. Available: https://ourworldindata.org/co2-and-greenhouse-gas-emissions

Sustainable Urban Planning, Housing, Real Estate and Construction Practices

Affordable Housing: An Appraisal of User's Perception, Case Delhi NCR

Shagun Agarwal, Deepak Bajaj, and Amit Hajela

1 Introduction

Rapid urbanization in developing countries has far exceeded the capacity of the cities to absorb the needs of the growing population in urban centers. This has resulted in tremendous stress on urban infrastructure facilities, housing being one of them. The concerns are not only limited to the shortfall in the number of housing units—required vs. available, but also in the living conditions of the people in the cities, especially the urban poor. The issues related to urbanization and housing are prevalent globally but are more pressing in developing nations.

Data indicates a global housing deficit of nearly 268 million homes, estimated to grow incrementally at the rate of 40 million homes annually. The majority of the deficit is recorded in the lower income groups since they lack any savings or disposable income to be spent on housing-related expenditures. However, housing poverty is not only limited to economic poverty but also has issues of adequacy and livability that demand attention. A sustainable future demands sustainable housing solutions since housing forms an integral part of the 17 SDGs as laid down by the UN and directly or indirectly contributes to the attainment of each one of them [1].

The objective of this study is to assess the adequacy of urban affordable housing and evaluate consumer satisfaction thereof. A comprehensive literature review on the Sustainable Development Goals (SDGs) and the role of housing in their attainment, Affordable Housing policies in India, and parameters to assess the livability in urban centers was done. A secondary case study was undertaken of the largest resettlement colony "Savda Ghevra" to map its progress over the years since its establishment, assess consumer satisfaction with the project, identify the strengths

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and weaknesses of the project, and draw inferences that may be used as learnings in future implementation strategies. A consumer data survey was conducted to validate the on-ground realities for different user groups. The learnings of the secondary case study and primary data study were used as a reference to draw the final conclusions and propose recommendations. The study can be further extended for a larger sample size, in different parts of the country for a holistic approach.

Need for the study: As the housing shortages continue to accelerate, there is a pressing need to balance the adequacy of housing solutions with affordability. A consumer-centric approach to housing, embedded in housing policies, is essential to achieve housing sustainability. The New Urban Agenda 2030 of the United Nations advocates the attainment of 17 Sustainable Development Goals (SDGs) by the year 20230. SDG 11 targets "Making Cities and Communities safe, resilient and Inclusive". Target 11.1 of SDG 11, on Affordable Housing, is an integral part of all the 17 SDGs, and hence, addressing the adequacy and livability concerns of the urban housing solutions is critical to the attainment of the SDGs. In view of the above, the study assesses the quality of life and consumer satisfaction in urban centers to enable a more integrated approach to addressing urban housing.

2 Literature Review

2.1 Slums: A Consequence of Unintentional Policies

Several researches have been conducted in the past, focusing on the challenges faced by slum dwellers and the quality of life experienced by them. The study conducted by Zhang [2] on "The Credibility of Slums: Informal Housing and urban governance in India" advocates the credibility and significance of slums in serving several functions such as low-cost housing provisions, economic opportunity generation, and vote collection. With Mumbai as the case area for the study, the highlights the formation of slums as a consequence of unintentional policies. The paper highlights the limits of the formal–informal distinction as a reflection on function rather than the form of informal housing. It implies that informality has become the "new normal" and the urban policy should reflect this notion in order to produce more livable and inclusive cities. Secondly, the paper proposes a new picture of the state's role by demonstrating that functional informalities in real estate and property rights must be regarded as produced and institutionalized by the state itself, rather than as the goal of governmental regulation [2].

In yet another study on measuring housing deprivations in urban India using Slum Severity Index by Patel et al. [3], the authors establish that the worldwide assessments of housing shortages and deprivations do not provide a comprehensive picture of the various types of deprivation faced by the urban poor, leading to incorrect estimations of the scale of the housing crisis. The paper focuses on how India's official slum statistics underestimate the extent of housing problems in India, the need to identify and benefit the most deserving beneficiary and emphasizes determining the type of interventions that may be adopted at the policy level to aid in the attainment of SDGs pertaining to housing and basic services for the urban poor across the globe [3].

Killemsetty et al. [4] in their study on housing preferences of slum dwellers studied the existing conditions in two of the slums in Odisha and demonstrated the different issues and requirements of the community in terms of housing and basic infrastructure facilities, as seen through the eyes of slum inhabitants, a voice that is frequently absent in slum policymaking, to support the policymakers understand the most important choices of slum residents among a variety of slum-improvement strategies [4].

Another study on "Life between the City and the Village" by Sahasranaman and Bettencourt [5] used census data to uncover general characteristics of infrastructure and services in Indian slums via urban scaling, focusing on attributes of neighborhoods such as access to basic services like water, sanitation, and electricity. The study discovered constant underperformance in service access in slums when compared to non-slum neighborhoods in the same cities, and indicate the need for urban policy to address two types of urban inequity: within cities' neighborhoods and across city scales and degrees of development [5].

Boateng and Adams [6] developed the scale for measuring housing insecurity in slums and informal settlements from data collected from three slums in Ghana on housing deprivations and characteristics, slum severity, resource insecurity, health outcomes, and socio-demography. This study provides positive preliminary evidence for the MMHIS's psychometric qualities and suggests additional validation of the scale in other slums and informal settlements in cities around the Global South. Cross-cultural validation across slums in various regions of the Global South will be useful in improving the scale's usage by scholars and practitioners. More importantly, this scale will aid in the identification and quantification of the multiple causes and consequences of housing insecurity [6].

Hence, the study on living conditions in slums, causes for slum proliferation and its possible linkage with the policies is imperative to formulate impactful interventions to achieve Slum free cities [7]. Having established the need to examine the adequacy of urban housing for the urban poor living in slums and informal settlements, a further literature review was conducted to establish the significance of housing in the attainment of Sustainable Development Goals (SDGs) as set by the UN to be achieved by 2030, review the global indices assessing the quality of life and livability in urban centers, and critically analyze the living conditions of households in a resettlement colony in Delhi through secondary case study [8].

2.2 Housing and the Sustainable Development Goals

In the year 2015, the United Nations established a set of 17 Sustainable Development Goals (SDGs), each of which addresses a key area of decent living, including Education, Poverty, Hunger, Water, Environment, etc., with the target of attaining these by the year 2030. SDG 11, in particular, focuses on “Making cities and human settlements inclusive, safe, resilient and sustainable”.

The UN Conference on Housing and Sustainable Development, Habitat III, held in Quito, Ecuador in 2016 emphasized housing as a major challenge faced by the urbanized world and highlighted the housing deficit that existed globally. Housing was thus identified as a key sector impacting each of the 17 SDGS, contributing significantly to the progress made toward the Urban Agenda 2030, which sets the goals for creating cities that are centers of growth and prosperity and culturally and socially sound, with a positive impact on the environment [9, 10].

2.3 Housing as an Integral Part of SDGs

Housing is integrated within 7 out of the 17 SDGs, being a major contributor to poverty reduction, good health and well-being, gender equality, access to clean water and sanitation, access to affordable and clean energy, making cities and communities safe and resilient, and mitigating climate change (Fig. 1). It directly contributes to 6 other SDGs related to economic growth, improved industry, innovation, and infrastructure, reduced inequalities and environmental protection, and requires collaboration among stakeholders for successful delivery. And somewhere, the provision of housing also indirectly impacts the other 2 SDGs on access to food and education for the people [11].

Adequate housing is a basic human need and a fundamental human right, significantly impacting access to health, education, and employment opportunities for the people [12].

Sustainable development focuses on three distinct areas of Economic, Socio-cultural, and Environmental sustainability. Housing development can boost the economic activity in the country, provision of user-centric housing can strengthen community ties, leading to community cohesion and well-being, and adopting sustainable construction practices can reduce the negative effects on climate.

The past studies suggest that though the importance of housing has been recognized globally, the integration of socio-cultural dimensions and adequacy of housing are often undermined in the policy frameworks, leading to poor housing solutions, especially in developing nations. In this context, this study attempts to assess the quality of life in Indian cities, with Delhi as the case example. With an estimated housing deficit of 18.78 million in India, providing affordable and adequate housing to all holds the key to a sustainable future [13, 14].

2.4 Measuring Livability: Global Indices

Urban Livability is defined as:

"Adequate housing means more than a roof over one's head. It also means adequate privacy, adequate space; physical accessibility; adequate security; security of tenure; structural stability and durability; adequate lighting, heating, and ventilation; adequate basic infrastructure, such as water supply, sanitation, and waste management facilities; suitable environmental quality and health-related factors; and adequate and accessible location with regard to work and basic facilities: all of which should be available at an affordable cost" (UN-Habitat, 2003).

Fig. 1 Housing to SDGs. *Source* [11]

Communities that are safe, attractive, socially cohesive and inclusive, and environmentally sustainable; with affordable and diverse housing linked by convenient public transport, walking and cycling infrastructure to employment, education, public open space, local shops, health and community services, and leisure and cultural opportunities [15].

Homelessness, densely congested accommodations, unstable jobs, unemployment, resulting in poverty, hunger, etc., are all a by-product of the increasing urban population in urban centers with limited resources. In this context, it is of significant importance to assess the livability in these urban centers, which is one very important aspect of sustainable development [16]. Several studies have been undertaken globally and indices have been developed to measure the quality of life experienced by city dwellers, along with different aspects of human expectations and their fulfillment. The matrix below comprehensively presents the indicators for the assessment of livability in urban centers (Table 1).

The above-listed indices are a few of the numerous indices that have been developed by countries across the globe to quantify and measure the quality of life experienced by its citizens A quick review of these highlights access to Housing, Health,

Table 1 Summary of livability indices

Global livability index (GLI)	Urban livability index (ULI)	Quality of life index (QLI)	Happiness index	Ease of living index (ELI)	Adequate housing index (AHI)	Better life index (BLI)
Stability	Transport	Material living conditions	Psychological well-being	Education	Access to water	Housing
Healthcare	Social infrastructure	Productive or other main activity	Health	Health	Access to sanitation	Income
Culture and environment	Employment	Health	Time balance	Housing and shelter	Adequate living space	Jobs
Infrastructure	Walkability	Education	Community	WASH and SWM	Durable material of good structural quality	Community
Education	Housing	Leisure and social interactions	Social support	Mobility	Security of tenure	Education
	Green infrastructure	Economic security and personal safety	Education, arts, and culture	Safety and security	Access to electricity	Environment
	Ambient environment	Governance and basic rights	Environment	Recreation	Access to clean cooking	Civic engagement
		Natural and living environment	Governance	Level of development		Health
		Overall experience of life	Material well-being	Economic opportunities		Life satisfaction
			Work	Gini coefficient		Safety
				Sustainability		Work–life balance
				Green spaces and building		
				Energy consumption		
				City resilience		

Source Author's/Author's Computation

Education, Employment, Infrastructure, and Environment as the key indicators to measure the quality of life promoted in the cities [17, 18].

A review of India's ranking on global indices reveals below-average attainment of livability goals in Indian cities. India has slipped by 4 ranks in the Global Index of SDGs, from 117 in 2020 to 121 in 2023. India ranks 89 out of 127 counties in the Quality-of-Life Index. Delhi ranks 141st in the Global Livability Index out of 173 cities and 140th in Urban Livability Index. Delhi ranked 6th in the list of 111 cities on the Ease of Living Index. However, Delhi was rated the worst in the human perception survey in the Ease of Living Index. Delhi stands at 180th position out of 186 on the Happiness Index [19].

It becomes of utmost relevance to address the decline or low performance of Indian cities and find relevant interventions to improve the consumer perception and satisfaction of life in Indian urban centers.

3 Assessing Livability: A Case Example of "Savda Ghevra"

India is urbanizing at a rate of 1.5%, with one-third of the population (35.39%) living in urban centers, further expected to increase to 68% by the year 2050, translating into the proliferation of slums and squatter settlements. With the national focus on "Slum free cities", several Slum Redevelopment and Slum Rehabilitation projects have been undertaken to improve the living conditions of slum dwellers. It is equally important to review the efficacy of such projects for improvisations in the housing policies and implementation of future projects [20].

The case example of "Savda Ghevra" the largest Slum Resettlement Colony in India has been selected to review its progress and analyze its implementation and delivery efficiency.

3.1 Savda Ghevra: Slum Rehabilitation Colony

The Savda Ghevra Slum Rehabilitation Project is the biggest Slum Resettlement Colony project in India, implemented by the Delhi Development Authority (DDA) in 2006. The Colony is home to almost 8,000 households with a population of over 46,000 people. The project demanded forced eviction and relocation of residents from the most congested parts of the slums in Delhi to the new location, as a consequence of the clean-up drive for the Commonwealth Games. The residents were given the choice to either own or rent the new houses in the resettlement colony (Fig. 2).

Savda Ghevra is located around 30–40 kms away from Delhi City Center, near Tikri Border.

Spread across an area of 250 acres, the project was completed in 2 phases, with 8686 plots in Phase I and 7620 EWS dwelling units constructed in Phase II. The plot sizes were limited to 18 and 25 sq. mt. and were allotted as per the eligibility criteria.

Fig. 2 Plan of Savda Ghevra resettlement colony—19 blocks—8686 plots and 7620 dwelling units, 6500 households, 46000 residents. *Source* [21]

The construction of the housing units involved the use of prefabricated technology to speed up the construction process. The project has a mix of Kutcha, Semi Pucca, and Pucca houses of up to 2.5 stories (Fig. 3).

Building Savda Ghevra: Phase-wise progress since 2006

Eighteen years after its inception, Savda Ghevra continues to struggle with unsafe, unhygienic, and inadequate living conditions. The development in the colony has been slow and ongoing even years after it was inhabited. Insensitivity toward the needs of the consumer and lack of public participation have only added to the resentment of the occupants and severe trust issues with the government agencies. The case example of the Savda Ghevra resettlement colony has been critically analyzed to correctly assess the gaps in implementation and key causes for its failure.

Challenges in the Implementation of the Project

The Savda Ghevra project faced several challenges in its implementation, some of which are listed below:

(a) Land Acquisition: The land required for developing the project was under dispute between the government and private landowners and required legal measures for acquisition, leading to delays in the initial phase of the project itself [22].
(b) Funding: The significant funding required for the construction of housing and infrastructure facilities for the project, required contributions both from government and private investors. However, due to the high risks associated with the project, private players were reluctant to invest, leading to delays in the project [23].
(c) Community Participation: The project faced resistance from the slum dwellers from the very beginning due to forced eviction, raising concerns regarding the adverse effect of relocation on their jobs and neighborhood ties. The success of the project was dependent on the participation of the slum dwellers, but the government struggled to gain the confidence of the slum dwellers, leading to further delays [24].

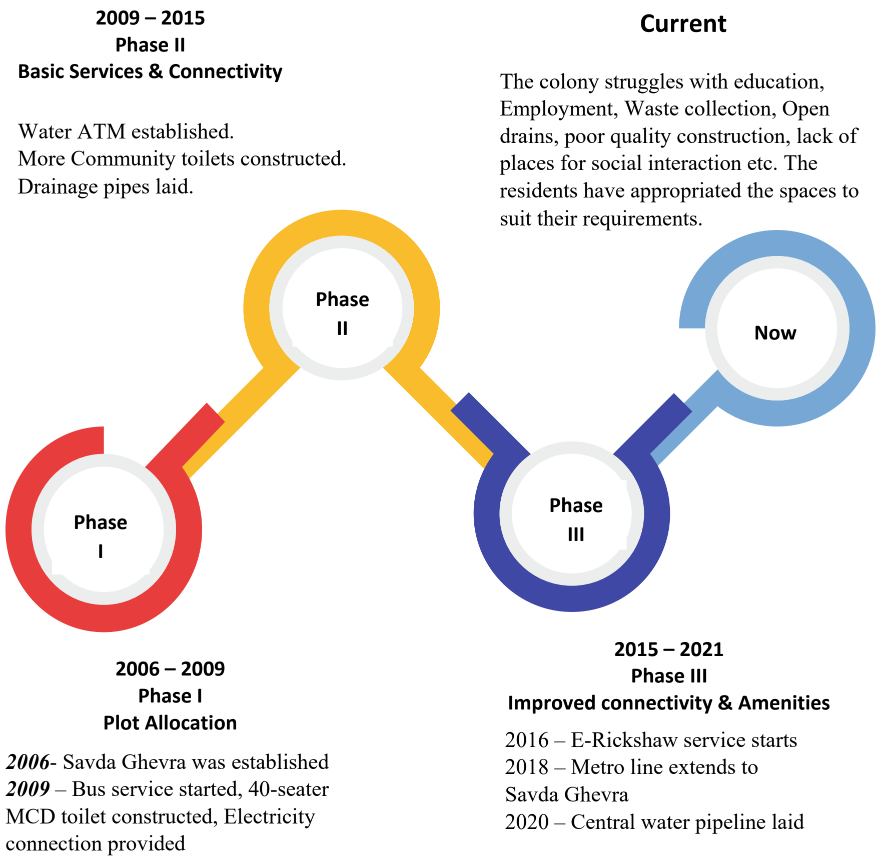


Fig. 3 Phase-wise development and implementation of Savda Ghevra project. *Source* Author's compilation

(d) Infrastructure Development: The lack of planning and coordination between different government agencies to provide basic infrastructure facilities led to time and cost overruns in the project [22].

(e) Maintenance and Sustainability: Lack of community participation and ownership in the project led to issues related to the maintenance of the infrastructure facilities provided in the settlement colony. Consequentially, this led to the facilities falling into disrepair and becoming unusable [24].

The progress of the Savda Ghevra Slum Resettlement project has been slow with 10,316 dwellings being developed till March 2018. Years after the occupation of the project, it continues to face challenges that could be great learning for government agencies, if taken cognizance of. Some of the key issues leading to the failure of the resettlement project are as under:

(a) Lack of Basic Amenities: The project lacked access to basic amenities when it was first established in 2006 and it still continues to be deprived of access to water and sanitation to the slum dwellers, due to lack of coordination between different government agencies. Water is made available through a daily supply of water tankers to the site. The lack of a proper waste management system results in garbage being dumped in the open. Open drain running at the back of the colony poses major health hazards to the residents. Besides, dirty water runs through the open channels in the center of the residential streets in the colony. The common MCD toilets provided on the site were insufficient, forcing the residents to come up with temporary solutions in the open areas. Though an MCD school was provided for the settlement, many children couldn't access it due to the loss of jobs of their parents as a consequence of the relocation. Hence, children were left with no choice but to waste their time on the streets rather than engage in education in school.
(b) Displacement of Slum Dwellers: The eviction and relocation of slum dwellers from different slums of Delhi were not handled sensitively enough by the authorities, leading to serious trust issues between the community and the government from the very inception. The project led to social unrest and criticism for displacing slum dwellers from their original settlements without providing adequate compensation or alternate housing options. Besides, the overall progress of the project was slow, and it took much longer to complete, causing uncertainties for the slum dwellers. Many lost their jobs and the commute to work from the new location increased for many others, but no compensation or support was provided to anyone.
(c) Poor Design and Quality of Dwellings: The dwelling units developed in the project had major flaws in design and quality of construction. The units were poorly ventilated and prone to waterlogging during the monsoon season.
(d) Lack of Community Participation: The residents were not adequately involved in the decision-making process and their opinions and needs were not considered in the whole process of resettlement. Hence, the project experienced very low community participation from the very beginning [25, 26, 27].

A Visual trail of existing conditions in the Savda Ghevra Resettlement Colony

The key learnings from the study of Savda Gehvra can be used to draw meaningful inferences regarding the (Figs. 4, 5, and 6):

(a) Relocation of Slum Dwellers: The relocation of the slum dwellers, as a consequence of the redevelopment process, should be dealt with sensitively since it has serious repercussions on the livelihood and financial stability of slum dwellers. One of the critical factors associated with the move is either the loss of employment or the increased time and cost of commuting to the workplace. Either way, the financial condition of the household gets adversely affected. Government agencies need to address this and aid the households till they are able to settle in new locations and provide for themselves.

Fig. 4 Condition within the resettlement colony with open drains, broken pavements, and long queues to get a bucket of water. *Source* [26]

Fig. 5 Insufficient number of MCD toilets in the colony (left) leading to the creation of temporary toilets in the open areas (center and right). *Source* [25]

(b) Provision of Facilities on Site: Provision of adequate basic amenities, sanitation, and public transport connectivity on the redeveloped site should be ensured before moving in the slum dwellers, lest the project might become a replacement of informal slums with a formal one.

(c) Public Participation: People's participation is essential for the success of any project, both during the implementation phase and post-implementation.

Fig. 6 Public interaction spaces (Left), poor structures (top center), and poor waste management on the site (Right). Building typologies that exist in the resettlement colony (bottom). *Source* [26]

Community involvement is the only way to successful operations and maintenance of the project post-occupancy. Hence, the authorities should engage with the slum dwellers and gain their confidence by involving them in the decision-making processes from the very beginning. The social and cultural needs of the people need to be adequately addressed while developing housing solutions. The involvement of people in the design and implementation of the projects increases their sense of accountability and responsibility toward using the facilities appropriately.

(d) Post-Occupation Operations and Maintenance: The project planning should not be limited to the development phase alone, but the mechanism for post-occupancy maintenance of facilities should also be worked out and put in place to make the project viable and sustainable in the long run.

(e) Post-Occupancy Feedback: The government should invest in collecting feedback from the residents once the project has been occupied and the key success and failure stories should be recorded as learnings for future projects.

4 Research Methodology

The aim of the study is to assess the living conditions of slum dwellers and other Economically Weaker Section households. Delhi, being the national capital and the most urbanized state, was chosen as the case area for the study. A mixed-method approach to research was adopted. A sample size of 274 was determined to achieve a confidence interval of 90% for the population size of Delhi NCR. 200 respondents from the EWS category, 75 respondents from LIG, and 75 respondents from the MIG category were selected through the "random sampling" technique for the survey. Primary data was collected through personal interviews and structured questionnaire surveys. 350 respondents from the Delhi NCR region were contacted to participate in the survey. Out of the total 300 responses received, 44 responses were discarded due to incomplete or incorrect data. 256 complete responses, with no missing information, were considered to conduct the survey analysis. The respondents belonged to the age group of 25–60 years and 189 respondents out of the total 256 respondents were male. It was observed that females were less forthcoming in expressing their opinions and preferences, which also suggested the existing gender bias in our society.

The respondents were interviewed on their household income and expenses, existing living conditions, problems faced in current accommodation, and the degree of importance attached to key issues of housing adequacy. The quantitative data was collected through a structured questionnaire, on a 1–5 Likert scale. The quantitative data was analyzed in MS Excel to sort, filter, and graphically represent the responses of the consumers from different income categories. The qualitative data was collected through interviews and question–answer sessions, the responses of which were recorded after content analysis, and used to further strengthen and formulate the final conclusions.

5 Assessing Livability: The Consumer Perspective

A primary study was conducted to assess the quality of life of different income groups in the Delhi region.

The results of the data are compiled and represented as bar charts below (Figs. 7 and 8):

Analysis: It is observed that the EWS has larger household sizes and smallest Unit sizes, raising concerns about the adequacy of living space available. The study reveals that the EWS category has larger household sizes of up to 7 members as they associate more children with larger future earnings for the family and due to their inability to buy a separate dwelling as the families grow. However, the dwelling size of these households is limited to 30 sq. mt., which makes it highly inadequate for a family of 5–7 members. In the higher income category, the average family size is 4–5

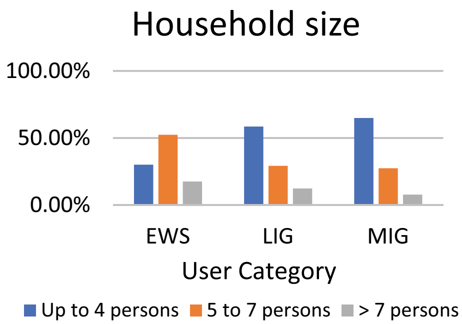
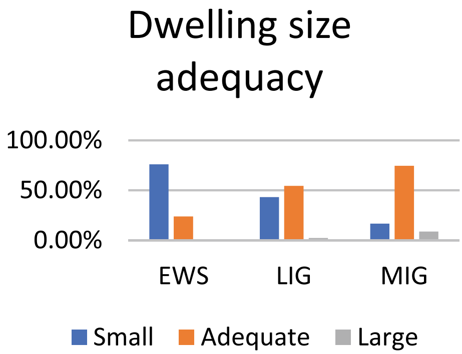


Fig. 7 Number of persons per household (by Author)

Fig. 8 Size of the dwelling unit (by Author)



members and the dwelling unit size increases up to 60 sq. mt. for LIG households and up to 120 sq. mt. for MIG households.

A more rational approach might be to consider household size and sq. mt. area required per person to calculate the proposed maximum dwelling size for different income groups, to ensure healthy living conditions for all (Figs. 9 and 10).

Fig. 9 Monthly savings of the household (by Author)

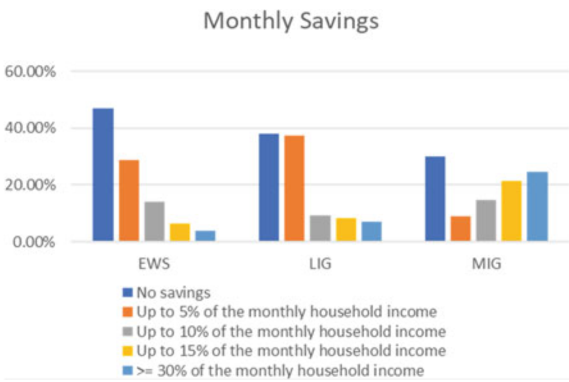
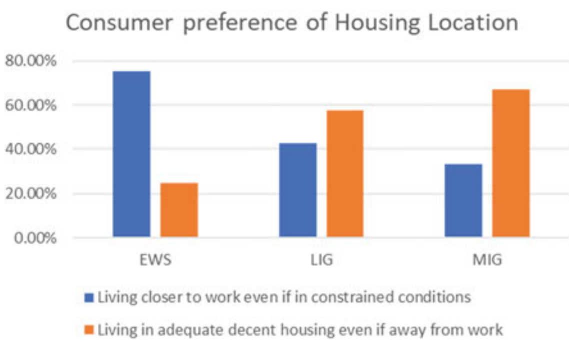


Fig. 10 Housing location preference (by Author)



Analysis: The majority of the EWS households are engaged in temporary unstable jobs and are daily wage earners. Their monthly incomes are low and savings or disposable income are negligible. Owing to their limited financial elasticity, they prefer to live in inadequate conditions closer to their workplace in order to save on travel expenses. However, the percentage of disposable income available for housing-related expenditure increases with the increasing income bracket. As a result, MIG households are more willing to live further away from their workplace and travel, as a tradeoff for better living conditions.

In order to offset the struggles and costs related to the daily commute to work, especially for the lower income groups, integrated planning, and development of the urban area need to be undertaken, which includes the provision of a robust public transport system in place to facilitate travel. On one hand, it reduces travel costs and time, and on the other, it provides a more environmentally sustainable mobility network. Parallelly, the lower income groups need to be economically boosted to upgrade their living standards. The government should undertake initiatives to create better and more stable job opportunities for the EWS category, resulting in improved household income and a higher percentage of available disposable income (Figs. 11, 12, 13, and 14).

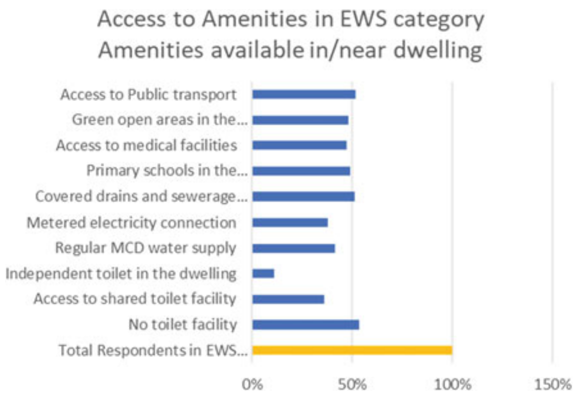


Fig. 11 Access to amenities—EWS households (by Author)

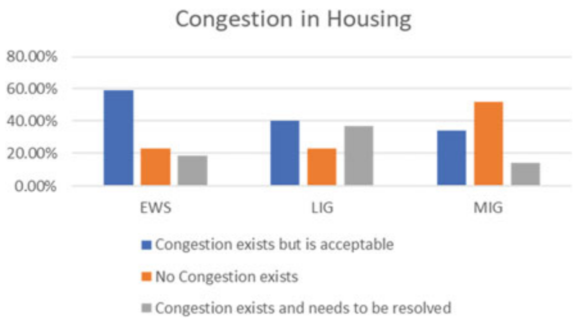


Fig. 12 Congestion in housing (by Author)

Fig. 13 Quality of construction (by Author)

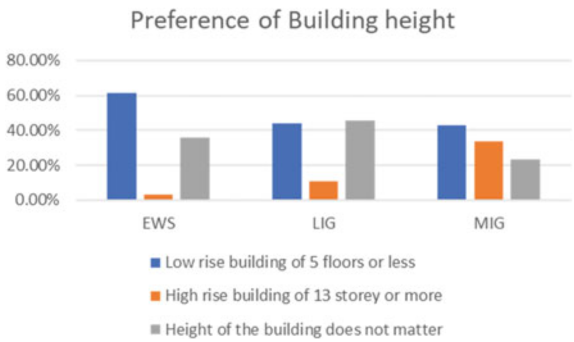


Fig. 14 Preference for building heights (by Author)

Analysis: The majority of the EWS households live in poorly constructed Kutcha or Semi Pucca houses, low-rise structures (up to 1 story) with limited access to basic amenities, and congested neighborhoods. These households have become so accustomed to living in such poor conditions that they have accepted these inadequacies as a way of life. These further translate into poor health conditions for the residents, resulting in poor performance in other areas of their lives, eventually leading to stunted national progress.

In this view, the housing policies may lay out the guidelines and the minimum acceptable standards, along with a well-detailed implementation framework, for adequate living to ensure a sustainable future for all.

Conclusions: Higher occupancy rates in dwellings, and congestion in neighborhoods, translating into higher densities, lead to stress on urban infrastructure and access to facilities by all. Affordability is often managed through compromise on unit sizes, construction quality, and provision of facilities in the neighborhood. Consequentially, consumer expectations and preferences are given the least consideration by the supply side, neither in the policies nor in the implementation and development of housing.

6 Conclusions and Recommendations

As the cities grapple with the adverse effects of rapid urbanization, it is probably time to hold and ponder—Are the cities able to meet the people's expectations of a better life and better future? Are the cities able to offer better living conditions to people as compared to their native place? And most importantly, are the current conditions in urban centers conducive to sustainable growth in the long run?

The urban population in Indian cities is a mix of different income groups which experience varied levels of housing adequacy. Out of the urban housing deficit of 18.78 million, 56% of the shortage lies in the EWS category. The learnings from the secondary case study of Savda Ghevra and analysis of the primary data collected through consumer surveys establish the existing inadequacies in the available housing options, especially for the EWS category. There exists a discord between the expectations of the demand side and the understanding of the supply side, leading to reduced efficacy of proposed housing solutions.

The UN advocates adequacy in all sectors, especially housing, to ensure holistic sustainable growth, with the target to attain the SDGs by 2030. However, the Indian housing policies are very stringent in adopting a consumer-centric approach to housing. Higher participation of the users in the development process, with a more comprehensive view of the existing housing scenario and effective implementation through robust planning is essential to ensure progress toward a sustainable future.

The diverse economic conditions, lifestyles, cultures, and preferences that exist in the social fabric need to be recognized and addressed adequately through policy. "One size fits all" is not the appropriate approach. There is a larger need to set guidelines for minimum acceptable standards of living, which are then enforced through the policy for all income groups. An index to assess housing adequacy may be developed to quantify the level of consumer satisfaction that may be expected from the occupants of the proposed housing. This could be a useful tool for government agencies and developers to assess the success of the project.

The mechanism for synchronization between different government agencies for integrated development of housing and its neighborhood, with robust infrastructure and facilities, needs to be developed for effective implementation. Affordability, Adequacy, and Accessibility being the three main pillars of housing, livability, and quality of life balanced with access to affordable housing hold the key to the social, mental, and economic well-being of society, contributing to the progress of the nation.

References

1. Habitat III issue papers 20-housing (2015) http://www.ohchr.org/Documents/Publications/FS21_rev_1_Housing_en.pdf
2. Zhang Y (2018) The credibility of slums: informal housing and urban governance in India. Land Use Policy 79:876–890. https://doi.org/10.1016/j.landusepol.2017.05.029

3. Patel A, Shah P, Beauregard BE (2020) Measuring multiple housing deprivations in urban India using Slum Severity Index. Habitat Int 101. https://doi.org/10.1016/j.habitatint.2020.102190
4. Killemsetty N, Johnson M, Patel A (2022) Understanding housing preferences of slum dwellers in India: a community-based operations research approach. Eur J Oper Res 298(2):699–713. https://doi.org/10.1016/j.ejor.2021.06.055
5. Sahasranaman A, Bettencourt LMA (2021) Life between the city and the village: scaling analysis of service access in Indian urban slums. World Dev 142. https://doi.org/10.1016/j.worlddev.2021.105435
6. Boateng GO, Adams EA (2023) A multilevel, multidimensional scale for measuring housing insecurity in slums and informal settlements. Cities 132. https://doi.org/10.1016/j.cities.2022.104059
7. Behr DM, Chen L, Goel A, Haider KT, Singh S, Zaman A (2021) Introducing the adequate housing index (AHI) a new approach to estimate the adequate housing deficit within and across emerging economies
8. Housing and the Sustainable Development Goals The transformational impact of housing (2021)
9. Gopalan K, Venkataraman M (2015) Affordable housing: policy and practice in India. IIMB Manage Rev 27(2):129–140. https://doi.org/10.1016/j.iimb.2015.03.003
10. Howden-Chapman P, Siri J, Chisholm E, Chapman R, Doll CNH, Capon, A (2017) SDG 3 ensures healthy lives and promote well-being for all at all ages
11. Urban transformation through Housing for All (2019)
12. The rising cost of housing and its impact on hunger Ontario Hunger Report (2017)
13. Analysis-Slum Population (2011)
14. Government of India Ministry of Housing and urban poverty alleviation national buildings organization new Delhi report of the Committee on slum statistics/census (2011)
15. Higgs C, Badland H, Simons K, Knibbs LD, Giles-Corti B (2019) The urban livability index: developing a policy-relevant urban livability composite measure and evaluating associations with transport mode choice. Int J Health Geogr 18(1). https://doi.org/10.1186/s12942-019-0178-8
16. Khee Giap T, Wing Thye W, Aw G (2014) A new approach to measuring the liveability of cities: the global liveable cities index. In Global Liveable Cities Index. World Rev Sci 11(2)
17. Ease of Living Assessment Framework Content (2019)
18. Final report of the expert group on quality-of-life indicators 2017 edition (2017) https://doi.org/10.2785/021270
19. Musikanski L, Cloutier S, Bejarano E, Briggs D, Colbert J, Strasser G, Russell S (2017) Happiness index methodology. J Soc Change 9(1). https://doi.org/10.5590/josc.2017.09.1.02
20. Bandyopadhyay A, Agrawal V (2013) Slums in India: from past to present. Int Refereed J Eng Sci 2(4). www.irjes.comwww.irjes.com
21. Rapid assessment for Sanitation Services 5th–12th February 2018 New Delhi Content (2018)
22. Sharadbala Joshi M, Khan S (2010) Aided self-help: the million houses programme – Revisiting the issues. Habitat Int 34(3):306–314. ISSN 0197-3975. https://doi.org/10.1016/j.habitatint.2009.11.010
23. Savda Ghevra Slum Rehabilitation Project (2011) https://cdn.cseindia.org/userfiles/Siddharth%20Pandey.pdf
24. Zuber M, Khosla C, Javed NB (2023) Housing conditions and their impact on health of residents. Eng Proc 56:46. https://doi.org/10.3390/ASEC2023-15334
25. Priyadarshini D (2017) Indian anthropological association resettling slums and slum-dwellers in Delhi: the view from Savda Ghevra 47(1), 69–84. https://doi.org/10.2307/26494016
26. Pandey (2010) Savda_Ghevra
27. Sheikh S, Banda S, Mandelkern B (2014) Planning the Slum JJC Resettlement in Delhi and the case of Savda Ghevra.
28. Wardrip K, Williams L, Hague S (2011) The role of affordable housing in creating jobs and stimulating local economic development: a review of the literature

29. https://www.youthkiawaaz.com/2019/04/a-visit-to-savda-ghevra-resettlement-colony/ Accessed 18 Aug 2022
30. https://www.academia.edu/3443446/Savda_Ghevra_Resettlement_Colony_Landscapes_of_Change_by_ARCSR Accessed 10 Dec 2022
31. https://www.wiego.org/sites/default/files/resources/file/Savda_Ghevra.pdf Accessed Aug 2022
32. UN-Habitat (2003) https://unhabitat.org/sites/default/files/download-managerfiles/The%20Challenge%20of%20Slums%20-%20Global%20Report%20on%20Human%20Settlements%202003.pdf. (The challenge of slums: global report on human settlements, 2003 / United Nations Human Settlements Programme. p. cm. ISBN 1-84407-037-9 (pbk.)–SBN 1-84407-036-0)

Impact of City Development on Artisans in the Context of Indian Cities

Renuka Kuber Wazalwar and Priti Pandey

1 Introduction

City development, worldwide, depends upon different factors like culture, traditions, beliefs, and so on. In nations like India which have complex societies, hence sustainable development of cities requires the overall thinking of the factors which directly or indirectly affect the city developments and the development of the people and communities residing in these cities. After the twentieth century, our society is getting affected significantly because of the number of social, environmental, and economic crises on a global scale. Hence [1] governments and their subsidiaries are bringing up the concept of smart cities worldwide which is again the successor of intelligent cities.

It is said that the global population residing in the city will be 66% by the year 2050. Because of this, rapid urbanization will happen and cities will face problems related to competitiveness, growth, performance, and residents' livelihood. Because of rapid urbanization deterioration of liveability challenges related to waste management, air pollution, traffic congestion, and scarcity of resources will happen which will cause concern about human health and aging public infrastructure. One of the solutions to address these issues will be the concept of a smart city. As per the name, the cities that aim to be more sustainable, equitable, efficient, and liveable will be smarter [2].

The urban components like economic, social, and political interact with each other for city making. The key to human settlement, culture, and society is the urban form which is more or less the result of urban experience. To produce and reproduce

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economic and social divisions and arrangements are crucial for the material organization of urban spaces. Hence the definition of urban forms cannot be restricted to their tangible and physical construct but also consider the understanding of the intangible aspects like social, cultural, economic, legal, and political, and their interaction with each other. The interactive environment happens due to socio-cultural and economic practices which is the outcome of society or a mix of people staying together. The urban spaces relevant to human settlement and urban context are depictions of some kind of arrangement or organization of organic pattern. This intricate urban fabric results from a complex process planned socially and economically [3].

India, one of the fastest-growing nations in the world, also witnessing fast growth in the cities. As we know that our nation is having diverse cultures, customs, and beliefs, which also give identity to our cities. These cultures, customs, and beliefs are sustained because of the local communities which are following them. The sustenance of these local communities is depending on their traditional skills. On the other hand, our fast city development emphasizes more on the physical fabric of the city. Which affect the socio-cultural, and economic need of the community [4]. These local communities are the ones who shape the culture of the cities and become the identity of that city in the world. The interaction of these communities with the surroundings, not only brings the liveability of the society but also creates financial sources which make this community base development more sustainable.

Textile weavers are also one of those artisans who are working with their rich skill sets in our cities and also supporting our exports through their vibrant and intricate weaves. In this study, the weavers and allied activity artisans are selected from Varanasi City. This city is well-known for its unique weave of brocade on silk cloth. Today there are lots of variants of this brocade design available in the market because of the advancements and creativity of these weavers. As these are old settlements of weavers who are involved in this occupation for generations, they develop their socio-cultural ties and their own economic system in their locality. Hence when new development happens, it affects the socio-cultural and economic stability of the locality. The objective of this study is to explore the effect of city development on the social, cultural, and economic development of Varanasi's weavers and people involved in allied activities.

2 Aim

To study and analyze the impact of city development on the weavers' community situated near the Ghats of Varanasi.

3 Literature Review

This literature review is done to understand the different aspects of sustainability, city developments, differences, and factors that affect the cohesive and comprehensive development of artisans in today's developing cities.

3.1 Sustainable Cities

As per the discussion done by Dingra and Chattopadhyay (2016), the cities are formed through the interaction of factors like economic, social, physical, and political urban components. Urban forms are developed due to urban experiences and interactions, which play an important role in human culture, society, and overall human settlement. These urban spaces are crucial to producing and reproducing divisions in social and economic arrangements. Hence, it's been observed that urban form requires a deep understanding of the intricate mix of economic, social, legal, and political modes of interaction and organization but it will remain incomplete without physical and tangible constructs [3].

In old cities, the transformation of space with time happens as many users use that particular space over time. As the urban context changes more quickly than the urban form hence, all urban occupations are temporary. We generally term urban design as expressive as urban spaces are formed not only by taking physical shape but also involve the personal and impersonal processes concerning the environment, political, legal, and socio-economical. Whenever a group of people come together and settle down in one place, an interactive environment is created through their social and economic practices. Most of the time these are the organic patterns depicted in the arrangement of urban spaces relevant to the human settlement which are socially and economically planned to form the intricate urban fabric through a complex process [3].

In general, in the old cities, communities have a heterogeneous mix of economic as well as social status. These communities satisfy their respective cultural needs by maintaining their social hierarchy. Hence a repetitive and continuous fabric is formed that is homogeneous and united by these diverse communities. Also, proper management of the region's creative economy is required to maintain its rich intangible heritage. In the cities, their cultural needs are generally satisfied by maintaining their social hierarchy. They have rich cultural and heritage backgrounds with a heterogeneous mix of communities in terms of economic and social status. However, these diverse communities are homogeneous and united with physical aspects like planning principles, climate-responsive architecture, and the use of locally available materials due to repetitive and continuous fabric. A holistic planning ideology that is intuitive and wholesome is shown in these traditional settlements. These societies are more inclusive, sustainable, and smart because they are guided by their spiritual values and social belief systems [3].

3.2 Community Development of the Artisans in India

India has a glorious history of artisan work and is famous for its art and craft. As per the study done by Dash [5] more than 4.1 million people are engaged in artisans' work in India as well and the amount of art products exported to other nations is also substantially large. Hence it is understood that a sizable portion of employment and contribution toward countries' wealth has been created by the artisan community. It is also been observed that these artifacts have huge demand in foreign countries and create a substantial number of foreign currencies [5].

Art and craft act as important tools for the economic development of local communities and can be considered an important aspect of sustainable development planning. In the art-based community, economic development happens with respect to practicing art which is generally considered an inherent asset of the community with exclusive skills and the individual member has the capacity to create associations and institutions within a community [5].

Even having the skill sets, it is been observed that lots of artisans migrate toward the nearby cities or even to the different states of the country. One of the biggest reasons for this migration is the absence of consideration given to the community and spatial planning in the planned development. One of the major reasons for the migration of artisans is the absence of an economic tool that can generate the required revenue at the community level. Hence guidance for the principal economic planning process is needed so that it can fabricate local community development by interlinking the locally available skills and resources to revenue-generating activities [5].

In some cases, like the handloom, which is not only the industry but also represents the cultural diversity and richness of India. As per the Handloom Export Promotion Council (HEPC) of India, in the year 2020–21, India exported handloom products of 223 cr [6]. Hence this particular industry is having greater potential and gives a greater push to the Indian economy. As per the study done by Mishra [7], in spite of having greater opportunities and the government providing help for the better development of this sector, artisans either migrated from the cities or changed their occupations to other sectors. Government campaigns like Make in India and efforts are taken by the planning commission by giving due priority to this sector to regain its original glory and identity [7].

Though the government is taking due efforts to protect and promote the handloom industries by providing different schemes and running government projects for the betterment and uplifting of the artisans, these schemes and programs are not known to the artisans and ultimately, they do not benefited from these government initiatives and their livelihood and further development get affected directly due to this [8].

3.3 Impact of Social Cohesion on the Development and Sustenance of Weavers

It is popularly believed that the sustenance of the handloom industry is only possible because of government interventions and policies. Whereas, the other viewpoint suggests that the handloom industry survived because of its adaptability to the fast-changing market needs in India and outside India, and its ability to provide unique designs and quality products with its skills. As handloom gives you the freedom of weaving a fabric with intricate designs, the machine-produced fabric cannot compete with them as machines require specific strength of the fiber to weave through machines whereas, in handloom, we can use a delicate fiber which again gives the freedom to stop and start at will and also additions at last moments [9].

Indian handloom comprises a number of steps, right from the crop collection to the final retail shop, and hence the number of people involved at these different stages. As these people work in the same handloom sector, they develop contacts with each other for smooth working, and on a large scale, they are looked like a cohesive network where each and everyone is interlinked. As discussed by Cowan and Kamath (2012), the people of same beliefs or working in the same sector in the same locality generally share their knowledge in an informal way due to which their business relations develop as a result of the social relationship [10]. And the capital that they earn through this social relationship is generally known as "Social Capital". These social networks nurture small entrepreneurs and businesses and also provide a competitive advantage. They also provide information about the resources, market needs, and even market opportunities. These closely placed social networks develop cohesive social ties in between people of having the same interests and also provide an identity to that particular community [9].

As per the observations done by Cowan and Kamath (2012), this social cohesion in some cases is also the reason for the decline of that particular cluster if the inter-relationship is not maintained with other clusters of that locality. Hence the information link between the inter-cluster needs to be formed and maintained for the overall sustenance and development of the community. In the Indian context, these relations are the driving force for the traditional technology-based industry hence, while suggesting their development these social relations need to be understood by the policymakers [10].

3.4 Social Cohesion and the Built Environment

The liveliness of the city and the social cohesion provide lots of benefits to the city and the residents of the city. As Jane Jacob argued in her book "The Death and Life of Great American Cities" in 1961, Social interaction makes the city more vibrant and liveable hence, to promote social and economic growth planners need to think about the requirements of the people living in the cities rather than following theoretical principles. As discussed by researchers Mouratidis and Poortinga (2020), the liveliness or vitality of the place can be achieved by providing the amenities or spaces which will increase the footfall of the people in that area and the usage of the space throughout the day, which will again increase the casual social interaction. This casual social interaction between the people of same interest generally gives rise to social cohesion [11].

Social cohesion is the connection between a group of people which connects them with each other through organization and networks and strengthens the efficiency of society [11]. Whereas the built environment plays an important role to maintain the social ties between the people through a simple urban feature like walkability [12, 13].

The characteristics of the built environment, like open spaces, amenities in the area, land use mix, public transport, and green spaces, and the relationship of these with social cohesion is still not explored to a great extent [11]. As discussed by Carmona [14], mixed land use works very well to foster social cohesion as these spaces provided maximum interaction of the people with each other. This could include the combination of built and unbuilt spaces or green spaces in between the houses which gives scope for community activities [11, 14].

Some researchers like Dempsey [15] mentioned in their study that, the quality of the built environment and its features influences social activity. The residents' perception of the quality and maintenance of the neighborhood influences their attachment to the place and sense of community. Whereas density has a negative impact on social interaction and further affects social cohesion [15].

3.5 Impact of Urban Development on Artisans

Cultural heritage plays an important role in shaping the community. There is a changing pattern observed where the intangible aspect of cultural heritage like traditional craft knowledge which was once lost and hard to recapture is now being preserved. Hence art and craft play a very important role in building and maintaining a sense of identity, developing tourism, and contributing to the urban and rural economy, and overall well-being of society [4].

In Indian history craft and trade concentrated in urban boundaries and played an important role in the existence of the cities. Even today some cities are known for their specialization in a particular craft. This craft gives birth to the bazaars which are even today nerves of every big or small city. One such city is Amritsar, which is one of the important cities in Punjab, having both spiritual and heritage values. This old city sprawls around the Sri Harmandir Saheb which is the holiest shrine of the Sikh community. The city has evolved for ages and has organic development with many lanes which are again enclosed in 12 gates [4].

It's been observed that the survival of any craft is based on its need in the market. In many cases, the demand for products is due to their importance and popularity in the local culture as well as among tourists. Whereas due to mass production and mechanical manufacturing techniques, some products lost their demand, and the art and craft of manufacturing these products are also lost. Technologies like computer-aided designs and a ban on some original materials also influence the process of traditional craftsmanship and transform it drastically [4].

In the Indian context, lesser emphasis is given to retaining the traditional skills in the urban conservation process which also affects the sustenance of the local communities. The conservation acts in India also talk about monuments and physical fabric which again lacs the intangible aspects of culture and communities in historical areas [4]. In most of the master plans of cities, the craft is not mentioned in the trade activities categories. Most of the development plans mentioned that less focus is given to the conservation of built heritage but there is no due attention given to the intangible heritage and also there is no mention of the policies or strategies addressing them. Because of this craft-based communities of Amritsar are shifted from the urban center to the outskirts of the city or the neighboring villages which disturbs the original fabric and identity of the city [4].

During city development, galleries were created, because of which some small craftsmen were shifted from the city center. Also, the tourism development projects are a boon for tourism, isolating the temple from the bazaars around it. In today's scenario, the plazas are created for pedestrian movement, which again restricts the interaction of the tourists or people with artisans in inner lanes. This lack of contact disconnects the age-old link between the temple and the bazaars around it [4].

The literature study suggests that the sustenance and development of the artisan community depend on major factors like socio-cultural aspects, technology, and the economy. These major factors include the sub-factors like social capital, housing, distance between the nearest available market, and interaction between the community people under the socio-cultural aspect. Under the major factor of technology, the sub-factors like technological changes from handloom to power loom, availability of cheap material, change in the traditional design because of technology, and loss of employment due to technology are considered for this study. Similarly, under economy, the sub-factors like availability of employment, ratio of supply and demand, availability of market for the products, and geographical location of the community are considered for this study.

4 Methodology

4.1 Development of Survey Instrument

The questionnaire is been developed depending on the factors identified through the literature study. The questions were related to factors including the socio-cultural aspect, technology, and economy. The respondents were asked to select the appropriate options from 1 to 5.

The draft of the questionnaire was reviewed by the experts and a pilot run for the same was taken with a sample size of 10 to investigate the reliability of the questionnaire. After running the reliability test with the help of Cronbach Alpha, the confidence factor was coming out to be 0.72, which means the survey questionnaire is reliable and can be used for the data collection.

As the respondents were not well-versed in the English language, the questionnaire was translated into Hindi language and the data was collected by running the questionnaire in the Hindi language. The questionnaire was then again translated back to the English language for analysis purposes.

4.2 Area of Survey

To run the survey questionnaire the small zone along the ghats of Varanasi was selected. This zone is inhabited by weavers and families involved in the allied activities related to textile making. Varanasi is an age-old settlement and is well-known for its textile industry. Also, it is one of the important pilgrimage centers for Hindus hence having a large footfall of pilgrims observed in this city. Varanasi is included in the first list of the Smart City Development Program, hence lots of development projects are also observed in this city. This whole situation makes a suitable environment to study the impact of these development activities on the weavers' community residing in this area for generations.

4.3 Data Collection and Analysis

To collect data from the weavers and people involved in the allied activities related to the textile industry, the cluster was selected and a questionnaire was distributed in that cluster. Over all 20 responses were received from one cluster which is considered for the data analysis. To understand the impact of the social, technical, and economic aspects on the development of the artisan's community, the collected data was analyzed through T-test to calculate the P-value. The calculation was done with the help of Excel.

Also, the documentation of the existing leaving and working conditions is also analyzed through observations and from informal discussions with artisans. The documented cluster and houses were represented through plans, sections, elevation, and photographs. The same cluster is then compared through recent Google maps and the impact of development is pointed out through observations.

5 Result

The result of the analysis of the data is divided into two parts. One is the analysis of the data collected through a questionnaire survey and the second is the data collected through documentation.

5.1 *Result of Questionnaire Survey*

To understand the effect of factors like social, technical, and economic on the development and sustenance of the artisans' community the T-Test by Pairing Two Sample for Means is carried out.

5.1.1 Effect of Economical Factor on Development and Sustenance of Artisans

To evaluate the effect of social factors on the development and sustenance of artisans, the variable considered for the T Testing under community development and sustenance is the percentage of the economy generated by the community per year (Variable 1), and under economy is the percentage of employment generated by the community per year (Variable 2).

Table 1 is showing the analysis of data received from the questionnaire with T-test and P-value is coming out as 0.002, which is less than 0.05. This also means that the community development and sustenance are dependent on the social factors.

Table 1 Shows the result of the T-test performed in Excel on effect of economical factors on development and sustenance of artisans

	Variable 1	Variable 2
Mean	25.5	28.5
Variance	2.5	5.833333333
Observations	10	10
Pooled variance	4.166666667	
Hypothesized mean difference	0	
df	18	
t Stat	−3.286335345	
P(T < = t) one-tail	0.002051596	
t Critical one-tail	1.734063607	
P(T < = t) two-tail	0.004103192	
t Critical two-tail	2.10092204	

Table 2 Shows the result of the T-test performed in Excel on effect of technological factors on development and sustenance of artisans

	Variable 1	Variable 2
Mean	1.8	1.1
Variance	1.288888889	0.1
Observations	10	10
Pooled variance	0.694444444	
Hypothesized mean difference	0	
df	18	
t Stat	1.878297101	
P(T < = t) one-tail	0.038318791	
t Critical one-tail	1.734063607	
P(T < = t) two-tail	0.076637582	
t Critical two-tail	2.10092204	

5.1.2 Effect of Technological Factor on Development and Sustenance of Artisans

To evaluate the effect of social factors on the development and sustenance of artisans, the variable considered for the T Testing under community development and sustenance is the percentage of loss of employment per year (Variable 1), and under technology is the percentage of conversion of handloom to power loom per year (Variable 2).

Table 2 is showing the analysis of data received from the questionnaire with a T-test and P-value is coming out as 0.038, which is less than 0.05. This also means that community development and sustenance are dependent on the technological factor.

5.1.3 Effect of Socio-cultural Factor on Development and Sustenance of Artisans

To evaluate the effect of social factors on the development and sustenance of artisans, the variable considered for the T Testing under community development and sustenance is the social capital generated per year (Variable 1), and the variable considered under the socio-cultural aspect is the percentage of maintaining the intercommunity relationship (Variable 2).

Table 3 is showing the analysis of data received from the questionnaire with a T-test and the P-value is coming out as 0.035, which is less than 0.05. This also means that community development and sustenance are dependent on the socio-cultural factor.

Table 3 Shows the result of the T-test performed in Excel on effect of socio-cultural factors on development and sustenance of artisans

	Variable 1	Variable 2
Mean	34	25.5
Variance	193.3333333	2.5
Observations	10	10
Pooled variance	97.91666667	
Hypothesized mean difference	0	
df	18	
t Stat	1.920771122	
P(T < = t) one-tail	0.035372449	
t Critical one-tail	1.734063607	
P(T < = t) two-tail	0.070744899	
t Critical two-tail	2.10092204	

5.2 *Field Documentation on Weavers of Varanasi*

Varanasi is the oldest living city in the world, which has a rich heritage and cultural values. In today's context, it is one of the fastest-growing cities in India and is listed under Smart City Mission. The city grows and develops over a period of time, as one of the important pilgrimage and handloom centers, this development affects the city dwellers on different levels.

To understand the effect of development on the people involved in weaving and allied activities, the different mohallas around the ghats were selected. The places and houses identified which are involved in weaving and activities related to it. Their working and living spaces were documented to understand their interaction with their surrounding and also how surrounding development affects their working and living conditions.

The following map shows the area around the Dashaswamedh Ghat and the Kashi Vishwanath temple with landmarks and major approaches to the Temple (Figs. 1 and 2).

In the selected Mohalla, there are lots of houses involved in weaving, dying, and embroidery activities, out of which some houses were selected for documentation. The weaving starts with the supply of raw material which is yarn, supplied by the yarn supplier. In this case, the yarn suppliers are the ones who are having shops in the marketplaces near the temple area. These suppliers not only supply yarn but also give the design for weaving and accordingly weavers weave the cloth. As per design requirements, the cloth then goes for dying, or for embroidery, or both. The final finished cloth then goes to the shop for sale.

The following map (Fig. 3) shows the hoses which are involved in weaving, dying, and embroidery work.

The documentation of these selected houses was done and plan sections and elevations were made to understand their working and living spaces. It has been

Fig. 1 Map of Varanasi showing the area near Dashashwamedh Ghat. *Source* Author 2017

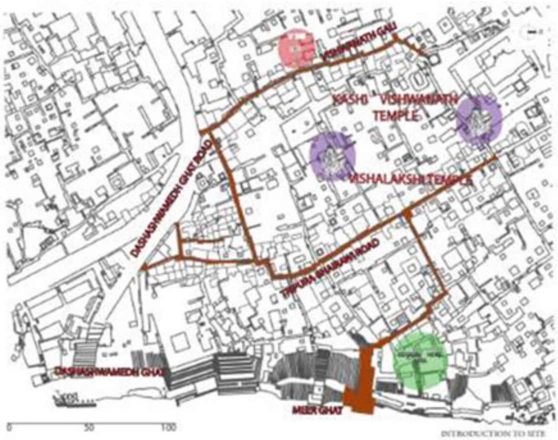


Fig. 2 Map of Varanasi showing the landmarks around Kashi Vishwanath Temple. *Source* Author 2017

observed that these people have dynamic spaces that can be transformed per their needs. The courtyard which is used for daily household activities like seating, drying, household working, etc., gets transformed into a working space for dying activity. Likewise, the family room gets transformed into a preparation room for the dyes and patterns, and so on (Fig. 4).

The above section shows how the spaces are being used for different activities. Blue color spaces are used for residential activities, and yellow color spaces are used as the working areas whereas pink color space is used for selling activities. The following photographs show the process of dying. The process starts with making motives on cloth (Fig. 5) and putting wax as per the design (Fig. 6). Then this cloth is soaked in the dye (Fig. 7). Once the cloth is dyed the wax is been removed and the cloth is allowed to dry (Fig. 8).

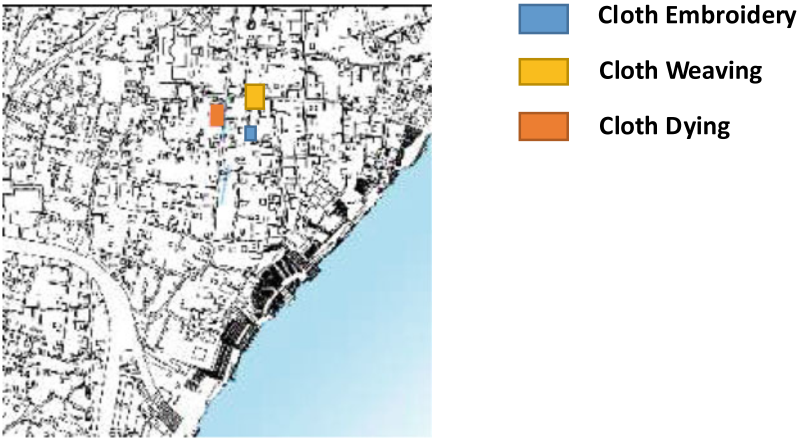


Fig. 3 Plan of the selected Moholla. *Source* Author 2017

Fig. 4 Section showing the different spaces used for different activities. *Source* Author 2017

Fig. 5 Show the process of waxing in cloth dying. *Source* Author 2017

Fig. 6 Show the process of cloth dying. *Source* Author 2017

Fig. 7 Show the cloth washing in dying process. *Source* Author 2017

The other house was selected in the same Mohalla which is engaged in weaving activity. In this house, the ground floor is utilized for weaving activity, whereas the upper floors are utilized for residential purposes. Documentation of the house is done and represented through the plan and section below in Figs. 9 and 10.

The other spaces on the ground floor of the house are utilized for the storage of raw materials and finished goods. The finished cloth is either sent to the dying process or for the embroidery work as per the design requirements (Fig. 11).

Another house in the cluster is selected which is involved in embroidery activity. The leaving room of the house is utilized for embroidery activity and depending on the quantum of work the semi-open area of the house is also converted into the

Fig. 8 Show the cloth drying in dying process. *Source* Author 2017

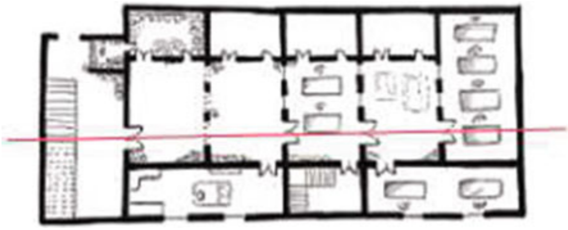


Fig. 9 Plan of house having weaving activity. *Source* Author 2017

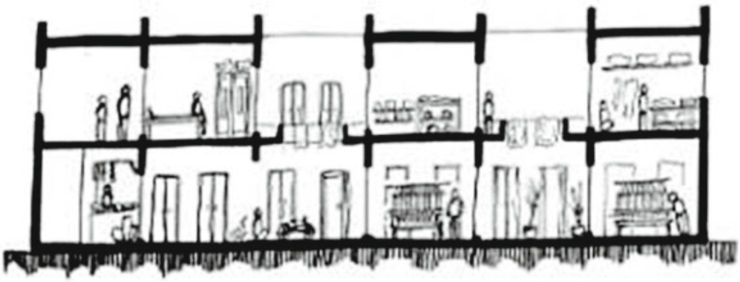


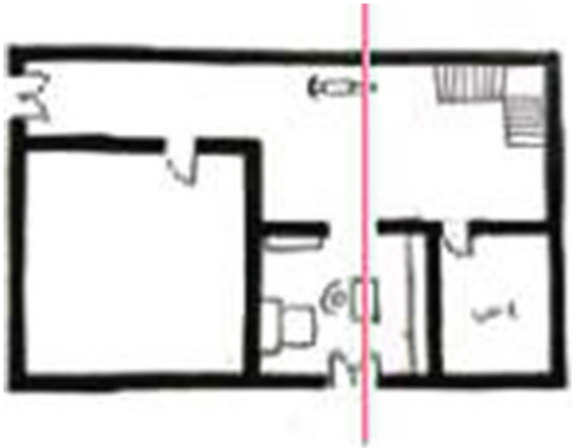
Fig. 10 Section of house having weaving activity

working area. Documentation of the house is done and represented through the plan and section below in Figs. 12, 13, and 14.

It's been observed that all these houses are arranged in a small cluster that also has common spaces. The families residing in these clusters are involved in different activities, some are related to each other and some are not. The open space in between is used as community spaces for their informal activities, and celebrations, as well as common workspaces. One such plan of a small cluster is shown in Fig.15.

Fig. 11 Cloth weaving in process. *Source* Author 2017

Fig. 12 Plan of the house having embroidery activity. *Source* Author 2017



During this documentation done in 2017, it's been observed that these clusters are the most sustainable way of development as it develops not only a sense of belongingness but also helps to develop social capital which makes them economically viable as well. But as development happens around the Ghats this community setup is been disturbed and the inhabitants have to move out of the place. As these communities work based on their interdependency, if they are moved out of the place, their community ties weaken and it directly impacts their economic development. The following Google map shows the newer development along the Ghat which disturbs the original cluster setup.

Figure 16 shows the development that happened along the Ghats of Varanasi in the year 2019 and Fig. 17 shows the selected area for documentation in 2017. From these maps, it is clear that the development impacted the original setup of communities along the Ghats and affected social cohesion.

Fig. 13 Section of a house having embroidery activity

Fig. 14 Artist doing embroidery work

6 Observations and Conclusion

Corresponding to the statistical data received it's been observed that the sustenance and development of the weavers community depends upon the socio-cultural, technological, and economic factors. Pertaining to the correlation between the community development factor, the economy generated by the community and the economic factor, generation of the employment is established with the help of the P-value, which is coming less than 0.05. Hence the confidence level of this correlation is

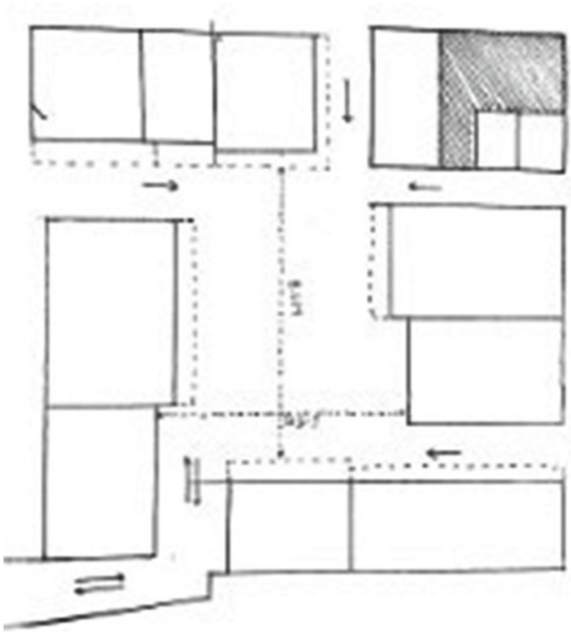


Fig. 15 Plan of a small cluster. *Source* Author 2017

Fig. 16 Shows a Google map of 2019 of the area around Ghat with development happening in area selected for documentation. *Source* Google Earth Pro

more than 95%. This also can be considered in a way that the community generates its economy through its social ties and connection and which further generates employment as well.

When the same method was utilized to test the relationship between community development and the effect of technology on the factor's conversion from handloom to power loom under the technological aspects and the loss of employment under the community development aspect. The confidence level is again coming to more than 95% which means the sustenance of the textile weavers' community also gets affected by the technology that they use. If the technology is used for the betterment

Fig. 17 Shows a Google map of the area documented in 2017 with the area selected for documentation. *Source* Google Earth Pro

and development of the community then it will not only increase the sustenance of the community but also will retain its identity.

The interaction between the community members to support each other under the socio-cultural aspect and the economic benefits that the community gets through their ties with each other under the community development aspect, when the correlation between these two aspects where studied the confidence level comes more than 95%. This also means that the community ties between the community members give the additional benefit to grow together. Hence, the socio-cultural aspect also affects the development of the community and sustenance.

With all this statistical study, when we see the ground reality through the documentation of the small cluster near Kashi Vishwanath Temple, it is been observed that the identified factors are clearly applicable to the selected cluster. The different community members residing in the same cluster with their own socio-cultural ties, technology, and economy complete the process of weaving until the final product. However, when it is compared with today's condition of the cluster, maps clearly show that the complete setup is been destroyed because of the development of the Kashi Vishwanath Corridor.

The Kashi Vishwanath Corridor was developed under the Central Government Scheme, HRIDAY (Heritage City Development and Augmentation Yojna). This scheme is for development of the heritage cities across India. This scheme also provides the guidelines for city development, which are heritage cities and included in the HRIDAY. The guidelines for this scheme talk about all physical aspect of the city but the cultural aspects related to the intangible knowledge of the craft posed by the artisans is not considered. Hence through this study, we see the development along the Ghats of Ganga, considerations toward the social, cultural, economic, and built requirements of the communities residing along it, are not taken care of by the authorities.

This study will help the planning authorities to take an inclusive approach considering the specific requirements of the old communities residing in the heritage cities like Varanasi. The factors which are discussed in this study and their impact on the sustenance and development of the communities can be considered at the time of developing the new policies and projects for the cities.

7 Future Scope

In this study, the selected factors are been studied and their interdependencies analyzed with the help of the P-value. The same can be analyzed with the help of other statistical tools. This study also focused on the sustenance and development of weavers and the people involved in the allied activities related to textiles and the effect of city development on their built environment, but the same method can also be utilized to study the impact of city development on other communities as well. Research can also be done on the barriers which are affecting the sustenance and development of the artisans in urban areas and ascertain the hierarchy of these barriers. Further, the effect of city development policies on the sustenance and development of different stakeholders of the city should also be studied.

References

1. Evelin PT, Marcus PFH, Eduardo MC, Jamile SM, Rogério CB, Tan Y (2017) Sustainable development of smart cities: a systematic review of the literature. J Open Innov: Technol Mark Complex
2. Toli AM, Murtagh N (2020) The concept of sustainability in smart city definition. Front Built Environ
3. Mani Dhingra SC (2016) Advancing smartness of traditional settlements-case analysis of Indian and Arab old cities. Int J Sustain Built Environ
4. Jigyasu N (2017) Impact of urban transformations on traditional crafts skills: Amritsar's historic core. In: International council on monuments and sites, 19th general assembly and scientific symposium, Heritage and Democracy
5. Dash DPK (2015) Tourism and community development-a study on handicraft artisans of Odisha. Int J Innov Educ Res 03–03
6. H.E.P.C. HEPC, Export scenario, Ministry of Textiles, Govt. of India, 2015–2021
7. Mishra N (2019) Livelihood creation for handloom weavers through 'unique recognition in global market'–a case study of Banaras brocades and sarees. Texila Int J Manage
8. Sushmita Singh PRK (2018) Handloom entrepreneurship & government intervention-a case study of Varanasi. Pac Bus Rev Int 10(9)
9. Bhagavatula S (2009) Weaving social networks. VRIJE Universiteit, Amsterdam
10. Robin Cowan AK (2012) Informal knowledge exchanges under complex social relations. In: UNU-MERIT working papers, Maastricht Economic and social Research Institute on Innovation and Technology, ISSN 1871-9872
11. Kostas Mouratidis WP (2020) Built environment, urban vitality and social cohesion: do vibrant neighborhoods foster strong communities? Landsc Urban Plan 204, 103951. www.elsevier.com/locate/landurbplan Published by Elsevier B.V.
12. Hippi. J. R. Butts. C. T. Nagle. N. N. &. Smith. E. J. A. Boessen (2018) The built environment, spatial scale, and social networks: do land uses matter for personal network structure? Environ Plan B: Urban Anal City Sci 45(3), 400–416. https://doi.org/10.1177/2399808317690158

13. Larnihan. V. Cochrane. T. &. Davey. R. S. Mazumdar (2018) The built environment and social capital: a systematic review. Environ Behav 50(2), 119–158. https://doi.org/10.1177/0013916516687343
14. Carmona M (2019) Place value: place quality and its impact on health, social, economic and environmental outcomes. J Urban Des 24(1), 1–48. https://doi.org/10.1080/13574809.2018.1472523
15. Dempsey N (2008) Does quality of the built environment affect social cohesion? Proc Inst Civil Eng Urban Des Plan 161(DP3), 105–114

Land Value Uplift Maps for Sustainable Urban Planning—A Digital Twin Approach

Sumant Sharma, Deepak Bajaj, and Raghu Dharmapuri Tirumala

1 Introduction

The sustainable development goals adopted by the UN member states in 2015 envisage peace and prosperity for people and the planet under a strategic blueprint comprising 17 goals at its heart. Goal 11 emphasizes the sustainable growth of urban settlement ensuring, affordable housing, and sustainable transport with a strong emphasis on sustainable human settlement planning and management in all countries highlighted under target 11.3 [1]. As the urban population grows, a lot of natural land cover is converted into hardscape to provide for the requirement of infrastructure and services. Increasing misuse of land resources is leading to desertification and land degradation; prioritizing individual needs over community is a threat to the sustainable use of land resources leading to its overexploitation and jeopardizing ecosystem services [2]. World health organization indicated that all the resources shall be utilized most efficiently, to achieve economic benefits [3]. Economic sustainability ensures long-term economic growth without compromising social, environmental, and cultural aspects leading to the overall sustainability of the cities [4]. Land is the most basic resource in urban areas and sustainable land management is a step forward in providing full economic benefit and equitable distribution of rewards to society. It deals with the efficient, acceptable, and sustainable land use distribution [5]. Modern planning systems also advocate a participatory planning approach where the stakeholders are involved in the proposal, evaluation, and finalization of development proposals so that the needs of the community are met without compromising on other urban systems. However, such schemes are developed with a perspective of 20 years and implementation is a time-intensive exercise and there are

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poor mechanisms of feedback to evaluate the scheme after implementation [2]. Moreover changes in technologies (Mobility, Real-Estate and Market) during perspective plan time are seldom considered making it a reactive approach only.

Need For Study: Modern technology has a major role to play in achieving sustainability by enabling process optimization, transparency, processing of data, and generation of behavioural patterns. Projections of future urban scenarios depend on growth patterns based on past data; it involves generating urban indices to predict future development [6, 7]. Digital Twin (DT) technology is one such approach which can generate behavioural patterns based on past data. Since urban areas are influenced by many parameters across various disciplines, it is difficult to accurately understand the impact on each stakeholder. Since digital twins can simulate multiple parameters simultaneously and can generate informative indices therefore their application to various aspects of urban planning needs to be explored. Among various indicators of urban sustainability, land prices are one of the leading indices of the urban local market, and data related to land values can bring insights into achieving economic sustainability [8].

Since the Brundtland Commission defines sustainability as satisfying the current needs without compromising on the needs of the future generation, this article emphasizes the integration of economic aspects related to planning, development, and management of urban areas to achieve overall sustainability [9]. The latest research articles related to sustainable urban planning, urban economic sustainability, and the digital twin approach were referred to build up the argument emphasizing the role of the digital twin approach in generating land value uplift maps for sustainable urban planning. Further sections of this article highlight the method adopted and the representation of results followed by a discussion on the impact of planning interventions on land values and the use of digital twin technology to generate land value upliftment maps.

2 Literature Review

The concept of a digital twin city was first proposed in 2017 and applied in construction to improve efficiency and monitoring of processes. Again in 2017, this concept was introduced as an urban virtual platform based on the Internet of Things (IoT) which can simulate and replicate changes happening in real cities. The main purpose was to achieve sustainability and improve the resilience of cities [10]. It had its basis in the information Mirrored Space Model introduced by Prof. Michael Grieves in the year 2002 [11] to set up a project life cycle management centre at the University of Michigan. Since then, the concept of the digital twin has been widely accepted and explored in its application in different domains like manufacturing, automobile, space exploration, building construction, urban interventions, etc.

The digital twin approach has been applied to urban scenarios where dynamic replicas of cities are generated in the cyber world. Such city twins map the complex dynamics of urban systems [10, 12, 13] and generate indices to help policy decisions at the urban level. Such digital cities are in connection with real cities and are constantly being updated with new information packages. With the help of a large volume of data collected, such twins can develop patterns and timelines thus helping planners and policymakers visualize future projections. This approach is new, and its application is recently being explored in different arenas of urban interventions. Singapore has developed a digital city system to facilitate climate change adoption and overall energy optimization [14]. Land on the other hand is mostly valued for economic benefits; however, non-market valuations are also critical for decision-making considering sustainable development goals. Studies [15] have indicated the need for an increased effort to capture the value of land and land-based ecosystems for a comprehensive understanding of their total economic value. Urban planning can greatly benefit from the use of the digital twin approach as it can assist during the proposal stage [16, 17]. It will lead to increased awareness and investment in sustainable development scenarios.

3 Methodology

This study intends to explore the potential use of the digital twin approach for practising sustainable urban planning therefore exploratory and qualitative research methods were adopted. Further, the most frequently adopted method for exploratory research is the study of existing literature and case examples [18, 19]. Therefore, a systematic search in reputed academic databases was performed. The flow diagram in Fig. 1 indicates the flow of the process.

The Web of Science is one of the oldest databases and it is extensively referred to for social sciences research. Recent articles related to digital twins and their application in urban studies were systematically searched in the Web of Science Database using a pre-defined set of keywords. The set of keywords was formulated using a study of a few articles around the application of the digital twin approach in urban studies.

4 Data and Results

Recent studies discussing the literature and application of digital twin technology in urban interventions were systematically searched in the Web of Science database using the following set of keywords:

Digital Twin OR Urban Land OR (Title) and Planning interventions OR Urban Planning OR Land Value (Topic) and Valuation OR price OR Appraisal OR values (Title).

The initial search returned 119 articles which were further subject to scoping review leading to the most relevant set of 41 articles. These articles were considered

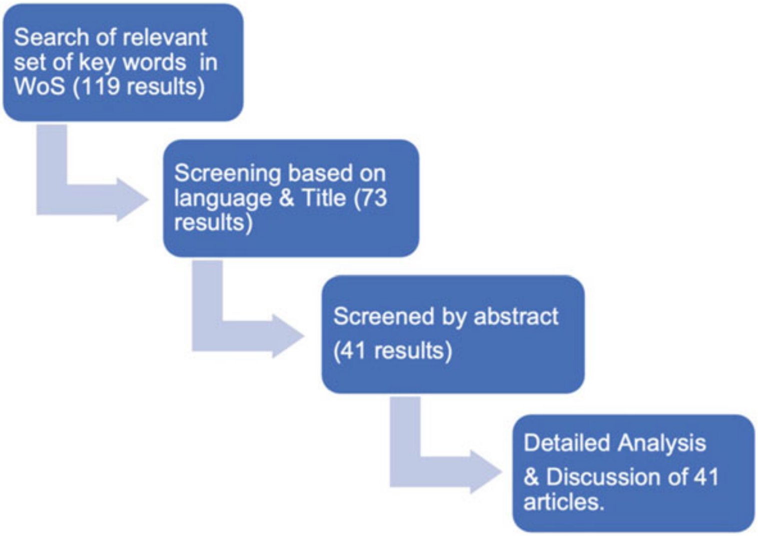

Fig. 1 Methodology. *Source* Author's computation

for building up arguments around the application of the digital twin approach for sustainable urban planning.

5 Discussions

5.1 Land Market, Value, and Planning Interventions

The land is the basis of all development, and it is a building block for the local market. It is also an important indicator of urban scenario, the understanding of determinants of land will help understand the local economy thereby leading to achieving economic sustainability [8]. There is a continuous demand for land in urban areas to provide infrastructure and services [20, 21]. Supply of land for urban development projects can be achieved through various methods like Land Acquisition, Land Assembly, Pooling, Consolidation, and Reconstitution of Land. For several urban development projects, the state is using the Land Acquisition method under the provision of LAA in most parts of the world [22], however, poor valuation and inadequate compensation are the major reasons for litigation causing a skewed supply of urban land for development. Modern planning systems governing spatial development and land markets suggest that the economic value of land is determined by its best use. With the modern systems of valuation, the value of land correlates well with the allocated land use during land-use planning practices and planning permissions thereon [7, 23, 24]. Along similar lines, scenario planning is a systematic way of evaluating the alternative scenario assuming a specific policy/development decision is taken thereby removing speculative elements in the initial planning development process. Several examples are available indicating the impact of such planning proposals and development on the value of land [25]. Periodic development of infrastructure via planning proposals develops positive or negative sentiments in the land market thereby informing land values [20]. During the participatory planning approach, the economic value of land along with the demerits are collectively discussed with all the stakeholders before the implementation of any development schemes. However, such a system competently depends on the understanding and quantification of the benefits and drawbacks of the attributes [26–28]. Conventional systems of urban development calculation are emphasizing the project-related yields and economic efficiencies of the initial funding and selling prices[29, 30]. However, in recent developments, public goals are being transferred into economic values therefore the planning proposals are calculated based on the customized tools created for the purpose. However, such a method lacks the authenticity of calculations of attributes to value [31–33].

Valuation systems based on developing the cost of infrastructure do not account for the value of ecosystem services where the degree of diversity and chances of conserving certain species are critical [34]. Each domain of rationality informs land value in its aspect; however, any proposed intervention affects all rationalities of the given urban system, therefore the recommendations must be holistic in nature. There are studies indicating the use of the multicriteria decision-making approach as an alternative to cost–benefit analysis to include the economic and non-market value of land and land-based ecosystems [2]. MCDA approach helped policymakers to make decisions benefiting the community as a whole, however, it has limited decision-making capacity restricted to the aspects included initially. As modern technology based on Artificial Intelligence has expanded its horizon with the help of big data collected by multiple devices, the use of new technology with a holistic approach is inevitable.

5.2 Digital Twin Approach and Urban Interventions

The digital twin concept has gained increased attention recently in the domain of urban development to understand and prepare for mitigating the impact of climate change [10, 12]. The digital twin approach has been successfully adopted by industries like manufacturing, aerospace, etc. A digital twin is a system of connecting a real-world system to a virtual world system through bi-directional communication making the latter a dynamic representation of the real world [12]. This approach requires the transfer of data (with or without human intervention) followed by qualitative and quantitative analysis to gain insights and thus support the decision-making process. Figure 1 indicates a basic flow diagram on the working of a digital twin.

Studies across industry and academia have highlighted potential benefits offered by the digital twin approach in fast-forwarding timelines and helping decision-makers visualize the impacts of present-day decisions [12, 13]. The definition of a digital twin city was first introduced in 2017, it was based on IT systems of identification, perception, communication, processing, and intelligent control [10]. Urban systems are complex and they envisage interventions that impact the land, environment, culture, social setup, and economic systems in such a way that aims to achieve better conditions. A large amount of data related to different aspects of urban space utilization helps computer-generated models to predict urban patterns and their interdependencies thereby enabling a realistic future prediction [12, 13]. Later improvements to digital city twins included more accurate controls based on the Internet of Things (IoT) [35] and information modelling. It collects real-time data from the environment, traffic, and other urban systems, This data is precisely mapped and run through pre-defined algorithms to generate meaningful insights that further help policymakers to make relevant decisions. These algorithms are developed based on the study of individual parameters in an urban system and based on the working of Artificial Intelligence technology such systems continuously learn [35] from the pattern in the physical city thereby generating meaningful insights for decision-making.

The use of such technologies has recently been found in certain parts of the world, Virtual Singapore [10] is a digital twin which collects data regarding solar exposure and helps to locate the urban heat island effect. Urban heat island locations are plotted on the digital model of the city along with the remedial measures thereby critically analysing the effectiveness of the measures. Digital twin technologies can help greatly in scenario planning where possible scenarios for urban planning problems can be addressed and the likely impact on the other urban systems can be looked into [12, 13]. The quality of life of habitants of the city can be greatly improved with informed and holistic decision-making supported by insights from the digital twin of the city. Boston Planning and Development Authority (BPDA) is analysing the impact of new development in line with the common shadow law. Similarly, Beijing, Shanghai, South Korea, etc., are using this technology to improve the quality of life in urban areas [10]. Table 1 indicates some of the applications of digital twin technology for urban development.

The application of digital twin technologies in urban areas as mentioned in Table 1 indicates the diversity of this approach and its potential to transform urban areas. Since the DT approach is a computational approach based on the data, therefore the collection of data from the physical city is the key component, it promotes the convergence of government and industry data with spatiotemporal data received through IoT devices [35]. In addition to many other applications of the digital twin of a physical city, it can generate land value upliftment maps as part of scenario planning to evaluate the financial viability of planning interventions. The flow diagram in Fig. 2 indicates the process and working of the digital twin:

The digital twin of a city shall virtually implement the planning intervention and simulate its impact on land values using automated land valuation models. The future value after planning interventions shall be calculated with the help of automated valuation algorithms comprising the actual data of change on amenities concerning each parcel of land [45–47]. Since the automated valuation model will be based on Artificial Intelligence [48–50] therefore continuous input from the physical city will

Table 1 Applications of digital twin approach in urban scenarios

Digital twin application in urban scenarios	References
Energy optimization, urban heat island, and forecasting floods for the city of Singapore	[14, 36, 37]
Urban shadow analysis to analyse new development for effective compliance to common shadow law of Boston	[38]
Identification of virtual visiting preferences for decision-making in Beijing	[39]
Introduction to the concept of fused twin based on the combination of DT and FT for smart cities	[40]
Digitation and land records management for effective land management in South Korea	[17]
Logistics for urban mobility planning	[41]
Understanding travel behaviours to develop an intelligent transportation system for effective planning	[42]
Building integrated solar chimneys for optimizing energy efficiency	[43]
Augmentation of planning, infrastructure, industrial, and public services system using digital twin approach for optimization and efficiency in Xoing'an Area China	[44]

Source Author's computation

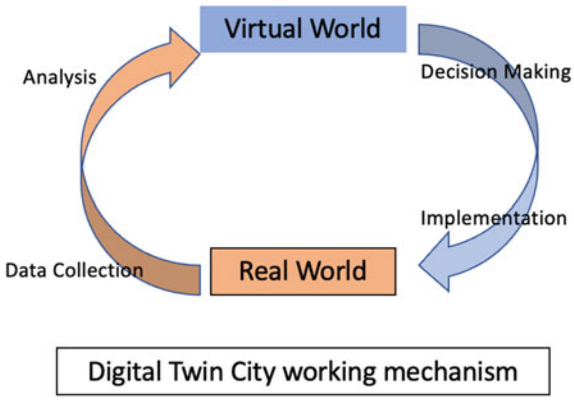

Fig. 2 Digital twin working mechanism. *Source* Author's computation

improve its accuracy. It is established [45–47, 51] that externalities generated due to planning interventions change the value of land in the immediate context thereby having an impact on the economic sustainability of the urban areas.

5.3 Policy Implications

Information on land values, when mapped, is critical to effective decision-making in spatial systems such as urban development financing, property taxes, and formulation

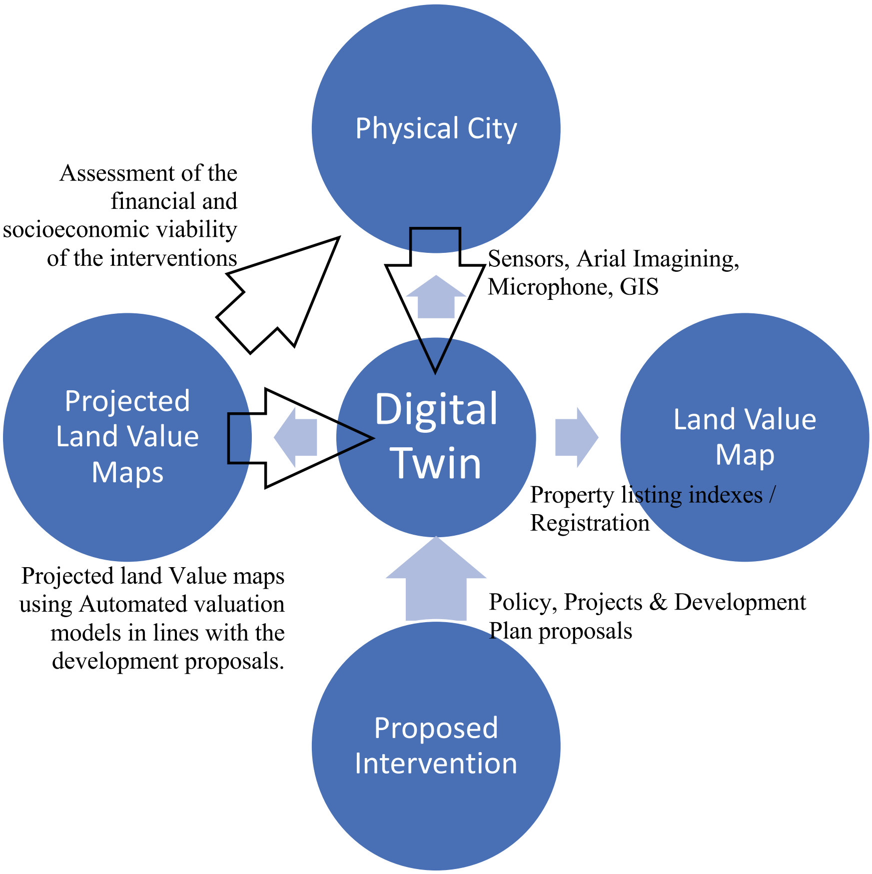

Fig. 3 Working diagram of digital twin for sustainable urban planning. *Source* Author's computation

of policies for tenure rights [47, 52, 53]. A digital twin approach shall be able to generate land value maps before and after planning interventions and will provide insights about the financial viability of the interventions. With a large amount of data and continuous learning a twin model will be able to suggest scenarios for the equitable distribution of urban resources and policy interventions can be made to achieve the desired sustainability goals.

6 Conclusions

This paper aims to propose a digital twin-based approach to generate land value upliftment maps for sustainable urban planning practices. It is established that sustainable development goal 11 is closely associated with the management and governance of urban areas. Contemporary planning practices consider the economic value of land to practise land-use planning interventions. Value estimates consider land-based ecosystems to understand the total economic value to the community. Land value change as a consequence, is one of the critical indicators of urban sustainability to the extent that it can inform policy decision-making. The digital twin-based approach has the potential to consider diverse urban parameters collectively. Holistic insights obtained from the digital twin of a city/urban area can help in achieving sustainable development goals. There are growing examples of the application of the digital twin approach across many cities to identify key components of urban systems for decision-making. A digital twin approach supported by an automated land valuation system will provide land value upliftment maps based on different planning scenarios. It will ensure critical evaluation of scenarios thereby enabling equitable distribution of resources. This is a step towards providing liveable and self-sustained communities to achieve sustainability goals.

Limitation: Like most of the AI-based models a digital twin approach is also a data-intensive approach and the quality of data will have much impact on the results projected therefore its application to thin and opaque markets shall done with much caution. Also, a detailed study of interventions with real-time data will provide more confidence in adopting a DT approach for urban planning practices.

Future Scope of the Study: A digital twin can collate multiple urban parameters simultaneously and can generate meaningful incites, therefore its application may be explored for other aspects of planning practices as well.

References

1. Goal 11 | Department of Economic and Social Affairs, https://sdgs.un.org/goals/goal11
2. Stewart N (2015) The value of land: report
3. Wu X, Zhi Q (2016) Impact of shared economy on urban sustainability: from the perspective of social, economic, and environmental sustainability. Energy Procardia. 104:191–196. https://doi.org/10.1016/j.egypro.2016.12.033
4. Ghaffar MMAA, El Aziz NAA (2021) Urban form and economic sustainability in housing projects. J Eng Appl Sci 68:1–16. https://doi.org/10.1186/S44147-021-00032-W/TABLES/4
5. John C (2004) The land use planning system
6. NITI Aayog (2021) Reforms in urban planning capacity in India. New Delhi
7. Mohanty PK (2016) Financing cities in India : municipal reforms, fiscal accountability and urban infrastructure
8. Fitzgerald M, Hansen DJ, McIntosh W, Slade BA (2020) Urban land: price indices, performance, and leading indicators. J Real Estate Financ Econ 60:396–419. https://doi.org/10.1007/s11146-019-09696-x
9. Simon D (2016) Rethinking sustainable cities

10. Digital Twin Cities (2022) Framework and global practices
11. Grieves M, Vickers J (2016) Origins of the digital twin concept. Florida Inst Technol 8:3–20
12. Shahat E, Hyun CT, Yeom C (2021) City digital twin potentials: a review and research agenda
13. Botín-Sanabria DM, Mihaita S, Peimbert-García RE, Ramírez-Moreno MA, Ramírez-Mendoza RA, Lozoya-Santos JD (2022) Digital twin technology challenges and applications: a comprehensive review
14. Singapore's journey towards a nationwide digital twin | GIM International. https://www.gim-international.com/content/article/singapore-s-journey-towards-a-nationwide-digital-twin
15. Arowolo AO, Deng XZ, Olatunji OA, Obayelu AE (2018) Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria. Sci Total Environ 636:597–609. https://doi.org/10.1016/j.scitotenv.2018.04.277
16. Ferré-Bigorra J, Casals M, Gangolells M (2022) The adoption of urban digital twins. Cities 131:103905. https://doi.org/10.1016/j.cities.2022.103905
17. Park J, Choi W, Jeong T, Seo J (2023) Digital twins and land management in South Korea. Land Use Policy 124:106442. https://doi.org/10.1016/j.landusepol.2022.106442
18. interviews—Research-Methodology. https://research-methodology.net/research-methods/qualitative-research/interviews/
19. Intner SS, Lazinger SS, Weihs J, Hsieh-Yee I (2010) Basic research methods for librarians
20. de Vries WT, Voß W (2018) Economic versus social values in land and property management: two sides of the same coin? Raumforschung und Raumordnung | Spatial Research and Planning 76. https://doi.org/10.1007/s13147-018-0557-9
21. Soni A, Nanda T (2019) Experiments of urban land supply and development: India
22. Mittal J, Kashyap A (2015) Real estate market led land development strategies for regional economic corridors—a tale of two mega projects. Habitat Int 47:205–217. https://doi.org/10.1016/j.habitatint.2015.01.026
23. Stewart N (2015) The value of land : prosperous lands and positive rewards through sustainable land management
24. Mirzabaev A, Nkonya E, von Braun J (2015) Economics of sustainable land management. Curr Opin Environ Sustain 15:9–19. https://doi.org/10.1016/J.COSUST.2015.07.004
25. Rodas JMC, Gómez JMN, Castanho RA, Cabezas J, Gomez JMN, Castanho RA, Cabezas J, Gómez JMN, Castanho RA, Cabezas J (2018) Land valuation sustainable model of urban planning development: a case study in Badajoz, Spain. Sustainability (Switzerland). 10:1–18. https://doi.org/10.3390/su10051450
26. Risbud N (2019) Land pooling policies in selected Indian states. SPACE 23:15–56
27. Bhide S, Gupta DB, Nandi T, Sethi DV, Jain N, Gupta S, Singh R, Evaluation and review of land pooling and development models for Delhi
28. Mathur S (2013) Use of land pooling and reconstitution for urban development: experiences from Gujarat, India. Habitat Int 38:199–206. https://doi.org/10.1016/j.habitatint.2012.06.007
29. Lse (2009) Urban land markets and policy failures Discussion paper
30. Irwin EG, Bockstael NE (2004) Land use externalities, open space preservation, and urban sprawl. Reg Sci Urban Econ 34:705–725. https://doi.org/10.1016/j.regsciurbeco.2004.03.002
31. Reinert J (2021) Valuation accuracy across Europe: a mass appraisal approach. J Prop Res 38:25–47. https://doi.org/10.1080/09599916.2020.1837209
32. Garmon FW (2020) Population density and the accuracy of the land valuations in the 1798 federal direct tax. Hist Methods 53:1–10. https://doi.org/10.1080/01615440.2019.1678444WE-SocialScienceCitationIndex(SSCI)WE-Arts&HumanitiesCitationIndex(A&HCI)
33. Dey Biswas S (2019) Land acquisition and compensation in India: mysteries of valuation
34. Fitzgerald M, Hansen DJ, Mcintosh W, Slade BA, Urban land: price indices, performance, and leading indicators. https://doi.org/10.1007/s11146-019-09696-x
35. Minerva R, Lee GM, Crespi N, Digital twin in the IoT context: a survey on technical features, scenarios, and architectural models
36. Can Digital Twins Transform Singapore's Built Environment?—Eden Strategy Institute. https://www.edenstrategyinstitute.com/2021/08/04/is-digital-twin-technology-the-key-to-transforming-singapores-built-environment-industry/

37. Singapore experiments with its digital twin to improve city life. https://www.tomorrow.city/a/singapore-experiments-with-its-digital-twin-to-improve-city-life
38. 3D GIS Helped Boston Create a Digital Twin. https://www.esri.com/about/newsroom/blog/3d-gis-boston-digital-twin/
39. Zhang Y, Li Y, Zhang E, Long Y (2022) Revealing virtual visiting preference: Differentiating virtual and physical space with massive TikTok records in Beijing. Cities 130. https://doi.org/10.1016/j.cities.2022.103983
40. Grübel J, Thrash T, Aguilar L, Gath-Morad M, Chatain J, Sumner RW, Hölscher C, Schinazi VR (2022) The Hitchhiker's guide to fused twins: a review of access to digital twins in situ in smart cities
41. Belfadel A, Hörl S, Tapia RJ, Politaki D, Kureshi I, Tavasszy L, Puchinger J (2023) A conceptual digital twin framework for city logistics. Comput Environ Urban Syst 103:101989. https://doi.org/10.1016/j.compenvurbsys.2023.101989
42. Feng H, Lv H, Lv Z (2023) Resilience towarded digital twins to improve the adaptability of transportation systems. Transp Res Part A Policy Pract 173:103686. https://doi.org/10.1016/j.tra.2023.103686
43. Tariq R, Torres-Aguilar CE, Xamán J, Zavala-Guillén I, Bassam A, Ricalde LJ, Carvente O (2022) Digital twin models for optimization and global projection of building-integrated solar chimney. Build Environ 213:108807. https://doi.org/10.1016/j.buildenv.2022.108807
44. Liu C, Tian Y (2023) Recognition of digital twin city from the perspective of complex system theory: lessons from Chinese practice. J Urban Manag 12:182–192. https://doi.org/10.1016/j.jum.2023.04.001
45. Perveen S, Yigitcanlar T, Kamruzzaman M, Hayes J, Yigitcanlar T, Kamruzzaman M, Hayes J (2017) Evaluating transport externalities of urban growth: a critical review of scenario-based planning methods. Int J Environ Sci Technol 14:663–678. https://doi.org/10.1007/s13762-016-1144-7
46. Pettit C, Shi Y, Han H, Rittenbruch M, Foth M, Lieske S, van de Nouwelant R, Mitchell P, Leao S, Christensen B, Jamal M, van den Nouwelant R, Mitchell P, Leao S, Christensen B, Jamal M (2020) A new toolkit for land value analysis and scenario planning. Environ Plan B-Urban Anal City Sci 47:1490–1507. https://doi.org/10.1177/2399808320924678WE-SocialScienceCitationIndex(SSCI)
47. Rawluk A, Ford RM, Williams KJH (2018) Value-based scenario planning: Exploring multi-faceted values in natural disaster planning and management. Ecol Soc 23. https://doi.org/10.5751/ES-10447-230402
48. Demetriou D (2017) A spatially based artificial neural network mass valuation model for land consolidation. Environ Plan B Urban Anal City Sci 44:864–883. https://doi.org/10.1177/0265813516652115
49. Baum A, Graham L, Xiong Q (2021) The future of automated real estate valuations (AVMs) 2 the future of automated real estate valuations (AVMs)
50. Sing TF, Yang J, Yu SM (2020) Decision tree and boosting techniques in artificial intelligence based automated valuation models (AI-AVM)
51. Nijhum F, Westbrook C, Noble B, Belcher K, Lloyd-Smith P (2021) Evaluation of alternative land-use scenarios using an ecosystem services-based strategic environmental assessment approach. Land Use Policy 108. https://doi.org/10.1016/j.lusepol.2021.105540 WE—Social Science Citation Index (SSCI)
52. Ferm J, Raco M (2020) Viability planning, value capture and the geographies of market-led planning reform in England. Plan Theory Pract 21:218–235. https://doi.org/10.1080/14649357.2020.1754446
53. Soria KY, Palacios MR, Gomez CAM (2020) Governance and policy limitations for sustainable urban land planning. The case of Mexico. J Environ Manage 259. https://doi.org/10.1016/j.jenvman.2019.109575 WE—Science Citation Index Expanded (SCI-EXPANDED)

Overview of Sustainable Development Initiatives in India

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1 Background

India's urban growth trajectory is quite remarkable, according to recent data. An increasing number of India's residents are choosing cities as their preferred dwelling places, as revealed in the World Urbanization Prospects 2018 report by the United Nations. Now, more than 34% of India's population are residing in urban areas, marking an increase of roughly 3% from the 2011 Census [1].

A particularly interesting trend is the stable count of larger urban centers (those with populations over five million), while the number of smaller urban areas is rapidly increasing [2]. A deeper dive into the Ministry of Housing and Urban Affairs' data highlights the varied urbanization landscape across India's states and Union territories. Especially, the National Capital Territory of Delhi and the Union Territory of Chandigarh are leading with a staggering 97.5 and 97.25% urban population, respectively. Other territories that are witnessing a high level of urbanization include Daman and Diu (75.2%) and Puducherry (68.3%).

Among the states, Goa has urbanized the most, with 62.2% of its residents now living in urban areas from the 49.8% observed in 2001 [2]. Rapid urbanization is also observed in states like Kerala, where the urban population has jumped from 25.9% a decade ago to the current 47.7%. In the North-East, Mizoram has 51.5% of its population living in urban areas. However, in terms of contributing to the national urban population, Mizoram's share is relatively small at 0.1%. A similar impressive leap is visible in Sikkim, which has seen its urbanized population grow from 11% to almost 25% over a decade [2].

Among the bigger states, Tamil Nadu retains the top spot with 48.4% of its population living in urban environments. This is closely followed by Kerala (47.7%), which has surpassed Maharashtra (45.2%). On the other hand, states like Himachal

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Pradesh, Bihar, Assam, and Orissa lag behind, with Himachal Pradesh registering the lowest urbanization at 10%. Despite this, Maharashtra still retains the largest urban population in terms of absolute numbers, accounting for 13.5% of the nation's total urban population, following close behind are Uttar Pradesh and Tamil Nadu [2].

According to UN projections, India's population is poised to reach approximately 1.67 billion by 2050, making it the most populous country globally. This growth implies that we will need to create spaces for around 450 million additional individuals over the next thirty years, nearly double the current urban population. In light of this immense task, the Indian Government's objective of developing 100 Smart Cities, alongside the AMRUT (Atal Mission for Rejuvenation and Urban Transformation) initiative, takes on critical national importance. The AMRUT initiative, which aims to provide basic services such as water supply, sewage, and urban transport to households, and to create amenities in cities that will enhance the quality of life for all, particularly the less fortunate, aligns perfectly with this necessity [3].

As the urban population and income levels grow, it is anticipated that the demand for crucial services, including water, transportation, and sewage treatment, will multiply five to seven times. However, creating a Smart City entails more than simply amassing land and erecting physical infrastructure. While these are indeed key components, comprehensive urban planning requires a broader vision. Acknowledging the above realities, it becomes essential to conceive and implement innovative techniques and technologies capable of addressing these challenges. Thus, offering integrated solutions by exploring the potential for adopting innovative approaches at the neighborhood level that can subsequently be scaled up to encompass the city level becomes crucial [4].

2 Introduction

As we stride toward 2050, projections suggest that nearly 70% of the global population will find their homes in urban centers. What needs to be emphasized is that cities account for over 80% of the world's total greenhouse gas (GHG) emissions, which is a leading contributor to climate change. A break-up of these emissions reveals that urban transportation contributes 25%, while the urban built environment and municipal solid waste contribute 32 and 5%, respectively.

In terms of global energy consumption, urban transportation, and the urban built environment account for 20 and 25%, respectively [5]. These figures demonstrate how cities, in their current form, exert significant pressure on the environment and contribute to global warming. Such climate changes, in turn, intensify strains on city infrastructure, including urban water supply, sewage systems, solid waste management, and intensifying urban heat island effects [3].

When we talk about urban infrastructure (UI), we're discussing a multifaceted concept that goes beyond just physical utilities. It also comprises local governance, interconnected aspects of economic growth, climate change, and municipal waste management. The complex challenges associated with urban infrastructure can be tackled at multiple scales, involving global institutions, national, and regional bodies, and Urban Local Bodies (ULBs). The way UI functions impacts a broad spectrum of stakeholders, including regulators, consumers, citizens, businesses, and the general population [4]. Hence, it is evident that urban spaces, by their very nature, are intricate and under intense stress not just for engineered utilities and facilities, but also for political and economic influence.

3 Critical Aspects of Sustainable Cities and Urbanization

Sustainability, a relatively recent domain of study, draws upon a multitude of disciplines including engineering, environmental science, economics, and social sciences [5]. As defined by the Brundtland Commission, sustainability represents the capacity to fulfill the requirements of the present generation without jeopardizing the ability of future generations to meet their needs [6]. Following the Triple Bottom Line (TBL) approach, sustainability encompasses social, economic, and environmental dimensions [7].

Sustainability presents a holistic vision of achieving human development over time and space, recognizing the interdependencies between the ecosystem and socio-economic aspects. It strives to maintain a balance in an equitable and secure manner that requires technological, scientific, and political intelligence [8, 9]. As Martos et al. rightly point out, "a sustainable, resource-efficient city can be defined as a city that is significantly decoupled from resource exploitation and ecological impacts and is socio-economically and ecologically sustainable in the long term" [10]. This makes the pursuit of sustainability, especially in urban settings, a critical concern for today's world.

In her research paper, Allen [11] emphasizes that rapid urbanization is a highly complex and significant socio-economic phenomenon of the twentieth and twenty-fisrt centuries. It involves not only a transition from rural to urban societies but also profound and irreversible changes in production, consumption, and the relationship between humans and the natural environment. Consequently, cities and the urbanization processes have come under the scrutiny of sustainability principles.

The pace of urban transformation is expected to be most pronounced in the world's poorest nations, which often lack the resources to invest in essential urban infrastructure such as water supply, sanitation, and secure housing. These countries also struggle to provide sufficient economic opportunities that enable urban residents to escape poverty. As a result, the urban poor are particularly vulnerable to biological and physical hazards and face limitations in accessing protective services and infrastructure. Therefore, the contemporary urbanization process in developing countries is characterized not only by a shift in poverty from rural to urban areas but also by the compounding effects of "urbanization of poverty and social exclusion," stemming from socio-economic, gender, and ethnic inequalities.

This analysis suggests that the current process of urbanization is marked by more than just rural–urban migration and a redistribution of poverty (at least in terms of population percentages). It entails a fundamental transformation of the interconnections between the global and local, urban and rural, and the wealthy and impoverished. Since its popularization by the Brundtland Report, sustainable development has been described as the convergence of social, environmental, and economic objectives [11] (Refer Table 1).

Analysis: Overall, the table demonstrates that sustainable development necessitates a balanced and integrated approach that considers the interdependence of the environment, society, and economy. We can reach a future where all people have access to the resources they need to prosper while also preserving the world for future generations by fostering sustainable natural and constructed ecosystems, equitable social conditions, and sustainable economic development.

In her research, Allen [12] critically analyzes the concept of sustainability and points out its inherent limitations. She notes, "This model grapples with the inherent trade-offs found in the simultaneous pursuit of social, environmental, and economic goals. Moreover, it's abstract in a way that makes it hard to grasp how sustainable development plays out at the urban level or acknowledge its inherent political dimensions." She highlights the fact that cities inherently aren't sustainable as their residents and associated economic activities rely on environmental resources and services from beyond their borders. This brings up crucial questions: What exactly does urban sustainability mean? How can we gauge the effects of urbanization and urban development on sustainable development? Answering these questions necessitates a more holistic understanding of sustainability, one that correctly outlines the objectives and trajectory of the system.

Indeed, the environmental, economic, and social goals still stand. However, in an increasingly urban world, the constructed environment, or "second nature," must be recognized as central to the habitability of our planet. Moreover, the quest for more

Table 1 The three pillars of sustainable development: environmental, social, and economic

Sustainable development		
Environmental	Social	Economic
A viable environment	Nurturing community	Sufficient economy
Environmental + Social = Sustainable natural and built environment		
Environmental + Economic = Sustainable economic development		
Economic + Social = Equitable social environment		

Source The Big Tent, Three Ring Circus of Sustainability, 2014

Table 2 The pillars of urban sustainability

Urban Sustainability				
Political sustainability	Economic sustainability	Social sustainability	Physical sustainability	Ecological sustainability

Source The Five Dimensions of Urban Sustainability, from Allen [12] sustainable forms of urbanization is predicated on political and institutional decisions that either foster competition or cooperation between different stakeholders. Therefore, Allen A argues that to evaluate whether a particular practice, policy, or trend is moving toward or away from urban sustainability, we need to scrutinize the interactions among the five dimensions she outlines [12].

Analysis: Overall, attaining urban sustainability necessitates a comprehensive and integrated approach that takes into account all of these elements, as well as the particular characteristics and demands of each city or urban area. Cities may create a more resilient, egalitarian, and sustainable future for all of their residents by encouraging political, economic, social, ecological, and physical sustainability.

Allen A's research [12] provides valuable insights into the five key dimensions of sustainability that shape our urban futures:

1. Economic Sustainability: This dimension focuses on the efficient utilization of local or regional resources to benefit the community in the long term, without causing harm or depleting natural resources. It requires a comprehensive assessment of the entire production cycle, considering both immediate and future impacts.
2. Social Sustainability: Allen emphasizes the importance of fairness, inclusiveness, and cultural suitability in interventions aimed at upholding equal rights over natural, physical, and economic capital that support local communities' livelihoods. It highlights the needs of marginalized groups and emphasizes cultural adequacy in preserving cultural heritage and acknowledging diversity.
3. Ecological Sustainability: This dimension pertains to the impact of urban production and consumption patterns on the health and integrity of the city, region, and global carrying capacity. It necessitates a long-term perspective on the relationship between environmental resources and services and the demands placed on them.
4. Built Environment Sustainability: The focus of this dimension is on enhancing the livability of buildings and urban infrastructure for all residents without causing harm or disruption to the urban environment. It also considers the efficiency of the built environment in supporting the local economy.
5. Political Sustainability: The final dimension addresses the quality of governance systems that guide the actions of various stakeholders across the other four dimensions. It advocates for democratized decision-making processes and active participation from local civil society in all areas of decision-making [12].

These dimensions provide a comprehensive framework for understanding and pursuing sustainable urban development. By considering economic, social, ecological, built environment, and political aspects, cities can work toward creating more resilient and livable urban environments that meet the needs of present and future generations.

Sustainable urban development emerges as a necessary response to the multifaceted challenges faced by urban areas, including globalization, decentralization, and rapid population growth. These transformative forces have far-reaching implications for the economy, social conditions, and the environment, giving rise to pressing issues such as social inequalities, slums or informal settlements, and climate change. In the research paper titled "Achievement to Sustainable Urban Development using City Development Strategies: A Comparison between Cities Alliance and the World Bank definitions" [13], sustainability is categorized into two dimensions:

Urban Sustainability or Sustainable City:

The terms "urban sustainability" and "sustainable city" encompass the prudent utilization of resources, preservation of the natural environment, minimization of nonrenewable resource consumption, and the pursuit of economic growth that fosters community confidence, individual well-being, and the fulfillment of basic human needs [14]. These concepts emphasize the responsible management of resources and the harmonious integration of economic, social, and ecological dimensions.

Sustainable Urban Development or Sustainable Urbanization:

In accordance with the United Nations Sustainable Cities Programme, a sustainable city possesses abundant natural resources that form the foundation of its development. It is resilient against environmental threats that could undermine its progress [15]. Whitehead [15] describes the sustainable city as an economic realm where the social, economic, and ecological contradictions inherent in capitalism are effectively addressed and managed. On the other hand, sustainable urbanization and sustainable urban development refer to dynamic processes aimed at achieving favorable conditions that encompass environmental, economic, social, and governance sustainability concerns [14].

By embracing the principles of sustainable urban development, cities can navigate the complexities of urbanization and foster long-term well-being for their residents while safeguarding the environment and promoting socio-economic progress.

4 Importance of Sustainable Urban Development in Indian Context

Indrani Sengupta and Varun Baranwal [16] highlight key aspects of sustainable development in an Indian context, particularly focusing on sustainable urban development. They emphasized the vital role of economic growth that respects social equity and safeguards environmental resources. The paper stresses that global environmental conferences consistently highlight the necessity for economic development to incorporate social equity and conservation of environmental resources. Urban areas, notably, are identified as hubs for excessive consumption of nonrenewable resources, leading to environmental degradation [16]. Climate change poses a global challenge affecting both affluent and impoverished economies. It threatens water supplies, ecosystems, and disproportionately impacts impoverished communities due to their increased vulnerability and limited resources to mitigate adverse climatic conditions [16]. Anthropogenic pollution worsens these challenges. The authors argue that sustainable urban development must address these issues, with an emphasis on mitigating climate change effects, curbing the depletion of nonrenewable resources, and reducing urban environmental degradation.

Sengupta and Baranwal further discuss deficiencies in India's urban basic services and their management toward achieving sustainable urban development [16]. They highlight the crucial role of land in sustainable urban development, pointing out inefficiencies in India's land policy. While environmentally friendly management of basic services like water and sanitation is vital for sustainable urban development, equity in service delivery also plays an important role and must be considered in planning processes. The paper concludes that true economic development should contribute to an increase in efficiency and quality of life within a community. Moreover, it suggests that the positive externalities of a city's economic growth, such as employment opportunities, should not generate negative consequences like air pollution and traffic congestion. Solutions should be locally viable, globally applicable, and respect indigenous practices.

A sustainable urban area must produce and manage essential services such as water, waste, energy, and transportation, in an economical, environmentally friendly, and equitable way [17]. Particularly in developing nations, cities lack the provision of basic services, contributing to environmental pollution. Despite some differences between cities and between developed and underdeveloped nations, urban infrastructure systems are often designed without thorough consideration of their environmental and social impacts [17]. Indian cities are often densely populated, which necessitates thoughtful management of basic service requirements, considering service insufficiency, environmental impacts, and inequality in service delivery [16]. The issue of water supply management is one of global concern, as the impacts of climate change on water supply and distribution are expected to be predominantly negative [17]. Adopting energy-efficient alternative systems and utilizing efficient practices such as using raw water or recycled water for non-consumptive purposes could potentially mitigate these effects. In Vermont, USA, a wastewater treatment system that uses a series of tanks filled with plants and other organisms naturally cleans wastewater, serving 500,000 people annually [17]. In Adelaide, Australia, a group has taken an integrative approach to this problem, developing and applying sustainability concepts to evaluate alternative futures for their water system [18]. This effort, known as the Water Sustainability in Urban Areas (WSIUA) project, investigated the feasibility and benefits of progressively replacing large scale, single-purpose water systems with small scale, multipurpose water systems [18]. Moreover, according to Grotter and O'neill [19], separating feces and urine from domestic wastewater is a critical step toward achieving a sustainable water concept. This approach has been implemented in a 100-unit housing complex in Lubeck-Flintenbreite, Germany, demonstrating the feasibility of such a model [19]. Shaikh et al. [20] present an alternative solution to the water crisis, proposing that water recycling and reuse have become attractive options for conserving and extending available water supplies in many countries. However, in developing countries, a primary challenge remains the provision of clean drinking water to all urban inhabitants, underscoring the need for the conservation of old water bodies like lakes and ponds to ensure a sustained water supply.

Additionally, they discuss waste management practices, stressing that they should be initiated and integrated right from the production and distribution stages of economic activities through reuse and recycling [17]. Hazardous waste should be handled carefully to prevent recycling, and plastic use should be reduced. Effective waste management practices have been recommended by the Department of Environment of the Indian Government and by the National Environmental Engineering Research Institute (NEERI) [17].

Furthermore, Sengupta and Baranwal delve into energy management practices, emphasizing their incorporation into the planning of buildings and the city form. They advocate for buildings and city forms that are energy-efficient and make use of sustainable energies like solar and wind energy. In terms of financing, policies should encourage energy-efficient practices with readily available loans and tax benefits [16].

The paper concludes by addressing the issue of inequality in urban basic services, stating that management of such services in cities should strive to reduce disparities between the rich and the poor [16]. Barbano and Egusquiza [22] underscore that enhancing the sustainability of urban environments is an escalating problem, which must be tackled through a multiscale and multidirectional approach.

Sustainable urban development in India involves integrating environmental, economic, and social factors to achieve growth that's equitable and respectful to the environment. Urban areas are significant consumers of nonrenewable resources and contribute to environmental degradation, and the paper by Indrani Sengupta and Varun Baranwal emphasizes the importance of addressing these issues for sustainable development. The authors discuss the necessity of improved management of basic urban services such as water, waste, energy, and transportation, with a focus on eco-friendly and equitable delivery. They suggest policies that promote energy-efficient practices, underscore the need for efficient waste management, and stress the importance of reducing service delivery disparities. The authors advocate for locally viable, globally applicable solutions that respect indigenous practices and argue that sustainable urban development should contribute to enhanced quality of life without generating environmental harms.

5 Sustainable Development Initiatives by the Government

The adoption of the 2030 Sustainable Development Agenda, comprised of 17 goals and 169 targets in September 2015, underscores the international recognition of sustainability's paramount importance. India, which aims to achieve these development objectives, must concurrently ensure the continued growth of its economy. However, this economic growth is not without its environmental ramifications. A burgeoning economy places considerable strain on natural resources such as land, water, minerals, and fossil fuels, potentially escalating energy and commodity prices. The degree to which the economy can transition toward "green growth" hinges on India's capability to decrease the quantity of resources needed to sustain economic development while improving social equity and generating employment [23].

Considering this situation, there's an urgent need to reconsider traditional governance procedures and strive toward creating empowered, enabled, and intelligent cities. The long-standing "closed and top-down" approach should give way to a more "open model," which includes and manages a diverse range of stakeholders and citizens. Innovation and inclusivity should be encouraged within governance systems. The use of open and inclusive networks, accessibility to data, public engagement, and comprehensive management systems could be pivotal in achieving these objectives. In the new millennium, the growing environmental consciousness among citizens has led to increased support for environmental and conservation goals at a local level.

To successfully implement these initiatives, however, concerted support from local, state, and national governments is essential. This includes providing economic and environmental backing, establishing favorable public and private institutional arrangements, and maintaining socio-technical infrastructure systems that facilitate effective resource flows [4].

The Smart Cities Mission, launched by the Government of India, promotes the creation of sustainable, inclusive urban environments. Key aspects of this mission can be illustrated with concrete examples from various cities across India [24].

- Promoting Mixed Land Use in Area-Based Developments: Indore, for instance, has adopted this principle in its Smart City plan, demonstrating a commitment to flexible zoning that can adapt to changing needs.
- Housing and Inclusiveness: The Pradhan Mantri Awas Yojana (PMAY) scheme exemplifies this approach, with the ambitious goal of providing 20 million affordable homes by 2022.
- Creating Walkable Localities: Cities like Bhubaneswar and Pune have embraced the concept of non-motorized transport, integrating walking and cycling paths into their Smart City initiatives.
- Preserving and Developing Open Spaces: Chennai's Smart City project underscores the importance of open spaces, aiming to create parks, playgrounds, and green areas that enhance the quality of life of its residents and promote ecological balance.
- Promoting a Variety of Transport Options: Delhi's Transit-Oriented Development (TOD) encourages compact, walkable communities centered around high-quality train systems, reducing the reliance on private vehicles and improving air quality.
- Making Governance Citizen-Friendly and Cost-Effective: Cities across India have adopted e-governance initiatives, such as Pune Municipal Corporation's "PuneConnect" mobile app, which provides easy access to civic services, boosting transparency and accountability.
- Giving an Identity to the City: Jaipur, known for its arts and crafts, has leveraged this unique identity in its Smart City vision, positioning these industries as both economic and cultural assets.
- Applying Smart Solutions to Infrastructure and Services: Surat, a hub for the textile and diamond industries, has implemented technologies such as the Integrated Command and Control Centre (ICCC) to efficiently manage the city's

infrastructure, enhancing disaster resilience, and offering more cost-effective services.

These examples collectively exemplify the ambitious goals and various initiatives of the Smart Cities Mission, illustrating its potential impact on sustainable urban development across India [24].

The AMRUT (Atal Mission for Rejuvenation and Urban Transformation) Cities Mission outlines specific elements aimed at enhancing urban life in India [25].

- Water Supply: This component encompasses the enhancement and expansion of water supply systems, water treatment plants, and universal metering. It involves rejuvenating water bodies for drinking water supply and groundwater recharging. Special focus is given to areas with water quality issues such as arsenic or fluoride contamination.
- Sewerage: The mission encourages the development and expansion of decentralized sewerage systems and sewage treatment plants. It includes rehabilitating existing systems and promoting water recycling and wastewater reuse.
- Septage: An important aspect is the management of fecal sludge through cost-effective cleaning, transportation, and treatment methods. The mission also includes mechanical and biological cleaning of sewers and septic tanks, ensuring full recovery of operational costs.
- Stormwater Drainage: The construction and improvement of drains and stormwater drain to reduce and eventually eliminate flooding are pivotal parts of this mission.
- Urban Transport: The mission focuses on providing diverse urban transport options including ferry vessels for inland waterways, buses, and facilities for non-motorized transport such as bicycles. It includes provisions for multi-level parking and Bus Rapid Transit Systems (BRTS).
- Green Space and Parks: A notable aspect of the AMRUT Mission is the development of green spaces and parks, especially with child-friendly features.
- Reforms Management and Support: This includes creating support structures, activities, and providing funding for implementing reforms. The mission also supports the establishment of independent reform monitoring agencies.
- Capacity Building: There's a focus on both individual and institutional capacity building, extending not only to mission cities but to other urban local bodies. This incorporates the continuation of the Comprehensive Capacity Building Programme (CCBP) with its alignment toward the new missions.

Each of these components aims to introduce smart features into urban physical infrastructure, thus aiming for a holistic urban rejuvenation in India [25]. The summary and mapping of various Government policies and initiatives to address the urban challenges are mapped with Sustainable Development Goals [26] and can be seen in the table below (Refer Table 3).

Table 3 Policies and SDG achievable chart

Sr no.	Policies in chronological order	Urban challenges addressed	SDG's achieved
1	National River Conservation Plan, 1995	Conservation and restoration of rivers in India	
2	National Biodiversity Act, 2002	Promoting conservation of biodiversity and sustainable use of biological resources, the act can help to preserve forests and other natural habitats	
3	Mahatma Gandhi National Rural Employment Guarantee, 2006	Providing employment opportunities and social security to the rural population	
4	National Action Plan on Climate Change (NAPCC), 2008	Addressing climate change and its impacts on cities and urban areas	
5	National Solar Mission, 2010	Promoting renewable energy and reducing dependence on fossil fuels in cities and urban areas	
6	National Cyclone Risk Mitigation Project (NCRMP), 2011	Mitigating the risks of cyclones and other natural disasters in coastal cities and urban areas	

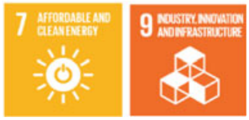
(continued)

Table 3 (continued)

Sr no.	Policies in chronological order	Urban challenges addressed	SDG's achieved
7	Swachh Bharat Abhiyan (Clean India Mission), 2014	Improving sanitation and cleanliness in cities and urban areas	3 GOOD HEALTH AND WELL-BEING; 6 CLEAN WATER AND SANITATION; 11 SUSTAINABLE CITIES AND COMMUNITIES
8	National Mission for Sustainable Agriculture, 2014	Ensuring food security and sustainable agricultural practices in urban and peri-urban areas	2 ZERO HUNGER; 11 SUSTAINABLE CITIES AND COMMUNITIES
9	Pradhan Mantri Jan-Dhan Yojana (PMJDY), 2014	Financial inclusion and access to banking services for the poor and unbanked population	1 NO POVERTY; 8 DECENT WORK AND ECONOMIC GROWTH
10	Smart Cities Mission, 2015	Improves economic growth, quality of life, facilitates local development with digital and IT, utilizes public–private partnership	8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES
11	Atal Mission for Rejuvenation and Urban Transformation–AMRUT, 2015	Improving basic infrastructure and services in cities, especially for the poor and disadvantaged	1 NO POVERTY; 6 CLEAN WATER AND SANITATION; 11 SUSTAINABLE CITIES AND COMMUNITIES
12	National Green Highways Mission, 2015	Promoting sustainable and green infrastructure development in highways and urban areas	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES

(continued)

Table 3 (continued)

Sr no.	Policies in chronological order	Urban challenges addressed	SDG's achieved
13	Beti Bachao Beti Padhao (BBBP), 2015	Promoting gender equality and preventing gender-based violence and discrimination	
14	Pradhan Mantri Awas Yojana (PMAY), 2015	Providing affordable housing to the urban poor and homeless	
15	Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY), 2015	Providing access to electricity and improving the quality of life in rural areas	
16	National Skill Development Mission, 2015	Enhancing the skills and employability of the Indian workforce	
17	Pradhan Mantri Ujjwala Yojana (PMUY), 2016	Providing clean cooking fuel to households in rural and remote areas	
18	POSHAN abhiyan, 2018	Addressing malnutrition and promoting maternal and child health	
19	Pradhan Mantri Jan Arogya Yojana, 2018	Providing access to healthcare services and financial protection for the poor and vulnerable population	

(continued)

Table 3 (continued)

Sr no.	Policies in chronological order	Urban challenges addressed	SDG's achieved
20	Samagra Shiksha Abhiyan, 2018	Improving the quality of education and ensuring inclusive and equitable access to education for all children	4 QUALITY EDUCATION
21	National Clean Air Programme (NCAP), 2019	Reducing air pollution in cities and urban areas	3 GOOD HEALTH AND WELL-BEING; 11 SUSTAINABLE CITIES AND COMMUNITIES
22	Jal Jeevan Mission, 2019	Providing access to clean and safe drinking water to every household in rural India	6 CLEAN WATER AND SANITATION
23	Sampanna Bharat-Samriddh Bharat (Prosperous and Vibrant India), 2020	Strengthening the Indian economy and promoting sustainable development	1 NO POVERTY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 10 REDUCED INEQUALITIES; 11 SUSTAINABLE CITIES AND COMMUNITIES; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION; 16 PEACE, JUSTICE AND STRONG INSTITUTIONS
24	The Net Zero Commitment, 2021	Reducing greenhouse gas emissions in cities and urban areas	11 SUSTAINABLE CITIES AND COMMUNITIES; 13 CLIMATE ACTION

(continued)

Table 3 (continued)

Sr no.	Policies in chronological order	Urban challenges addressed	SDG's achieved
25	Prime Minister Gati Shakti Mission, 2021	Improving the infrastructure and logistics sector of the country to support economic growth	8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
26	Namami Gange, 2021	Cleaning and rejuvenating the Ganges River and promoting sustainable use of water resources	6 CLEAN WATER AND SANITATION; 14 LIFE BELOW WATER

6 Observations and Conclusions

The observations highlight the significant increase in urban population and incomes, leading to a substantial rise in demand for key services such as water, transportation, and sewage treatment. As a result, urban areas have become the focal point for environmental impacts stemming from development. It is crucial to ensure that the gains achieved today do not necessitate extensive restructuring in the future, as this would place additional strain on resources and have a considerable environmental impact. Therefore, our attention should be directed toward sustainable urban development and the relationship between macroeconomic strategies and sustainability in contemporary urbanization.

Taking a broader view of urban sustainability, it becomes evident that cities have diverse and far-reaching impacts on society and the environment within the context of the global political economy. Reforms and initiatives cannot be isolated from this broader framework; rather, they should be integrated with it to achieve effective and lasting change.

To assess the progress of urban sustainability, it is essential to consider the interplay among five dimensions: economic sustainability, social sustainability, ecological sustainability, sustainability of the built environment, and political sustainability. These dimensions provide a holistic understanding of urban development and its impact on various aspects of society and the environment.

The challenge posed by climate change affects both rich and poor economies worldwide, impacting water supply, ecosystems, and various other factors. This necessitates a comprehensive approach to managing cities, placing emphasis on effective water management, waste management, energy management, and inclusivity.

To address the challenges of urbanization and make Indian cities smart and sustainable, the Government of India has outlined its vision of building 100 Smart Cities and implementing the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) initiative. These initiatives aim to provide basic services such as water supply, sewerage, and urban transport to households and improve the overall quality of life, particularly for the underprivileged. However, further research is required to better understand the impacts of these initiatives and develop innovative strategies to ensure that future cities are smart, sustainable, and resilient.

In mapping these observations and conclusions to the SDG 2030 framework, it is evident that certain sustainable urban development initiatives of the Government align with several goals, including Goal 11: Sustainable Cities and Communities. This goal emphasizes the importance of inclusive, safe, resilient, and sustainable cities, which are at the core of our observations and recommendations. By focusing on economic, social, and ecological sustainability, as well as the built environment and political dimensions, we can contribute to achieving multiple SDGs, such as Goal 6: Clean Water and Sanitation, Goal 7: Affordable and Clean Energy, and Goal 13: Climate Action. By integrating these principles into urban planning and development, India can strive toward a more sustainable and equitable future.

References

1. UNDESA (United Nations, Department of Economic and Social Affairs), Population Division (2019) World urbanization prospects: the 2018 revision (ST/ESA/SER.A/420). United Nations, New York
2. Ministry of Housing and Urban Affairs (MOHUA) (2020) Level of urbanisation. Available: http://mohua.gov.in/cms/level-of-urbanisation.php. Accessed 18 June 2020
3. Kleerekoper L, Van Esch M, Salcedo TB (2012) How to make a city climate-proof, addressing the urban heat island effect. Resour Conserv Recycl 64:30–38. https://doi.org/10.1016/j.resconrec.2011.06.004
4. Hodson M, Marvin S (2010) Can cities shape socio-technical transitions and how would we know if they were? Res Policy 39(4):477–485
5. El-Diraby TE, Osman H (2011) A domain ontology for construction concepts in urban infrastructure products. Autom Constr 20(8):1120–1132
6. World Commission on Environment and Development (WCED) (1987) Our common future. Oxford University Press, Oxford
7. Elkington J (1994) Towards the sustainable corporation: win–win–win business strategies for sustainable development. Calif Manag Rev 36(2):90–100
8. Adams R, Jeanrenaud S, Bessant J, Denyer D, Overy P (2012) Innovating for sustainability: a systematic review of the body of knowledge. Netw Bus Sustainy. Available: https://www.nbs.net/knowledge
9. Gladwin TN, Kennelly JJ, Krause TS (1995) Shifting paradigms for sustainable development: implications for management theory and research. Acad Manag Rev 20(4):874–907
10. Martos A, Ruiz JPG, Eliche-Quesada D (2016) Towards successful environmental performance of sustainable cities: intervening sectors: a review. Renew Sust Energ Rev 57:479–495

11. Allen A (2009) Sustainable cities or sustainable urbanisation? Available: https://mycourses.aalto.fi/pluginfile.php/219334/mod_resource/content/1/sustainable_urbanisation_allen.pdf. Accessed 18 June 2020
12. Allen A (2001) Urban sustainability under threat: the restructuring of the fishing industry in Mar del Plata, Argentina. Dev Pract 11(2–3):152–173
13. Rasoolimanesh SMJM, Rasoolimanesh BN (2014) Examining the contributing factors for the successful implementation of city development strategy in Qazvin City, Iran. Cities 10–19. https://doi.org/10.1016/j.cities.2014.05.002
14. Shen LY, Ochoa JJ, Shah MN, Zhang X (2010) The application of urban sustainability indicators: a comparison between various practices. Habitat Int 1–13. https://doi.org/10.1016/j.habitatint.2010.03.006
15. Mark W (2003) (Re)Analyzing the sustainable city: nature, urbanization and the regulation of socio-environmental relations in the UK. Urban Stud 40(7):1183–1206
16. Sengupta I, Baranwal V (2012) Sustainability in urban development: an Indian standpoint. Int J Urban RegNal Stud 8(2)
17. Roberts P (2008) Alternative urban futures: designing urban infrastructures. City and Regional Planning
18. Pudney RA, Clark SW (1997) Water sustainability in urban areas-an adelaide and regions case study. Report One—an exploration of the concept. Dept. of Environment and Natural Resources. Adelaide, Australia, Draft
19. Grotter M, Otterpohl R (1996) Integrated urban water concept. In: Proceedings of the 7th international conference on urban storm drainage. Hannover, Germany, pp 1801–1806
20. Shaikh SY, Shaikh SS (2015) Grey water reuse: a sustainable solution of water crisis in Pusad city in Maharashtra, India. Int J Recent Innov Trends Comput Commun 3(2):167–170
21. Thakur K, Singh A (2006) Access to drinking water in urban India: an analysis of emerging spatial pattern in the context of new system of governance. In: Ratna Reddy V, Mahendra Dev S (eds) Managing water resources: policies, institutions and technologies. Oxford University Press, New Delhi
22. Barbano G, Egusquiza A (2015) Interconnection between scales for friendly and affordable sustainable urban districts retrofitting. In: Proceedings of the 6th international building physics conference; IBPC Energy Procedia 78:1853–1858
23. TERI (2015) Green growth and sustainable development in India—towards the 2030 development agenda. Available online: https://www.teriin.org/projects/green/pdf/National_SPM.pdf. Accessed 18 June 2020.
24. Government of India (2015) Smart cities mission guidelines
25. Government of India (2015) Atal mission for rejuvenation and urban transformation (AMRUT).
26. United Nations. Sustainable Development Goals. Accessed [15 June 2023]. Available at: https://sdgs.un.org/goals

Thriving Vernacular Economies in the Sustainable Built Environment of *Purani Delhi*

Alpna Rohatgi

1 Introduction

1.1 Sustainable Built Environment

The interdependent and mutual link between the three pillars of sustainable development, which are: economic growth, environmental protection, and social equity, are intended to be protected until a few years. Recently established studies have indicated culture to be an essential fourth pillar in achieving sustainable development [9, 10]. Research studies have shown that generic cultural indicators act as a primary reference to develop context-specific cultural indicators while developing/enhancing building assessment/rating systems [10].

1.2 The Role of Culture in Sustainable Built Environment

Nobel Laureate Amartya Sen's words on culture, 'Cultural matters are integral parts of the lives we lead. If development can be seen as an enhancement of our living standards, then efforts geared to development can hardly ignore the world of culture' [5, 17]. Cultural diversity is the end product of many years of history, and it is the prominent heritage of humanity [4]. Cultural diversity is very much necessary for the existence of humankind [4, 15]. If the built environment is an integral part in the construction of spaces, and the history of a building would be considered its identity, any building alterations involve elements and forms that relate to a particular cultural and societal practice [2]. Hence, cultural heritage is a powerful asset for inclusive economic development since it attracts investment yet ensuring green, locally

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based, viable and environmentally sustainable developments such as conservation [8]. Therefore, it is critical to place culture at the centre of development strategies for its role in structuring human behaviour and its relationship with the surroundings [16].

It has been established that cultural sustainability is accredited to preserving the tangible and intangible cultural elements of society in ways that promote environmental, economic, and social sustainability [6, 12]. There is a paradigm shift in the worldview on sustainability to include cultural sustainability in ways that do not damage our ecosystem, environment, and social well-being [9].

1.3 What Are Vernacular Economies

Moving to the region-specific domain in the research, the need for vernacular was explored. The use of vernacular is not necessarily a relic of the past or a sign of regress. The question of whether local economies are sustainable and better than new technologies is a complex one, with no simple answer.

Local economies can provide a number of benefits, including supporting local businesses, promoting economic diversity, and reducing the dependence on large corporations. By relying on local resources and expertise, these economies can be more resilient and better equipped to weather economic disruptions. They can also help to promote community cohesion and provide a sense of place (Fig. 1).

Fig. 1 A couple of vernacular economies: cards printing, paper envelopes/paper industry, *jild* (hard book cover), bookbinding, file making, wholesale cloth, *bedmi-nagori aloo* a fried traditional savoured delicacy. *Source* Author

1.4 The Contemporary/New Age Vernacular

The dichotomy of the traditional vs the new age ceases to exist here, so intrinsically blended, as is evident when taking the examples of any of those vernacular economies. Specifically vernacular food is an excellent example of a flourishing economy with all its visceral feel, smell, ambience, serving and taste. The new age dynamism is in marketing and food delivery through apps and internet connectivity. Though some aspects, like the visceral feel may be lost or compromised, it still carries on the traditions and nostalgia.

New technologies on the other hand, can provide benefits such as increased efficiency, lower costs, and greater accessibility. They can also support or foster innovation, propel economic growth, and open up new avenues for entrepreneurship and employment.

In terms of whether going back to being primitive is the solution, it's important to note that there is no one-size-fits-all answer. A balance between local economies and new technologies can offer the best of both worlds, by combining the strengths of each approach. For example, local economies can support sustainable development by utilizing the resources and knowledge available in the local community, while new technologies can provide access to global markets and increase productivity.

Vernacular economies are based on the local conditions, cultures, and resources of a given area. They often involve small businesses that focus on providing goods and services to local communities, which can help to foster connection and collaboration between people in the area. In terms of built environments, vernacular economies can help to ensure that the design and function of built spaces align with the needs and preferences of the local population. New age vernacular maybe different from the past or contemporary.

2 Research Question

Are the age-old vernacular economies in the Built Environment of *Purani Delhi* still sustainable, thriving yet dynamic to address the need of the built environment in contemporary times?

3 Research Objectives

A. To study how sustainable is vernacular in the built environment in contemporary times.
B. To study, are vernacular economies the answer to our needs of sustainability of the present and then also the future.

Fig. 2 Research methodology. *Source* Author

C. To understand, are the vernacular traditions/economies/culture a thing of the past, regressive or still relevant?
D. To study the association of these economies, their popularity with the current generation, and their interdependence on the market economy.

4 Research Methodology

See Fig. 2.

5 Research

Secondary Research: Literature Survey: **Inductive Research** (Table 1).

Literature Review: Concepts of **sustainability** have been deeply studied on four rather than three, new pillars with mutual interdependence of all established. Study of vernacular is incomplete without its link to the built environment hence literature studies for research were conducted on **vernacular architecture**, its relevance, relationship to environment and time, climatological and sociological impact. **Culture** has been proven to be an important marker in sustainable development goals as studies have indicated (Refer Sects. 1.1 and 1.2).

Anthropological and Ethnographic research methods deployed in fieldwork using Gupta and Ferguson practices of conducting qualitative research, visual ethnography, walking ethnography yielded rich data captured in images presented in the study here. James Scott's reading on experiences helped capture empirical data presented as narratives in findings in Sect. 4. **Sociology** studies introduced concepts of urbanization, dynamism, neo-liberalism in contemporary ***Purani Dilli*** from readings of Sanjay Srivastava and Brosius among others. The dichotomy of traditional vs. modern, nostalgia and conspicuous consumption brought forth through qualitative research conducted in the twenty-first century by sociologists and anthropologists have added value to this research. Detailed in Sect. 5.1 Research Gap, Sect. 5.2 Description of Case Study.

Table 1 List of literature studied/referred

S.No	Genre	Year	Keywords	References
1	Sustainability	1982–2022	Sustainable development; sustainable built environment; vernacular architecture, cultural sustainability, climate	Sustainability [4, 5, 9, 10, 12, 16, 17]
2	Vernacular architecture	1969–2023	Local building materials, sustainable architecture, vernacular architecture, neo-vernacular architecture	Vernacular [1, 7, 11, 14] https://doi.org/https://doi.org/10.3390/en16031301 https://doi.org/https://doi.org/10.1016/j.foar.2018.04.002
3	Role of culture	2001–2018	Vernacular architecture, cultural sustainability, culture, fourth pillar, identity	Culture [4, 5, 9, 10, 14, 17]
4	Anthropology/ ethnography	2001–2019	Anthropology, fieldwork, narrative, genealogy, class, sensory ethnography	Edwards, Elizabeth 1994. Anthropology & Photography, 1860–1920. New haven: Yale University Press Gupta, A. & Ferguson, J. 1997. Anthropological Locations: Boundaries and Grounds of a Field Science. Berkeley: University of California Press Scott, J. W 1991. "The Evidence of Experience", Critical Inquiry 17: 773–797
5	Sociology/ economics	2001–2019	Global city, Neoliberalism, Postcolonialism, Urbanization, identity	Sociology [1, 3, 7, 13] https://doi.org/https://doi.org/10.1146/annurev-soc-073117-041131
6	Research methods	2015–	Social Research, Ethics, Fieldwork, Questionnaire, Concept Mapping	Babbie, E. R. (2020). *The practice of social research.* Cengage learning Kothari, C. (2017). research methodology methods and techniques by CR Kothari. *Published by New Age International (P) Ltd., Publishers*, *91*. https://www.jstor.org/stable/1511517

(continued)

Table 1 (continued)

S.No	Genre	Year	Keywords	References
7	History/heritage	1857–	Shahjahanabad, Nostalgia, Conservation, Walled City, Colonial Rule, Mughal, Culture	History [1, 7] Dalrymple, W. (2003). City of Djinns: A year in Delhi. Penguin Dalrymple, W. (2009). The Last Mughal: The Fall of a Dynasty, Delhi, 1857. Germany: Bloomsbury Hearn, G. R. (1906). The Seven Cities of Delhi. India: W. Thacker & Company
8	Delhi	1993–2018	Sociability, culture, ecological balance, commercial Hub, Nostalgia Conspicuous Consumption	Delhi [13, 14] https://www.jstor.org/stable/https://doi.org/10.7588/worllitetoda.90.3-4.0036

Source Author

Since the case study presented is sociological qualitative research the methodologies adopted are experiential, empirical, and descriptive (Refer Research Methodology).

Primary Research: Case Study/Fieldwork: *Purani Dilli*: **Empirical research**.

Context of study is the local *churiwala, lehngawale, hakim/vaid, rafewgar* (person performing clothes' alterations)*, pansari, mochi* (cobbler), the famous *nagori/bedmi wala*, *jildwala, parchoon ki dukan* (retailer) in the *Dilli Che* (Delhi-6, postal code of this part of Delhi is 110006) zone of the city of Delhi that are thriving while adapting with the times. Delhi itself is unique being a heritage city and continues to be a contemporary, relatively modern, global and a world-class city [3, 13]. Established research emphasizes the fact. Quoting here, Jolly Rohatagi in her article, brings out the story of the city in all its glory, describing each of these folk experiences enriching her memories to capture the essence vividly [14]. Each zone of the city popularly known as *Purani Dilli, Dilli Che, and Sheher* (another name for "city") encapsulates many stories to narrate, which were self-confined within an ecosystem yet catered to the outer world just as, even to this date.

5.1 Research Gap

The researcher, brought up in this part of the city of Delhi, observed that research on culture, heritage, historical monuments, vernacular architecture, redevelopment, restoration, and conservation has happened. Under study is for this part of Delhi in terms of architectural style, socio-cultural anthropology, secondary research data shows the vernacular economies and their sustenance through centuries and presently their dynamic adaptation into the contemporary has not been studied. This is the research gap that is sought to be studied.

Firstly, *Dilli Che* or *Purani Dilli* with its rich historical, heritage, mystic city tag continues to be a contemporary city or relatively modern catering to the demands of the new in a vernacular lifestyle [13.3] Delhi has layers to unfold.

Secondly, focusing on the social anthropology, from every necessity of life to luxurious indulgences (like fine traditional clothing, ethnic fusion to jewellery) the place seems to have it all in arm's reach, which the researcher still remembers and longs for (researcher has now shifted base). Though with problems of urbanization like vehicular traffic, congestion, pollution, and overpopulation, is where the city chokes and is considered a prohibited zone or faces ridicule. As they say, you love it, you hate it, but you cannot negate it.

Thirdly, a judicious articulation of spaces, visual interplay of light and shade, hierarchy of spaces, public vs private spaces, access, or egress; these are sites of a sustainable habitat. Fourthly, the belief that this part of the present-day Delhi N.C.R. is primarily the site first recognized as the seat of power by the colonials and was the nucleus on which the rest of Delhi grew and developed, also the reason for its pseudonym, *sheher.* Lastly, hub of commercial activities in vernacular settings catering to all domains, be it industrial raw material, iron *jaalis* (iron mesh), hardware, paper industry, jewelry, the wholesale market of books and copies, cloth, spectacles, shoes, dry fruits, spices, and many more, these vernacular economies are still **unexplored**.

The fieldwork was done and analyzed based on the said four pillars of sustainable development. The analysis and subsequent findings are discussed in Sect. 4.

5.2 Description of the Case Study

Taking the case of the famous and iconic *lehngewale* of *Chandni Chowk* which is considered the *Mecca* or haven for ethnic wear including *lehnga* (traditional full-length skirt) as a vernacular economy of the context site, the entire journey of the product is being traced since inception with its linkage and effect on the built environment. The article is conceived by the local craftsmen who are the *desi* designers, for which the raw material required is readily available within metres away, next door in the same zone. The material, including cloth, threads, accessories, and embellishments all ferried into from different parts of the country to this commercial hub through railways, Old Delhi Railway Station barely a kilometre or two away or inter-state buses, I.S.B.T (Inter State Bus Terminus) again two–three kilometres away. Transportation from this destination is through rickshaws, *hath-thelas* (hand pulled cart to ferry goods) or battery-operated rickshaws/four-wheelers. Porters ferry stuff on their heads into the narrow by-lanes up to last mile into the shops or godowns, which are converted from residential into a commercial centre. The *katras* (enclosed

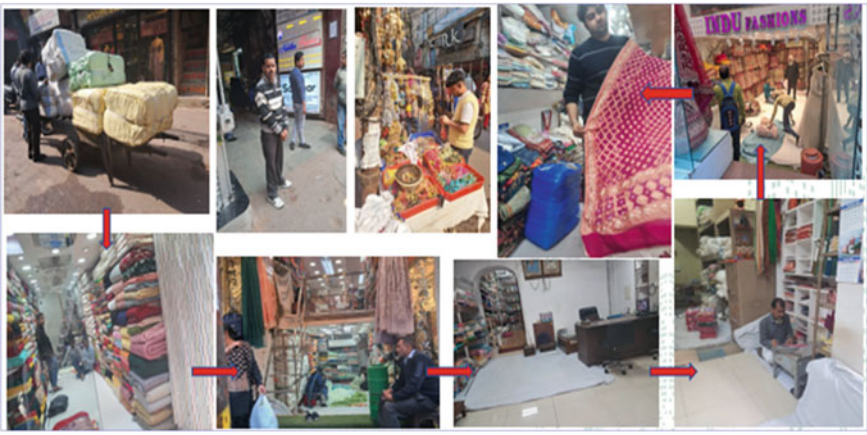

Fig. 3 Story of a lehnga. *Source* Author

spaces like colonies now mostly converted to commercial) are now a hub of wholesale cloth/spice market once had been residential in the interior lanes. To feed the designs and crafts of traditional ethnic wear, stitching, tailoring, and embroidery, *karigars* (craftsmen) conveniently own or rent out spaces for living or working in the interior lanes of *Chandni Chowk*. There is no cost of travelling or client meetings, negotiations, alterations, or small-scale industrial setup with easy climatological benefits (Fig. 3).

Customers are made to sit on mattresses while shoes are removed as the shop is a place which gives one his daily bread and butter and hence needs reverence. Goddess *Lakshmi* is the Goddess of wealth. Touts are still hired to engage and invite a customer to a particular shop. Of course, enough is there to savour one's taste buds and customers, too, are treated well when engaged for long, as *Dilliwalas* (residents of Delhi, a term used fondly for Delhites) are known for their big hearts and hospitality!

Once the deal is struck, *lehngas* are customized and made to order in said number of days with fitting/alterations that may require visits. Delivery is, per the convenience of the client, generally included in the cost of the product. If there is no deal, the whole market is there to explore. It is admirable that many of such ethnic pieces are unique. *Dilli Che* takes pride in resisting the mass production of such clothing. This speaks of their workmanship and authenticity. Though the same may not be true now that copies of designers' collection are easily available everywhere and this place is no exception.

6 Sustainable Concepts and Case Study Findings

The four pillars of a sustainable built environment are arranged under these four verticals. The findings of the case study were analyzed based on these verticals below, to establish it as a sustainable built environment (Fig. 4).

6.1 Social Sustainability

Ease of access to the bazaars, inviting nature of shop fronts, items on display, doubly loaded corridors and all the shops facing each other (Figs. 5 and 7) in a hierarchy pattern of streets with the major central spine, *Chandni Chowk* selling readymade display items, then interior shops selling more discreet products. The deeper one goes inside these markets, the more there is to discover, just like a Pandora box, the layers of streets unfold (Fig. 6).

These smaller street bazaars catering to a specific typology of cloth material are called *katras*. They are slightly at a raised level on a slope from the surrounding street which may have vehicular access. These are pedestrian access only. They also have a sense of neighbourhood security concept one experiences (experienced) in residential neighbourhoods under the watchful eyes of the fellow shopkeeper. This is a social existence which also needs sustenance. An occasional doorway or *Phatak* (Fig. 8) may still be seen at one of the *katras* surviving still, from the age-old times.

Items on display in a dense pattern with touts and shopkeepers/ their salesmen calling out potential buyers are luring enough for commerce to flourish in a relatively pleasant environment without air-conditioning. However, there are few fall-outs to such a setting, the privacy of shopping is also compromised in some situations. Another setback is the lack of open spaces or break-out zones for people (any of the stakeholders) to take a break from shopping, daily chores or routine jobs.

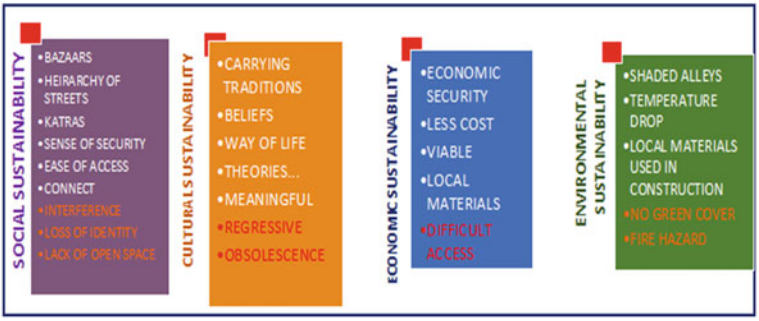

Fig. 4 Sustainable concepts under four verticals of sustainability. *Source* Author

Fig. 5 This is a typical picture of a *katra* in *Chandni Chowk, Nai Sarak* area where suits and dress materials are being sold at very comparative prices for the local and the wider market. The choice of the product in question is vernacular clothing. *Source* Google image (2023)

Fig. 6 Hierarchy of streets. *Source* Author, Base image: Google maps, street view 2023

6.2 Cultural Sustainability

The majority of shop owners are carrying forward their family professions and practices. However, dynamics have a major role to play. Numerous examples of descendants are there with high management and finance degrees from national and international universities of repute, joining parental businesses in *Chandni Chowk* and bringing significant and positive changes in the ways of functioning. Local has also taken to a global reach. E-commerce, strategic planning and nouveau ideas have added to the economics and have given a boost to trade with vernacular culture. On

Fig. 7 Labyrinth or maze: Each *gali* with shops facing each other

Fig. 8 *Phatak* to a gated colony of *katra* (commercial) or residential block for safety and security purposes. *Source* Author

conditions of anonymity and privacy, the author refrains from quoting big names of such people in business from the area.

The *Baithak* (formal sitting area) area of the shop, which is generally on a higher level from the ground and has to be accessed by sitting on the *gaddi* (mattresses) on the floor, is considered sacred; it is one's source of income, Goddess *Laxmi*. Shoes are to be removed to access this space. This also works since the entire area is laid out with mattresses and it is hygienic not to put your dirty shoes on *gaddi* with specifically white sheet spreads (*Chandni*). These about a foot and half high plinth areas, are judiciously utilized for keeping shoes or lockable cupboards, even as janitors (Figs. 9 and 10).

Fig. 9 Raised plinth to shops for keeping shoes out, tucked inside, or any other storage. *Source* Author

Fig. 10 Local vernacular economies:local *pansar*i. *Source* Author

However, certain economies may face obsolescence, such as cobbler (Fig. 12) and *haththela* (Fig. 3), which is regressive manual labour. Certain others such as *bandanwars* (festoon) for festivities and decorations for ceremonies, have taken a twist where vernacular handwork material has now been replaced by imported plastic Chinese *bandanwar* which is mass-produced, and hence out-numbered meeting demands and henceforth cheaper (Fig. 11).

Progressive and dynamic, this local *pansari*, with his measuring pan, still pulls crowds from near and far and has clientele the world over, is a famous one. An age-old shop located at the very corner of *Kinari Bazaar,* this is famous for *desi* (local) species and condiments and has a sustainable way of dispensing, directly into one's container brought along. He also keeps poly packs as per current market demand and delivers too at one's doorstep on demand through delivery apps on request.

Flourishing and catering to the needs and demands of the various stakeholders such as the shop owners, staff, workers, shoppers, and clients and importantly the

Fig. 11 Local vernacular economies:*bandanwar* selling shops in Kinari Bazaar. *Source* Author

Fig. 12 Local vernacular economies: local cobbler. *Source* Author

food tourists are the other thriving economies such as the *patila cholewala*s (chick-peas and sour bread delicacy), famous street food of *Purani Dilli*, special morning time delicacies, the *bedmi-nagori a*loo which in itself are unique to the land. There are numerous other such delicacies, each unique to a particular culture of the multi-cultural population to whom they primarily catered to (Figs. 13 and 14). Not to miss the *nukkad* (street corner) *paanwala* (betel leaves stimulant, an after-dinner treat) for social interactions at corners, a rare sight in the Delhi urbane.

Another aspect of cultural sustainability evident is flexibility and adaptable building design which seamlessly incorporated the different uses or variety of economies over time and continued to support still.

Fig. 13 Other vernacular economies: famous *matara kulcha* delicacy. *Source* Author

Fig. 14 Other vernacular economies: bedmi nagori delicacy. *Source* Author

6.3 Economic Sustainability

The hierarchy at which the flow from raw material procurement to final product i.e., the *lehnga* and its dispensing (ability to supply or release a product) is within a small radius of a kilometre or less is economic viability. Similar concepts are seen in each of these *galis* (lanes) known specifically for a specific kind of product only for example, *Kinari Bazaar* for *gota* (laces) (Fig. 17), *kinari* (laces), tassels, and embellishments, *Nai Sarak* north end spilling into *Chandni Chowk* famous for *lehngas* at lower price ranges, *Jogiwara* for cheaper saris and fusion dresses and so on. *Dariba Kalan*, on the other end of *Kinari Bazaar*, is known for gold, silver and diamond jewelry all over South Asia.

While the case study in question is particularly of the vernacular dress or *lehnga* but besides the images of the *lehnga* and the raw materials were easily procured while doing the fieldwork, the images of the people working on these small-scale industries, such as a machine or hand embroidery or cutting and tailoring units could not be taken for issues of privacy and discomfort. However, similar images of other economies such as bookbinding, using naturally made *lei* (glue) as an adhesive in file and papercutting industry in residential localities were possible, credit goes to the local workers for their permission. The best example of human resource can be seen here where one walks or at time climbs down to the place of work, conserving a million kilojoules of energy and travel costs and manpower. No tiring traffic, pollution, time consumption and hence economically viable. This concept has a term "*upar makaan niche dukaan*" (phrase meaning residential upper and shops lower) and is the seed for the age-old concept of sustainable built environments proposing mixed-use developments. While, in certain societies and by certain anthropologists, *Purani Dilli* may have been declared as a slum, the residents or the old *Purani Dilliwala*s refuse to accept this [7]. For them it is still a mystery to be explored.

The land value of the zone is considerably lower compared to the other zones of the city, with dense and compact planning. However, the same may not be true for the major *Chandni Chowk* spine or the major streets such as *Fatehpuri, Dariba Kalan* et al. The lower cost of living in this part of the city than the rest of Delhi makes it easier to sustain for all economic classes, own, rent, live or earn.

6.4 Environmental Sustainability

The high-density compact planning of this part of Delhi is much talked about and has been an in-depth area of study in all architectural and planning colleges across, which states that this zone is five to seven degrees cooler than the rest of New Delhi comparatively in summer and the same has been felt too [7]. Likewise, during winters the compact settlement pattern works for the conservation of heat and irregular meandering street patterns cleverly evade dust storms during dusty dry summer months sitting well environmentally in Delhi's composite climate. The compact buildings mutually shade each other from the harsh sun and the entire Chandni Chowk spine runs on the East–West axis of the sun with shaded arcades for shopping. Refer to maps (Figs. 15 and 16) and the pictures (Fig. 20).

Using traditional building materials and following traditional building styles, the shops with higher plinths also contribute to higher energy efficiency through reasonable temperature control and humidity levels in the environment. No wonder the earthquakes, some of which were significantly disastrous in the past, have shaken Delhi, considering Delhi lies in seismic zone IV, and there have been a lot of talks and speculations on its earthquake vulnerability; the compact nature of the built environment (Fig. 17), the wooden beams and *tukdi* (pieces) flooring/roofing, compact form to an extent has survived many centuries. Speculations and vulnerability owing

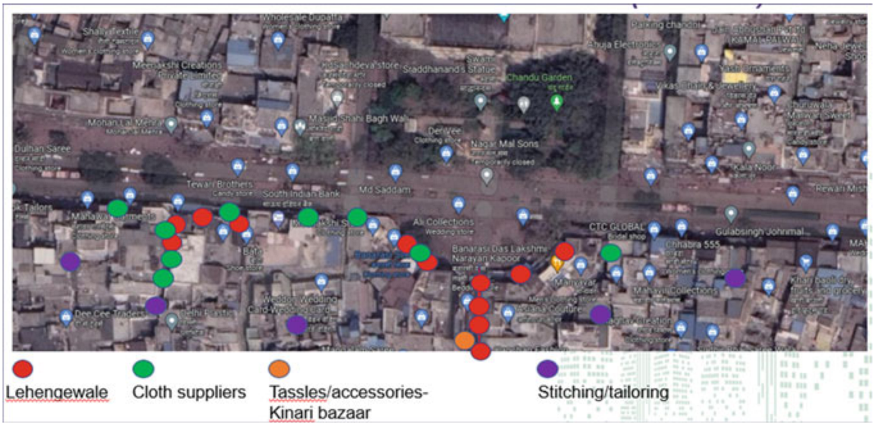

Fig. 15 Sites of activities in *lehnga* making economy (Google map of *Chandni Chowk,* Town Hall area 2023)

Fig. 16 Main *Chandni Chowk* Spine with *Kinari Bazaar* Street and *Dariba Kalan* (Google Maps 2023)

to the concerns of dense construction and population, as well as age-related issues, are valid, though and continue to pose a challenge.

The zone has now replaced residential with commercial majorly since the economy was a major determining factor besides others. Commerce is thriving having stated the various factors while residential facing major issues such as limitations of green cover, vehicular access, pedestrian, universal accessibility, lack of open spaces, play areas and fire hazard (Figs. 18 and 19).

Another major issue related to diminishing residential in these areas is increased commercial activity here. Due to this during the day all kinds of known-unknown people visit these alleys making it unsafe and vulnerable for residential and during nights, very few residential left, for a sense of security and well-being (Fig. 20).

The above images show the hierarchy of streets, starting from the major spine to secondary streets to finally the smaller ones, all have provisions for shading as shaded arcades in major streets with wide corridors to shop (Figs. 21 and 22) and smaller lanes shaded due to height of the built (Figs. 23 and 24), judicious use of local materials such as local yellow sandstone and red sandstone in pavements is visible. The recent restoration and redevelopment work of *Chandni Chowk* in phase I, 2020–21, has been done keeping in mind the vernacular architecture of the region; hence the new red sandstone paving is visible throughout the central spine. These are

Fig. 17 Blow-up of *Kinari Bazaar* Street (Google Maps 2023)

Fig. 18 Using naturally made *lei* (glue) as adhesive in file and paper industry

Fig. 19 Bookbinding and pater cutting industry in residential localities). *Source* Author

Fig. 20 View of *Balli Maran* from *Chandni Chowk* past noon showing mutual shading from building block on the main lane. *Source* Google Images (2023)

thermally efficient for Delhi's composite climate. For inside alleys, the old pavings are generally either of brick or cement concrete. However, here in the picture, cemented flooring of a roughly four feet wide alley is considerably cool and at a higher-level sloping towards its major street for better drainage (Figs. 23, 24 and 25). The shade and the alley width vs the height of the entire building which is a maximum of three to four storeys high is an all-season workable affair. During monsoons too, nothing much is left to open to sky hence works throughout the year.

Fig. 21 Hierarchy of spaces with shaded corridors: encouraging commercial activity: socio-economic aspect (North facing street at 3 pm). *Source* Author

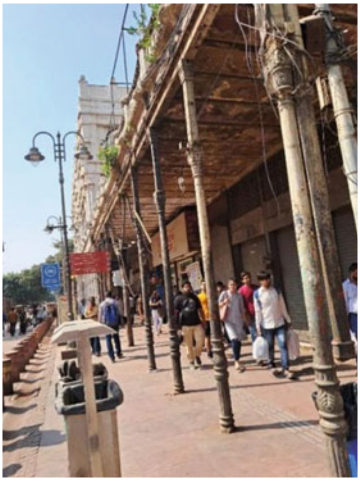

Fig. 22 Hierarchy of spaces with shaded corridors: encouraging commercial activity: socio-economic aspect (South facing the street at 11 am). *Source* Author

7 Critical Analysis

Certain issues need addressal collectively as socio-economic and cultural such as the receding residential pockets in the interiors of *Chandni Chowk* slowly as a large amount of raw material storage into godowns is not only restricted to only the ground and first floors of these colonies but also to second floors or intermediate (mezzanine) floors/attics called *duchhatti.* Since the requirements for storage for commercial purposes increased, and space was required, residentials were sold off. This is for the economy but certainly is not vernacular economy! Vernacular is for the local people [1, 11] and the local people themselves are waning from this area and dislocated. Secondly, vernacular is not mass-produced in those proportions which may

Fig. 23 Mutual shading round the day in Delhi's composite climate, all seasons affair. Cemented floor 4′ wide clean and totally shaded, sloped street section for rainwater drainage. *Source* Author

Fig. 24 Mutual shading round the day in Delhi's composite climate, all seasons affair. Cemented floor 4′ wide clean and totally shaded, sloped street section for rainwater drainage. *Source* Author

start having a bearing on the immediate environment to have long-term effects. The environment is not planned or able to support the services such as additional electrical load, load on the structure, plumbing and garbage generated of this magnitude to name a few. Other implications are the inaccessibility of the zone to the potential. They are then offered services at an elsewhere location outside the walled city by the same stalwarts in the field. This is detrimental to the interests of the culture,

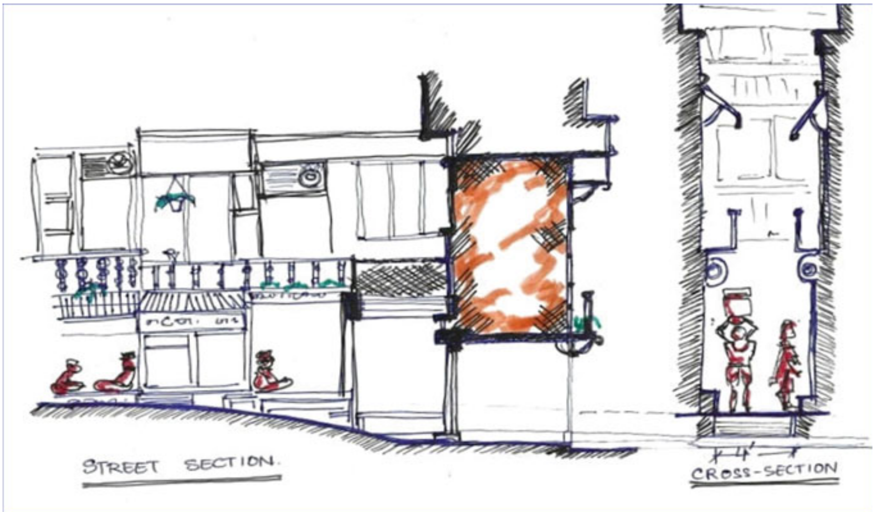

Fig. 25 Sketch by author showing street slope. *Source* Author

location and social well-being, discouraging entry into this zone and keeping it out of reach. This is a major blow to the whole vernacular ecosystem, whether vernacular language, culture, economy, food, clothing, arts, architecture et al. This requires further study and in-depth exploration and is beyond the scope of this research.

Measures in Built Environment

However, all is not lost with better connectivity to all the zones of the Walled city of Delhi from different locations through the Delhi metro, which is the most preferred form of public transport for this area. This has been verified by searching on all the major search engines, Google, Mozilla Firefox, Microsoft Bing, Internet Explorer and others. Designated car parking zones have been allotted and functional for private vehicles such as cars or two-wheelers. Connectivity with public transport apart from Delhi Metro, through buses, is also there. The central spine of *Chandni Chowk* is now totally pedestrianized. E-rickshaws for last-mile connectivity from Metro, buses, etc., are also available for convenience to promote commerce and accessibility. Cycle rickshaws, bicycles, two-wheelers, and bikes are common in the narrow lanes of *Purani Dilli*, zooming past.

There is no denying that ethnographic diversity, food, culture, and materialistic desires cause socio-cultural sustainability. The vernacular economies are the outcome of this want, and this area is considered a haven for gastronomic delights. Curated heritage food walks are an outcome.

Uppar makaan-niche dukaan, a very workable concept of mixed-use residential and commercial development, is a highly sustainable practice with no commuting, transportation, pollution, or energy consumption-related issues. Climatological balance all throughout the year and compact cohesive planning for thermal comfort in Delhi's composite climate are quite apt. A sense of belongingness and cultural identity in residents of the area still practising their age-old professions and now their younger generations bringing freshness and dynamism is commendable.

Protecting part of one's culture and practising it, is of immense value in own life and contribution to society. It gives society meaning and direction. In the words of postmodern French philosophers or theorists Deleuze and Guattari, society should promote arborescent thinking, which is seed and roots based and germinates like a tree against rhizomatic thinking which has no base, no character and grows out of nowhere and just anywhere. This study recognizes and establishes that the existing three dimensions of economic growth, social inclusion and environmental balance no longer reflect all the dimensions of our global societies, and culture is another interdependent marker.

8 Conclusion and Takeaways

The symbiotic relationship of man and the environment is most beautifully understood in vernacular-built environments which have been sustainable. Another aspect of sustainability is **flexible and adaptable design** in vernacular mode of building. **Self-sustaining self-sufficient sub-city concept** catering to a larger network globally are the setting markers from which lessons are to be followed. The impact of new age business strategies and new investment ideas through young minds into the age-old vernacular economies is bringing **dynamism** or threat to culture is an aspect of study and an area of research.

With certain limitations of **lack of break-out zones, green and/or open spaces**, and safety in case of fire eventuality, the compact cohesive meandering lanes pose a design challenge, which this paper further suggests exploration.

The paper, through the case study, brings up the verticals, social, economic, cultural and environmental interests in the thriving vernacular economy in question/economies existing. Their adaptation to the climatological changes throughout the year, cultural nostalgia, carrying food traditions, practices, choice and use of local materials, resources, craftsmanship and **eventual resilience** all matters.

Challenges are many with air-conditioned high-end swanky malls located at the outskirts of the city catering to all the basic urbane amenities like the decent parking lots, safety and security to vehicles, lifts, choicest fast foods on the go for shopaholics selling "CHANDNI CHOWK KE GOLGAPPE/SITARAM BAZAAR KI CHAAT" for nostalgic consumption [3]. No visceral connection to experience. **Cross-cultural exchanges**, hence ethnographic diversity may bring obvious changes and that is the reason for the changing dynamics, which is inevitable and is a sign of a progressive society ready to adapt along with the past.

[Hyderabad gets its first zero waste grocery store that encourages customers to bring their non-plastic packaging—The Hindu 2021] Our local pansari (Fig. 10) has ever since been doing this without recognition, only to realize when Hyderabad grocery store stakes claim. This itself reiterates and validates the relevance of this study for present and for future.

Each *katra* or zone offers independent quantitative study and qualitative ethnographic research on relationship of the vernacular economy with the local and their interdependencies as further scope.

References

1. Asquith L, Vellinga M (eds) (2006) Vernacular architecture in the 21st century: theory, education and practice. Taylor & Francis
2. Beynon D (2010) Defining cultural sustainability in multicultural built environments. Int J Environ Cult Econ Soc Sustain 6(5):255–266
3. Brosius C (2012) City Fantastic, India's middle class: new forms of urban leisure, consumption and prosperity. Routledge
4. Cities U, Governments L (2004) Agenda 21 for culture. Committee on culture–United Cities and Local Governments, Barcelona
5. Duxbury N, Baltà J, Hosagrahar J, Pascual J (2016) Culture in urban development policies: an agenda for local governments. In: Culture: urban future–global report on culture for sustainable urban development, pp 204–211
6. Duxbury N (2012) Cities, culture and sustainable development, Summer Lab'12: art, climate change and community development. Torres Vedras, Portugal, 5 Sept 2012. http://www.ces.uc.pt/myces/UserFiles/encontros/1097_DUXBURY_Torres_Vedras_05.09.2012.pdf.
7. Goodfriend DE (1982) Shahjahanabad-Old Delhi: tradition and planned change. Ekistics, pp 472–475. http://www.jstor.org/stable/43621804
8. Hosagrahar J (2013) Recommendation on historic urban landscapes: relevance in India. Context 10(2):19
9. Hawkes J (2001) The fourth pillar of sustainability: culture's essential role in public planning. Common Ground
10. Lazar N, Chithra K (2022) Role of culture in sustainable development and sustainable built environment: a review. Environ Dev Sustain 24(5):5991–6031
11. Vellinga M (2013) The noble vernacular. J Archit 18(4):570–590. https://doi.org/10.1080/13602365.2013.819813
12. NZMCH (2006) Cultural well-being and local government report 1: definition and context of cultural well-being. New Zealand Ministry for Culture and Heritage (NZMCH); Wellington Parodi O (2011) Three steps towards a culture of sustainability. In: Parodi O, Ayestaran I, Banse G (eds) Sustainable development-relationships to culture, knowledge and ethics. KIT Scientific Publishing, Karlsruhe, pp 76–92
13. Ren X (2018) From Chicago to China and India: Studying the city in the twenty-first century. Ann Rev Sociol 44:497–513. https://doi.org/10.1146/annurev-soc-073117-041131
14. Rohatagi J (2018) Crafts and craftspeople of Shahjahanabad | Sahapedia https://www.sahapedia.org/crafts-and-craftspeople-of-shahjahanabad
15. UNESCO (2001) Universal declaration on cultural diversity. In: General conference of UNESCO, Paris, http://unesdoc.unesco.org/images/0021/002110/211094e.pdf

16. UNESCO (2012b) The future we want: the role of culture in sustainable development. The United Nations Scientific, Educational and Cultural Organization (UNESCO). http://www.unesco.org/new/en/rio-20/culture-for-sustainable-development/
17. United Nations Educational, Scientific and Cultural Organization (UNESCO) (2016) Global education monitoring report summary 2016: education for people and planet: creating sustainable futures for all

Understanding Notion of Public Spaces: Learnings from Historic Cities in Rajasthan for Planning Sustainable Urban Habitats

Urvashi Srivastava, Amit Hajela, and Jaya Kumar

1 Introduction

1.1 Challenges of Urban Habitats

India is now world's most populous nation with a booming population of 1.42 billion as per World Population Review [6]. A closer look at its immediate context reveals the challenges of a globally linked and fast urbanizing world. It has been estimated that by 2050 two-thirds of the population in Asia will live in urban areas [8]. Its implication for the world and particularly for India is of critical importance. Urbanization is inevitable. It is also not a uniform and harmonious process. While on one hand urbanization is a measure of economic progress, prosperity, and quality of life on the other hand it exposes and brings to the forefront the vulnerability of the most susceptible sections of the urban population. Urbanization is a driving force for environmental degradation. Cities are responsible for almost 75% of global carbon-di-oxide emissions with transport and buildings being among the largest contributors [3].

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1.2 Statement of Problem

Indian cities today face the daunting task of managing rapid urban growth and at the same time becoming equitable, liveable, and sustainable. In Rajasthan urbanization has put pressure on urban resources, services and infrastructure, leading to deterioration in quality of life, poor sanitation and solid waste disposal, water shortage, pollution, poor transport system, congestion, encroachment, dilapidated built heritage, inadequate drinking water, public toilets, health facilities and has also created dilapidated ghost towns due to migration [16]. NIUA report states that 11 out of 40 historic cores in Rajasthan are distinctively transformed whereas remaining 29 cities have retained more than 50% of the character but are under continuous pressure. Public spaces especially in historic cities in Rajasthan are under distress and at risk.

United Nations Sustainable Development Goals (SDGs) are an urgent call for action to meet the challenges of urbanization by all countries both developed and developing nations. SDG 11 specifically deals with urbanization and aims to 'Make cities and human settlements inclusive, safe, resilient and sustainable'. Target 11.7 lays emphasis on providing universal access to safe, inclusive and accessible, green and public spaces by 2030. Public Spaces are an important intervention area for attaining sustainability in urban habitats. Achieving SDG targets will require planning strategic measures to intervene in historic cities and towns.

1.3 Need of the Study

Inherent peculiarities of inner core areas in historic cities in India pose several constraints, as a result transformation phenomenon triggered by urbanization, have over the years altered their urban fabric. Further public spaces that form a significant part of any city are not untouched by the larger urban processes taking place. Insensitive transformation of inner core area in the form of encroachments, unplanned vehicular traffic, insensitive infrastructure interventions, changes in land use, inadequate additions and alterations to built fabric, incompatible new construction, misuse, disuse, and lack of maintenance of historic buildings and structures have greatly impacted tangible and intangible attributes of public spaces. Public spaces are increasingly becoming inaccessible, uncomfortable and unattractive for people significantly affecting the way residents interact with and within these spaces. There is an urgent need for a systematic investigation of public spaces in inner core areas in historic cities for understanding 'notion of public space' and therefore their unique attributes that need to be safeguarded.

1.4 Objective of the Study

Public spaces in inner core areas in historic cities in India especially a holistic understanding of their distinctive tangible and intangible attributes have been a relatively underexplored domain. In order to safeguard public spaces a detailed investigation is required to understand processes that resulted in the creation of their distinctive material dimension as well as their intangible attributes. The objective of this study therefore was to develop a holistic understanding of public spaces in inner core area in historic cities by evaluating their varied attributes namely morphological, social, cultural, behavioral, economic, institutional, and environmental.

1.5 Relevance of the Study

Public spaces in historic cities are at the core of urban life. They are critical to physical and mental well-being of inhabitants. In India cities are witnessing exponential growth that has posed several challenges to the existence of public spaces. In order to make historic cities liveable it is important to safeguard public spaces. This research is a unique opportunity to develop a better understanding of historic cities through the study of public spaces. This research gains increased relevance in the context of the growing negative impact of the transformation phenomenon on public spaces and therefore on the quality of life of local communities in historic cities.

1.6 Research Methodology

A Mixed Method Research Strategy using a blend of Case Study, Historical, and Phenomenological Research techniques was deployed for the study of public spaces in inner core area in four historic cities in Rajasthan to examine the nature of public spaces, public realm and inner core area. Both qualitative and quantitative tools have been used to conduct the study. Literature on the subject of both Western and Indian thought on public space was studied. In the four historic cities study of urban structure of inner core area, public realm, public space morphology, and activities was undertaken using techniques of in-situ observation, field notes, visual documentation tools (photographs and videos), spatial mapping, study of archival material, historical maps and literature review on the subject including local literature and architectural history.

Key components of public space were identified based on empirical observations of public spaces in four cities. Theory of 'Geometrical Analysis' and 'Chronological Comparative Analysis' [9] were utilized to understand the physical structure of elements of inner core area and growth and transformation of that structure through time. Using 'Hierarchy of Components as a Tool' study of elements at the level of resolution of buildings, plot pattern, street, and block pattern was undertaken. Further mental mapping technique [12] was used to identify paths, nodes, edges, districts, and landmarks to establish imageability and character of inner core area of four historic cities. Finally based on literature review and empirical observations conceptual models and a parametric framework was developed to systematically evaluate public spaces.

2 Review of Literature

2.1 The Idea of Public Space

Public spaces in historic cities were not only an integral part of the morphologically distinct urban tissue of the inner core area but were at the core of city planning. Understanding public spaces and their role in the creation of sustainable urban habitats requires an understanding of what constitutes public spaces as well as the process of their creation. In the West several public space thinkers have attempted to articulate the idea of what constitutes public space. Carr suggests public spaces are publicly accessible places where people go for group or individual activities [2]. Mitchell talks of the notion of public space as an unrestrained public sphere where social and political movements can occur [15]. Madanipour talks about space that is not controlled by private individuals or organizations and hence is open to the general public [13]. Porta emphasizes the 'idea of social contact' going on to state that people are attracted by other people; adults adore the sight of ever-changing human activities [17]. Mehta talks of various definitions of public space based on ownership, control, access, and use [14]. Given the above thoughts and deliberations public space can be best defined as space accessible to all irrespective of its ownership, is free to be used for public purposes, does not have any particular restrictions on users, and fosters social interaction.

2.2 Public Realm

Integral to the understanding of what constitutes public space, is the understanding of the process of creation of space both physical and social and also inextricably connected to this is the concept of public realm. Lefebvre studied in detail the process of production of space and states that each living body is space and has its space; it produces itself in space and also produces that space [10]. Soja talks of lived spaces being socially constructed indicating humans have an impact on other human beings and ways in which cities and social spaces are constructed can have a big impact on our daily lives [19]. Thomas elaborates the relationship of public space to public realm and argues that public space is only one part, a physical manifestation of public realm and plays an important role in sustaining it [22]. Lofland talks of public realm as the city's quintessential social territory [11]. Jacobs studied how the building blocks of city-its households, streets, neighborhoods, districts-affected one another and the whole and discovered webs of social linkages [7]. Whyte talked of social life of public spaces and studied human behavior in urban settings through the pioneering Street Life Project [24]. Appleyard studied social effects of cars on cities, studied different streets and found that they affected the social life of people [1]. These studies suggest that public space as a physical construct is intimately linked to its context and its subject i.e. humans who create it and also indicates that complex apparently imperceptible processes operate behind the visible material public space imparting it a dynamic, experiential, and subjective character.

2.3 Historic Cities and Inner Core Area

Public spaces rooted in their immediate context have a dynamic and evolving character. As the city changes so do the public spaces. Lynch talks of city design as a temporal art, says that it is ever changing in detail and that only partial control can be exercised over its growth and form [12]. Rossi talks of the form of the city as the form of a particular time of the city; there being many times in the formation of the city [18]. Kropf talks of urban fabric as a result of accumulation of historical acts-acts of building or rebuilding; having a 'distinct structure'-patterns of pattern, being product of a long process of formation with many additions, subtractions, replacements and transformations containing examples of buildings from many periods having variety, richness, and individuality [9].

The result of constant growth is a morphologically distinct urban tissue in historic cities that has evolved over centuries and is referred to as inner core area. Steinberg remarks that most inner cores still stand replete with buildings, artifacts, and other features of historical and cultural value, are living museums that fell into neglect during the twentieth century, often as unintended by-product of rapid urbanization [21]. Srivastava in her study of Banaras remarks that urban structure of the historic city is characterized by neighborhood clusters or mohallas, its primary building blocks, interspersed by interconnected and hierarchical public spaces [20]. Inner core area is not only physically distinct but also socio-culturally diverse. Faetanini talks of old city areas as melting pots of diverse groups of people with different social, cultural and religious backgrounds which makes up the traditional peculiarities of historic neighborhoods [5].

Inner core area in historic cities thus apart from being morphologically distinct are also socio-culturally rich and support a hierarchy of diverse public spaces. The characteristic tangible and intangible attributes of public spaces in historic cities are a manifestation of the unique morphology of inner core area, its public realm and related activities.

2.4 Gap in Research

Public space is not just physical, is conceptual and experiential, has socio-cultural, economic, political, and behavioral spheres that operate within the physical space constituting its public realm. While such concepts are well-developed in Western thought, they are yet to be crystallized in the context of public spaces in Indian historic cities. 'Notion of Public Space' in historic cities needs to be systematically examined. Also there have been no studies undertaken to understand the impact of large-scale interventions especially related to infrastructure on public spaces in inner core areas especially on their experiential attributes. Lack of holistic understanding of public spaces in inner core areas has resulted in such traditional spaces not being qualified as 'public spaces' within the planning framework and hence there are no strategies for mitigating negative impact of urbanization on such spaces. Through crystallizing the 'Notion of Public Space' in inner core area of four historic cities this study hopes to address these gaps in research.

3 Case of Four Historic Cities in Rajasthan

Public Spaces were investigated in the inner core area in four distinct geographical, political, and socio-cultural contexts in Rajasthan. Spread of inner core area, spatial structure, time period, geo-morphological context, population, and scale of urbanization were factors taken into consideration while selecting the four historic cities namely Jaipur, Bikaner, Udaipur, and Bharatpur. Based on literature review and empirical work in inner core areas in four historic cities in Rajasthan a conceptual model for the hierarchy of spaces and public realm was developed for the study of public spaces. The conceptual model of 'Hierarchy of Public Spaces' in historic cities developed based on literature review and field studies (see Fig. 1) establishes the hierarchical nature of space planning in inner core area in the four historic cities.

The conceptual model of 'Public Realm' defines public realm as an intangible domain in which political-economic, socio-cultural, and behavioral spheres interact and intermingle to produce social and physical space (see Fig. 2).

3.1 Urban Structure of Four Historic Cities

Study of Jaipur, Bikaner, Udaipur, and Bharatpur revealed that the planning and design of the cities was a function of a complex interaction of several factors such as topography, climate, locally available building resources, trade and economic growth, strategic military considerations, religious beliefs, social organization, and behavioral norms. The inner core area in each of the four cities was found to have a well-defined settlement boundary, delineated by fortification walls, bastions, and

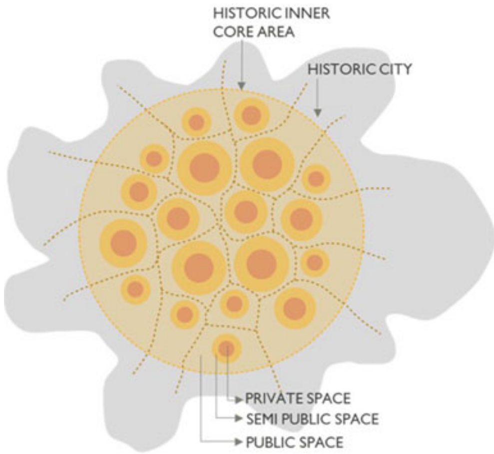

Fig. 1 Hierarchy of public spaces in historic cities. *Source* Author

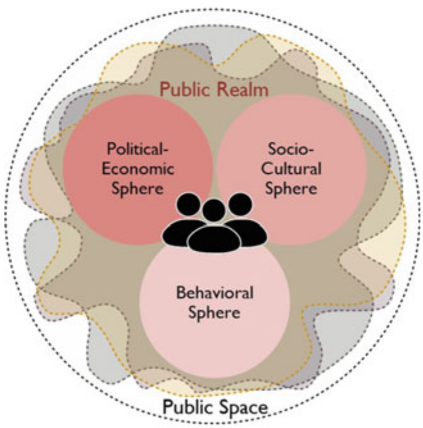

Fig. 2 Conceptual model of public realm. Based on the concept of 'Interplay of Spheres' for production of social and physical space. *Source* Author

gates. In each of the four cities urban blocks are defined by a hierarchical network of streets (see Fig. 3).

While Jaipur has well-planned urban blocks in the form of nine square *chowkris* (blocks) defined by a monumental grid iron network of streets, rest of the three cities have irregular urban blocks delineated by an intricate and hierarchical street network. In all cities primary streets connect with a network of secondary streets. Secondary streets further lead to a much narrower network of tertiary streets mostly residential in character. Plots within urban blocks are organically organized in all cities and compact close knit built to edge buildings define street edges. Inner core area in all four historic cities was found to be characterized by extremely high density having undergone different levels of transformation. Mixed land use pattern having an interesting mix of commercial, residential, institutional, and religious use was predominant in the inner core area mostly along the primary streets in all cities. It

Fig. 3 Street network, urban blocks and plot patterns in four historic cities in Rajasthan. *Source* Author

was observed that within urban blocks, neighborhoods were socially organized into mohallas having social diversity, strong social networks, and well-defined social boundaries often reinforced by physical elements such as street, open space, temple, shrine, tree, etc.

3.2 *Public Space as Manifestation of Public Realm*

Four historic cities investigated for the study dating from the late fifteenth century to early eighteenth century beginning with Bikaner followed by Udaipur, Jaipur, and Bharatpur experienced growth over several centuries. Each city has a distinct character which has been an outcome of several centuries of political development, economic growth, urban expansion, socio-cultural practices, and way of life. Diverse social structure gave rise to varying activity patterns within the spaces. Trade was found to be one of the primary functions in all four cities. Rulers promoted cities as trading hubs attracting merchants from around the region. Being the seat of power for their respective kingdoms, cities were center of political and administrative institutions. Political authority controlled the public realm, with clear demarcation of spaces, both royal and common. Well-organized social structuring of mohallas constituted by clusters of havelis facilitated a community or wider social group bonding based on caste, professional, and social attributes. In all four cities interaction between political, economic, socio-cultural, and behavioral spheres created a unique public realm. It was observed that there was a clear demarcation and hierarchy of private and public realms. Social and cultural norms influenced nature of activity in public spaces and behavioral pattern of individuals strictly governed by social norms influenced the activities of individuals in public space.

In Bikaner it is said that Rao Bikaji founder of the city administered his kingdom from the royal throne in the shape of a '*pata*' and so did his chiefs. The tradition continued and eventually the public realm in the city came to be centered around *patas*, large rectangular wooden benches. *Patas* placed in galis (streets) and chowks (squares) became centers of social life in the neighborhood where Bikaneri men gathered for discussions. Bikaneri Pata fostered the spirit of community, encouraged conversations, enabled the exchange of views and news fostering a unique culture or '*Pata sanskriti*' [4]. Chowks, streets, lanes, and by lanes functioned as stages for daily social interaction and collective festive celebrations.

In case of Jaipur, the renaissance city of eighteenth century, planned as a trading hub, public realm manifested itself in the form of monumental-scale public spaces where commercial transactions went hand in hand with social interactions and festive celebrations. City had bustling *bazaar* (market) streets and *chaupars* or large squares for commerce. Bazaars planned along primary streets had intense and diverse commercial activity. Enclosed spaces attached to the city gates also functioned as public spaces.

Udaipur planned as the capital of Mewar kingdom on the banks of lake Pichola, had grand scale public spaces along the lake edge associated with landmark buildings and structures. Public realm in the city centered around the lake, ghats (steps reaching out to the water edge), bazaar streets, and chowks. Streets and ghats transformed into celebratory spaces during festivals. Socio-cultural expressions were deeply intertwined with the overpowering natural context of hills, water bodies, and forests. Lakes, reservoirs, streams, channels, wells, and step-wells were perfect settings for expression of religious, cultural, and functional needs.

Bharatpur designed as a capital of the Jat kingdom had monumental-scale public spaces associated with landmark buildings as well as along *Sujan Ganga* the grand moat surrounding the fortified royal enclave. Spiritual underpinnings and ingenious thinking of Jat rulers coupled with the skills of talented refugee planners, designers, tracers, artists, and stone craftsmen of Delhi, Agra, and Jaipur [23] created innovative socio-cultural institutions such as the *Ganga Mandir* (temple), *Lakshaman Mandir* and *Jama Masjid* (mosque) along with unique associated public spaces. City had a unique tradition of *Bageechis* (gardens) and *Akharas* (traditional wrestling arena) on the periphery that acted as socio-cultural and leisure spaces.

3.3 Public Space Planning Principles in Four Historic Cities

A distinct public realm in each of the four cities of Jaipur, Bikaner, Udaipur, and Bharatpur endowed public spaces with a unique identity. In all cities hierarchical network of primary, secondary, and tertiary streets intersected to create attractive public spaces. All cities boasted of diverse spectrum of public spaces ranging from city level monumental squares or *chaupars* as in the case of Jaipur to micro level threshold spaces the hallmark of neigborhoods with built-to-edge buildings. Clear demarcation of private and public realms created a hierarchy of public spaces in each of the cities. Hierarchical organization of space in all cities started from the innermost and most intimate private space or the dwelling interspersed with semi-public spaces linked to city level public spaces (see Fig. 4). In all cities, neighborhoods were planned as a mix of residential units, religio-cultural institutions, and water points to

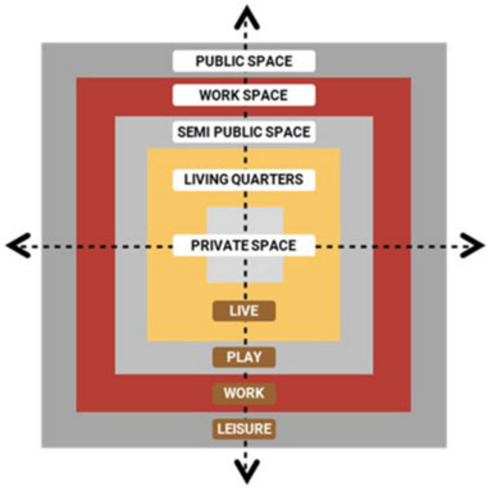

Fig. 4 Hierarchical model of spatial organization in inner core area in historic cities. *Source* Author

create self-contained urban blocks. Work spaces were planned on edges of the urban blocks in close proximity of residential quarters. This ensured walkability across the city. This hierarchical model of spatial organization found a mature expression in case of Jaipur where the inner core area was found to be well-planned with a distinct spatial organization starting from the private space to the semi-public leading to the city level public space.

In all the cities it was observed that streets, nodes, and incidental spaces were interconnected and held urban blocks together. Dense network of streets, nodes, open spaces, and incidental spaces supported an active public realm and constituted thriving public spaces in the cities. Hierarchical network of primary, secondary, and tertiary streets intersected to create nodes or *chowks*. Havelis organized as linear and group clusters created shared social spaces for informal play, social interactions, and family gatherings. Compact close-knit built-to-edge buildings had incidental social spaces associated with the edges. Informal social spaces such as *chabotras* (platforms), *otlas* (seating space), and steps created opportunities for spontaneous day-to-day interactions.

Inner core area in the four historic cities is characterized by diverse types of public spaces namely streets and transit spaces such as *sadak* (road), *rasta* (street), *gali* (alley) and sidewalks; *bazaars* (street market) and *katla* (enclosed market); *chaupar* (square), *chowks* (node), spaces associated with religious structures, water harvesting structures namely *baori* (step well), *ghat* (flight of steps leading to water edge) and *kuan* (well) and leisure spaces such as parks, fair grounds, and open spaces (see Fig. 5).

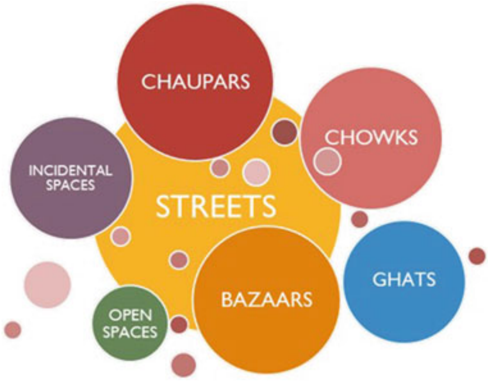

Fig. 5 Types of public spaces in inner core areas in historic cities. *Source* Author

4 Data Analysis and Inferences

4.1 Comparative Analysis of Four Historic Cities

A unique public realm resulting from the interaction of political, socio-cultural, economic, and behavioral spheres imparts a unique identity to public spaces in the four historic cities both physically and experientially. Comparative study of urban morphology, public spaces, and public realm revealed that all cities have a distinct inner core area delineated by fortification walls, bastions, and gates and a dense hierarchical network of primary, secondary, and tertiary streets punctuated by *chowks, bazaars, chaupars* and incidental social spaces (Table 1).

It was observed that the nature of activity in public spaces depends on location, scale, building uses and social structure in its immediate context. In each city public spaces promote commerce, collective celebrations, gatherings, and daily social interactions. Public Spaces function as shared spaces and are free to be appropriated by communities for diverse functions ranging from day-to-day interaction to being used as staging grounds for grand collective celebrations. Practice of traditional arts and crafts thrives in public spaces based on the social structure. Public spaces support an active public realm and nurture a wide range of activities such as trade, commerce, social discussions, practice of traditional crafts, festivals, religious and cultural activities, classical folk music and dance performances, street dining, and informal social interactions (see Fig. 6).

All four cities with their diverse public spaces sustain a distinct way of life in response to the prevalent socio-cultural norms. Hierarchical and interconnected public spaces facilitate smooth and seamless transition between the public and the private realms. Public Spaces nurture creativity and diverse activities make the city vibrant, sociable, and liveable. Walkable, accessible, interconnected, and sociable public spaces promote physical and emotional well-being of inhabitants. With their unique response to the geographical context, public spaces as in the case of Udaipur and Bharatpur are deeply intertwined with the natural context with water being an

Table 1 Comparative Study of Four Historic Cities in Rajasthan

	Bikaner	Jaipur	Udaipur	Bharatpur
Evaluation of inner core area				
Boundary				
	• Inner core area has well-defined settlement boundary, delineated by fortification walls, bastions, gates			
Area population	• 2.67 km^2 • 6.44 Lacs (2001)	• 6.7 km^2 • 30.7 Lacs (2001)	• 2.08 km^2 • 4.51 Lacs (2001)	• 4.01 km^2 • 2.53 Lacs (2001)
Growth pattern				
	• Organic & dense hierarchical network of primary, secondary & tertiary streets punctuated by varying scales of *chowks* except Jaipur which has distinct planning & hierarchical grid iron street network intersecting to create monumental *chaupars*			
Urban block pattern				
	• Irregular urban blocks defined by primary streets except Jaipur which has regular urban blocks defined by primary streets that create 9 *chowkris*			
Building pattern				
	• Compact close knit built to edge buildings with incidental social spaces associated with the edges			

(continued)

Table 1 (continued)

	Bikaner	Jaipur	Udaipur	Bharatpur
Understanding public space in inner core area				
Character type & typology	• Streets, nodes, open spaces & incidental spaces constitute public spaces • Diverse types & typology of public spaces, distinct from those found in modern cities • All cities have incidental spaces that function as active social spaces			
Understanding public realm in inner core area				
Socio-cultural sphere	• Clear demarcation of spaces, hierarchy of private and public realm in all cities • Urban blocks socially organized into mohallas having social diversity, well-defined social boundaries, and strong social networks • Mohalla functions as nurturer of cultural traditions • Socio-cultural norms influenced activity in public spaces • Socio-cultural expressions deeply intertwined with natural context in Udaipur			
Political-economic sphere	• Political domain controlled public realm • Clear demarcation of public spaces both royal and common in all cities except Bikaner • Trade and commerce primary generator of public space activity in all cities			
Behavioral sphere	• Social norms strictly governed individual behavior, public spaces largely dominated by males with limited activity of women and undefined public spaces for children			
Essence of public realm				
	• Public realm centered around public spaces such as chowks and bazaars as stages for daily interaction and collective celebrations. Bikaner has *Patas*, Jaipur has monumental *Chaupars*, Udaipur has grand ghats and Bharatpur has *chowks* and *bageechis*			

Source Author

Fig. 6 Characterizing public space activities in inner core areas in historic cities. *Source* Author

important element. Public spaces integrated with water and greens bring the two together making them part of the day-to-day experience of people.

4.2 Developing a Parametric Framework for Understanding Public Spaces

Detailed analysis of public spaces in the four historic cities has revealed that the material public space had been conceptualized as an armature for sustaining the distinct public realm which was seen as an evolving domain created through the complex interaction of the political-economic, socio-cultural, and behavioral spheres operating in the public space. Four key underlying principles of public space namely being sociable, accessible, having no restrain, and free to being used were identified across all cities. These fundamental principles define public space in the four historic cities.

On the basis of literature review and empirical study in the four historic cities five physical attributes namely natural features, space morphology, buildings and structures, objects and ground surface features, and utilities that define the material public space have been identified. Nine non-physical and user attributes of image, activity, linkage, access, social interaction, right to use, safety, livelihood, and participation that characterize intangible attributes of the public space have also been identified. A parametric framework for understanding public spaces in historic cities has been developed using the four identified fundamental principles, five physical, and nine non-physical and user attributes (see Fig. 7). The proposed framework is a significant

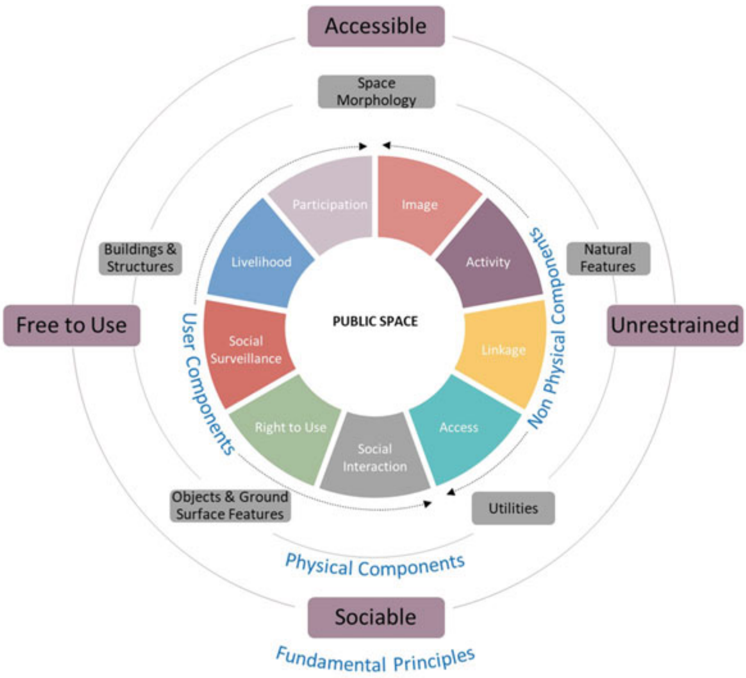

Fig. 7 Parametric framework for understanding public space in historic cities. *Source* Author

tool that can be deployed for a systematic evaluation of public spaces in historic cities in order to establish the notion of public space.

4.3 Parametric Evaluation of Public Spaces in Four Historic Cities

A comparative study of public spaces in four historic cities was undertaken using the proposed parametric framework developed for understanding the notion of public space. The study revealed distinctive characteristics of physical, non-physical, and user-related attributes that form an integral part of public spaces in the four cities (Table 2).

4.4 Crystalizing Notion of Public Space

The parametric study of public spaces in the four cities clearly established that the 'Notion of Public Space' in all cities is that of a seamless, hierarchical, and shared

Table 2 Parametric study of public spaces in four historic cities in Rajasthan

	Bikaner	Jaipur	Udaipur	Bharatpur
Physical elements				
Natural features	• Trees important part of *chowks* and incidental public space	• *Chaupars* and incidental public spaces had trees as important feature	• Public spaces centered around two lakes, trees, hills were integral part	• Trees were integral part of *bageechis* and incidental spaces
Space morphology	• Buildings and structures defined space • Distinct edge interface (raised plinth, *chabootra, gokha*, verandah, *jharokha*, steps)	• Buildings and structures defined space • Distinct edge interface (raised plinth, *chabootra*, *gokha*, verandah, *jharokha*, steps)	• Buildings, structures, and natural features defined the space • Distinct edge interface (raised plinth, *chabootra, gokha*, *jharokha*, steps)	• Buildings and structures defined the space • Distinct edge interface (raised plinth, *chabootra*, *gokha*, *jharokha*, steps)
Buildings & structures	• Built-to-edge buildings with rich architectural features	• Monumental built to edge buildings with rich architectural features	• Built-to-edge buildings with rich architectural features	• Built-to-edge buildings with rich architectural features
Objects & ground surface features	• *Patas* (large wooden benches) in chowks • Small shrines • Stone paving	• Small shrines, wooden benches • Stone paving • Street lamps	• Small shrines, stone benches • Stone paving	• Small shrines, worshiping stones, symbolic stone footprints • Stone paving
Utilities	• Water points (wells, *piyaoo or* water facility, water troughs)	• Water points (*baori*, wells, *piyaoo*, water troughs), streetlights	• Water points (wells, *piyaoo*, water troughs)	• Water points (wells, *piyaoo*, water troughs)
Non-physical elements				
Image	• Landmark buildings and structures • Presence of spaces for rest and relaxation	• Landmark buildings gave distinct character to spaces • Visual harmony through signage • Presence of spaces for rest and relaxation	• Landmark buildings and structures defined spaces • Presence of spaces for rest and relaxation	• City level public spaces centered around landmark buildings

(continued)

Table 2 (continued)

	Bikaner	Jaipur	Udaipur	Bharatpur
Activity	• Multifunctional spaces, wide variety of activities, diurnal and periodic pattern (*patabazi*, classical and folk music and dance performances, festivals) • Opportunities for social interactions on *patas* in chowks	• Multifunctional spaces, wide variety of activities, diurnal & periodic pattern, grand festive celebrations • Opportunities for close social interactions in *chaupars*, *chowks* and streets	• Multifunctional spaces, wide variety of activities, diurnal & periodic pattern, grand festive celebrations • Opportunities for close social interactions in, *chowks*, streets, *ghats and baghs* (gardens)	• Multifunctional spaces, wide variety of activities having diurnal & periodic pattern, festive celebrations • Opportunities for close social interactions in *chowks*, streets, *ghats, bageechis, akharas*
Linkage	• Well connected with adjacent public spaces	• Well connected with adjacent public spaces	• Well connected with adjacent public spaces	• Well connected with adjacent public spaces
Access	• Accessible and walkable spaces	• Accessible and walkable spaces • Sidewalks prevented vehicular conflict	• Accessible and walkable spaces	• Accessible and walkable spaces
User elements				
Social interaction	• Chowks and streets served as gathering spaces	• *Chaupars* were great opportunities for interaction at the city level	• Ghats were excellent spaces for celebrations and daily interactions	• Chowks and streets facilitated daily interactions
Right to use	• Free to use, celebrations brought together diverse social groups	• Free to use, celebrations brought together diverse social groups	• Free to use, celebrations brought together diverse social groups	• Free to use, celebrations brought together diverse social groups
Safety	• Presence of people of diverse communities • Social surveillance through close community living	• Presence of people of diverse communities • Social surveillance through close community living	• Presence of people of diverse communities • Social surveillance through close community living	• Presence of people of diverse communities • Social surveillance through close community living

(continued)

Table 2 (continued)

	Bikaner	Jaipur	Udaipur	Bharatpur
Livelihood	• Traditional vocations, art and product manufacture (*Bandhej*, *Meenakari* and *Kundan* jewelry, *Usta kaam*) food specialties, hawking, and performances	• Traditional vocations, art, and product manufacture (Blue Pottery, Lac bangles, Gems and Jewelry, Marble artifacts, *Jootis*), food specialties, and hawking	• Traditional vocations, art and craft product manufacture (paintings, handmade paper, metal engraving, damascening, jewelry, leather work, pottery), food specialties, and hawking	• Traditional vocations, pottery, food specialties, and hawking
Participation	• Tradition of organizing cultural activities and festivals collectively by mohalla-based *Navyuvak Mandals*	• Tradition of organizing cultural activities and festivals collectively	• Tradition of organizing cultural activities and festivals collectively	• Tradition of organizing cultural activities and festivals collectively

Source Author

domain of multi-functional spaces exhibiting a strong sense of place, belongingness and bonding in which day to day activities of people unfold. The study further validated that the material public space has been conceptualized as an armature for sustaining the public realm. Four fundamental principles 'accessible, unrestrained, sociable and free to use' define the notion of public space in the inner core area in Jaipur, Bikaner, Udaipur, and Bharatpur, firmly establishing that public spaces comprise of physical, non-physical, and user components and can be characterized by five physical and nine intangible attributes. This distinctive research outcome is critical for ensuring the continuity of public spaces in historic cities.

5 Conclusion and Recommendations

Public Spaces in four historic cities of Bikaner, Jaipur, Udaipur, and Bharatpur are at risk. Rapid urbanization has resulted in a negative impact on the inner core area in the cities especially on public spaces, putting tremendous pressure on urban resources, services, and infrastructure. All this has led to a deterioration in quality of life. Poor sanitation and solid waste disposal, water shortage, and pollution have decreased liveability. Poor transport system, congestion, and encroachments coupled with dilapidated building stock have made the situation extremely complex. Transformation phenomenon namely obsolescence in buildings, underutilized infrastructure, change in land value and rentals, change in building use, growth of informal settlement, strained infrastructure, environmental degradation and change in demographics are threats to public spaces. The distinctive 'Notion of Public Spaces' in the four cities defined by physical, non-physical, and user attributes needs to be safeguarded against these threats.

The proposed parametric framework for the evaluation of public spaces in historic cities can help plan appropriate interventions. Understanding and appreciation of the distinctive attributes has the potential of not only helping safeguard existing public spaces in historic cities but also guide planning and design of new public spaces that are sociable and sustainable. Understanding behavioral, cognitive, and experiential aspects of users in public spaces can help plan good public spaces. Understanding types of activities and activity patterns of users can help optimize the efficacy of public space usage. Walkability, accessibility and interconnectedness, key qualities of public spaces in all the four cities promotes physical well-being and can help plan sustainable modes of transport significantly reducing dependence on fossil fuel. Seamless integration of blue and green networks with public spaces as seen in the case of Udaipur and Bikaner can encourage community-led environmental protection. Safeguarding attributes of sociability, inclusiveness, ease of access, and freedom to use public spaces and providing for these attributes in new public spaces can contribute to liveability. Improved sociability and quality of life can in turn encourage community involvement in planning and decision-making for ensuring the sustainability of interventions in public spaces. This would also help facilitate community participation in activity programming, maintenance and management of public spaces and help build resilience of local community in mitigating the negative impacts of transformation on public spaces in the long run.

Planning and design in the four cities responded to all four aspects of sustainability namely environmental, economic, social, and cultural (see Fig. 8). City planning was in response to local topography and environment sensitively preserving the indigenous blue and green networks and associated resources. Facilitation of regional trade and commerce linked to the global economy helped to create diverse livelihood opportunities for local inhabitants within the traditional economic ecosystem. Strategic military considerations in spatial planning ensured that the cities were designed to take care of the safety of inhabitants. Planning of neighborhoods as per prevalent social organization patterns enabled harmonious coexistence of diverse social groups within the city and a sensitive response to religious belief systems facilitated smooth enactment and coexistence of diverse ritual practices and expressions. Space planning responded to behavioral patterns governed by prevalent socio-cultural norms.

Learnings from spatial planning of inner core area of four historic cities and their distinctive public spaces based on this research indicates that their urban habitat to a great extent was a function of sustainable principles and practices. Understanding the distinctive 'Notion of Public Spaces' in the Indian context of historic cities using the parametric framework developed through this research therefore is critical for not only safeguarding existing public spaces in inner core areas but also has the potential

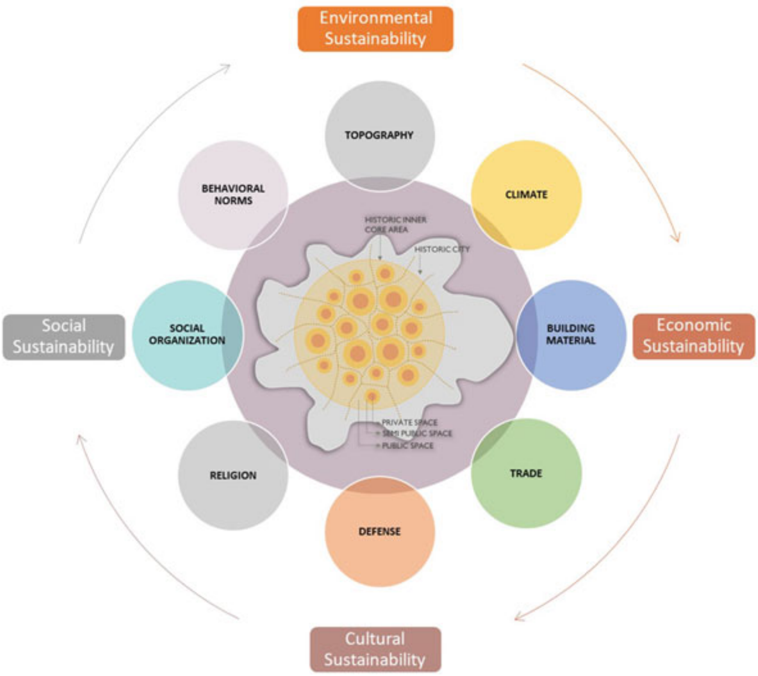

Fig. 8 Criterion for planning of historic cities. *Source* Author

of contributing to planning and design of new vibrant, sociable, liveable, equitable and sustainable urban habitats. Historic Indian cities have much to offer to understanding the idea of sustainability and developing ways and means of incorporating traditional space planning principles and practices in the creation of new sustainable urban habitats.

References

1. Appleyard D, Gerson M, Lintell M (1981) Livable streets. University of California Press, Berkeley
2. Carr S, Francis M, Rivlin LG, Stone AM (1992) Public Space. Cambridge University Press, New York
3. Cities and climate change (n.d.) UNEP—UN Environment Programme. http://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/cities-and-climate-change
4. Dhaka A (n.d.) Care for some 'patapari' on the traditional patas of Bikaner? Clamber on! Gaon Connection. https://en.gaonconnection.com/bikaner-rajasthan-culture-tradition-covid-pandemic-patas/
5. Faetanini M (2010) Historic Districts for All—India, a social and human approach for sustainable revitalisation (Manual for City Professionals). UNESCO/UN-HABITAT
6. India Population 2023 Live (2023). World population review. https://worldpopulationreview.com/countries/india-population
7. Jacobs J (1961) The death and life of great American cities. Vintage Books, New York
8. Khor N, Arimah B, Otieno R, Oostrum MV, Mutinda M, Martins JO (2022) World Cities Report 2022 envisaging the future of cities. United Nations Human Settlements Programme (UN-Habitat). https://unhabitat.org/
9. Kropf K (1996) Urban tissue and the character of towns. Urban Des Int 1:247–263. https://doi.org/10.1057/udi.1996.32
10. Lefebvre H (1991) In: Nicholson D, Malden S (trans) The production of space. UK Black-well, Oxford
11. Lofland L (1998) The public realm: exploring the city's quintessential social territory. Aldine De Gruyter, New York
12. Lynch K (1960) The image of the city. MIT Press, Cambridge, MA
13. Madanipour A (1996) Design of urban space. Wiley, New York
14. Mehta V (2014) Evaluating public space. J Urban Des 19(1):53–88
15. Mitchell D (1995) The end of public space? People's park, definitions of the public, and de-mocracy. Ann Assoc Am Geogr 85:108–133. https://doi.org/10.1111/j.1467-8306.1995.tb01797.x
16. NIUA (2018) Inclusive revitalization of historic towns and cities-strategic framework for Rajasthan state heritage programme. National Institute of Urban Affairs, New Delhi
17. Porta S (1999) The community and public spaces: ecological thinking, mobility and social life in the open spaces of the city of the future. Futures 31(5):437–456
18. Rossi A, Eisenman P (1982) The architecture of the city. MIT Press, Cambridge, Mass
19. Soja EW (1996) Thirdspace: journeys to Los Angeles and other real-and-imagined places. Blackwell, Cambridge, Mass
20. Srivastava U (1999) A participatory approach towards regeneration of living cultural environment of Kabir Chaura—A traditional Mohalla of Musicians in Banaras. Unpublished M. Arch Thesis. School of Planning & Architecture New Delhi
21. Steinberg F (2008) Revitalization of historic Inner-City Areas in Asia, The Potential for Urban Renewal in Ha Noi, Jakarta, and Manila. Mandaluyong City: Phil.: Asian Development Bank

22. Thomas M (1991) In: Nadin V, Doak J (eds) The demise of public space. Town Planning Responses to City Change, pp 209–224
23. Verma CS (2004) Bharatpur-a saga of invincible courage. Konark Publishers Pvt. Ltd., Delhi
24. Whyte WH (1980) The social life of small urban spaces. Conservation Foundation, Washington, D.C

Urban Public Services Delivery and Sustainable Development: A Survey of User Opinion in Four Major Metropolitan Cities in India

Bidisha Banerji and Pallavi Maitra

1 Introduction

The core function of modern urban governments is to provide efficient and quality public services to citizens [1]. In the context of Public Services, overpopulation and informal settlements in urban areas lead to congestion and make land scarcity a big problem that influences the space available for service infrastructure and thereby impedes efficient public service delivery [6]. The problem of uneven access to services is severe in cities due to the large population of the poor, which is exacerbated by a deficient urban infrastructure. This leads to a service gap which results in the problem of excess demand over supply for services like water and sanitation. This situation often gives rise to the spread of contagious diseases and the degradation of the overall public service management system [9, 20].

In India, urban service delivery has still a long way to go when compared to other developing nations. The government in India, from the start, has given more attention to power supply than other services like sanitation and drinking water. In recent times, it has invested considerably in different service areas, however, problems still persist [7, 18]. For example, in Delhi, the water demand has exceeded its supply by around 120–170 million gallons per day since 2000 [30].

Solid Waste Management is an essential service and is a critical infrastructure supporting the needs of society and is a collective responsibility of everyone [37]. In India, solid waste management is lagging behind as there is hardly any proper segregation of waste taking place, either at the source, or at landfills filled to their highest capacity [16]. Data from the Census of India shows that urban areas generate over 1,40,000 metric tonnes of solid waste daily, with the numbers increasing daily.

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With limited capacities, land availability, and financial constraints, urban local bodies continuously need help to meet the challenges [19].

Studies conducted by the Ministry of Urban Development have found that public transport per 1000 people is an abysmal 0.504, and the average waiting time for Delhi Transport Corporation routes is around 70 min [30]. In the Indian context, water supply, waste management, and public transport are three critical public services that need to be studied.

Urban public service delivery is provided by local government and private institutions. After 1947, there were a series of committees to deliberate and conceptualize local self-government—the Balwant Rai Committee (1957), the Ashok Mehta Committee (1977–1984), GVK Rao Committee (1985), and then the LM Singhvi Committee (1986). This culminated in the Constitutional Amendment Acts of 1992—73rd/74th Amendment in which Local Government had a constitutional status. However, the power to devolve functions to the Local Government rests with the State Government. After three decades of the 73rd/ 74th Amendment, Urban Local Bodies still face problems, such as low effectiveness, unplanned urbanization, untrained personnel, and low level of citizen participation [21]. Financial restrictions are another major problem, local government expenditure as a percentage of GDP is very low. Moreover, social problems like discrimination and deprivation are problems that need to be reduced to ensure that resources are allocated in a just and fair manner to all citizens [22]. Corruption at the local government level has also had a significant negative impact on the delivery of services [17].

Recently, Public Private Partnerships have been forged between government and private sector entities to deliver services. Studies show that PPP ventures suffer from lack of accountability and professionalism, large outstanding debts, severe delays, cost overruns, and accepting projects at small margins due to competition [4, 32].

As one of the fastest-growing economies in the world, India has committed to sustainable development in the realm of urban public services. Furthermore, as a part of Sustainable Development Goals, governments around the world have committed to ensuring access to services like water (SDG 6), closing urban–rural and equity gaps (SDG 10 and 11), and high-quality delivery of services that are reliable and accessible. This indicates that a shift in policy framework regarding service delivery is urgent and should also address long-term sustainable management [38].

Service Delivery Models work best when "there are strong accountability relationships between actors in the service delivery chain, including policymakers, providers, and citizens" [6]. Another factor pushing for improved service delivery models is that public authorities do not get to choose their customers but are required to service them [27].

2 Problem Statement and Research Gaps

In India, Public Service Delivery systems have not changed much over the last few decades, and a study to understand issues that plague public services delivery in metropolitan cities could be a starting point to begin improving them. Introduction of new technologies, and processes and bringing together multiple stakeholders to make the public delivery service system more robust, is critical. However, in order to undertake reforms, it is important to understand how public service delivery actually plays out at the ground level and the deficiencies faced by the consumer. Only then policymakers and other stakeholders will be able to find solutions that solve the problems.

3 Research Objectives

This study aims to identify the key problems associated with three selected public services—water supply, waste management, and public transport and the perception of the customers and location across four metropolitan cities—Delhi/NCR, Mumbai, Bangalore, and Kolkata. The public opinion survey tool will assess satisfaction and dissatisfaction measures, progress in the area of sustainability, and users' willingness to pay for better public services. Inputs received directly from the users will help in identifying the key lacunae that exist in the delivery of public services in these cities and come up with best practices that can be emulated by them from each other. Intervention should be city-based because every city is subject to different constraints, resources, population distribution, etc., and needs localized intervention based on empirical analysis.

In the "Theory Building" section, we discuss Urban Service, Grounded Theory Methodology (GTM), and two case studies that have utilized GTM to revamp the existing policy framework. In the "Literature Review" section, Public Service Delivery models given by researchers and organizations have been discussed followed by the "Research Methodology" section, which is focused on the public opinion survey design, sample, and methodology. In the "Results" section, key findings of our study across the four metropolitan cities (Delhi/NCR, Mumbai, Kolkata, and Bangalore) with reference to the three public services have been presented. Lastly, in the "Key Findings and Conclusion" section, we discuss the implication of our research on policy making.

4 Theory Building

An Urban Service is "one which serves the public interest by accomplishing one or more of the following purposes: preserving life, liberty, and property; and promoting public enlightenment, happiness, domestic tranquillity, and the general welfare. It is provided by one or more of the sectors in the economy through government regulation, co-production, or direct provision." [2].

Grounded Theory Methodology (GTM), as developed by Glaser and Strauss [11], and "joint data collection and constant comparison," as identified by Urquhart et al. [35] are quite pertinent in understanding the various elements of the delivery of Public Services.

In the Krivaja River Basin in Serbia, Grounded Theory was applied to identify eight stakeholders and their subgroups and showcased the challenges associated with implementing public perception regarding water resource management [31]. In another study conducted in Zambia using GTM, the analysis revealed that current service delivery needs extensive remodelling of the existing policy framework to cater to informal settlements' needs and that operational incentives should induce service providers to service these areas and create partnerships [3].

GTM is a good way of understanding various dimensions of the delivery of public services as it relies on field data and observation, which varies from place to place. This variability is best captured by GTM, which will be the basis of this study.

5 Literature Review

The government's accountability to its people for public service delivery is a crucial element of a democratic polity. The World Development Report 2004 has put forward two routes to accountability. The first route or the "long route," is concerned with the idea that citizens' voices are heard through their elected agents, who then implement policies for service delivery. The other route is called the "short route," where people can skip the long route through direct contact with the service providers [5]. The central idea of democratic theory is the assumption that the people's wants, tastes, preferences, and needs have a prominent existence and that the policymakers should convert them into public policy [12].

In a study on the South African Municipality District by Ndevu [23], specific rules to be followed by the authorities for effective public service delivery have been identified. Some of them are transparency and accountability, direct engagement and communication between employees and leadership, job evaluation, and performance management of politicians and administration. In another study by Khalil and Salihu- [15] "Modified Quantitative Service Delivery Model (MQSDM)", the factors that affect efficient service delivery, such as Managerial Accountability, Funding/ Management of resources, and leadership have been identified.

The World Bank has given a 4-stage model of modernization of public service. The first stage is rationalization; the second stage is reengineering, the third stage is digitization; the last stage is delivery, where service is delivered through multiple channels and is customer-centered [39]. These four stages are strengthened by coordination, citizen engagement, monitoring and control of performance, and communication and training for better performance and efficiency. The emphasis is on putting the citizens at the centre of the operations and collaborating with them in designing the services around the needs and wants of the citizens through participatory design and journey mapping. This model's successful implementation is enabled using modern technology, including digital service delivery, which makes the process more inclusive and increases citizen satisfaction. For example, in South Korea, the government implemented a program called "One stop package service on a life cycle," whose purpose was to provide accurate and reliable information to a person on services that they may require at every stage of their life like childbirth, education, employment, retirement, and death in advance on government portals.

In India, in 2010 Madhya Pradesh was the first state to enact a "Public Services Guarantee Act (PSGA)." The objective was to have statutory laws that guarantee time-bound public service delivery and a mechanism to punish delinquent officers if they fail to deliver or in case there is a deficiency. This Act has been enacted in 20 States.

Global cities like London, Mexico City, and Kuala Lumpur have per capita emissions lower than cities like New Delhi and Kolkata, which emit more than double their national average. In India, urban areas contribute 2/3rd more CO_2 emissions per person than rural areas, and the share of smaller Indian cities in the list of most polluted cities in the world is also rising [8]. According to a study of Niti Aayog cited by Jha and Udas-Mankikar [14], a 40 trillion Rupees investment is required by 2030 for India to revamp its infrastructure, but the revenue generated by all the Municipal Corporations combined is not more than 1.2 trillion, which is approximately—1% of the GDP. Since local governments are dependent on the state government for meeting their expenditure needs, they are not able to function effectively.

Another significant concern in this area is the coping ability of the frontline workers. Tummers et al. [34] found that social workers and police officers break the rules less often than healthcare professionals and teachers. Even under extreme stress, employees maintain customer attention, indicating that the citizen agent narrative significantly influences their behaviour. However, academics are paying more attention to the state agent narrative.

The digitization of service delivery aims to increase public access to the services. This is especially relevant in the case of people with disabilities. Therefore, governments worldwide are now moving on from the traditional Unichannel Approach, where people had to physically go to a government office to request a specific service, have started to incorporate multichannel and omnichannel approaches to leverage numerous mediums [39].

6 Research Methodology

This research aimed to assess, measure, and analyze public opinion and perceptions on urban public services delivery in four metropolitan cities in India. The three urban public services delivery selected for this study are—Water Supply, Public Transport, and Waste Management. The three services were standard services where recipients could not influence the quality of public service and there is no bias regarding recipient quality. Each service was assessed on four dimensions: user satisfaction or dissatisfaction, ranking, willingness to pay for better delivery, and sustainability focus. Four metropolitan cities chosen within India were—Delhi/NCR, Bangalore, Mumbai, and Kolkata– one each from North, South, East, and West of India.

The current population data of the four metropolises is shared in Table 1. Primary data was collected through a survey, administered primarily through Google Forms, and in some cases, the questionnaire was filled up physically by the respondents. The survey tool was titled "*User Opinion-Critical Issues on Urban Public Services Delivery in India.*" It was designed to assess user satisfaction/dissatisfaction, rank of Public Service, willingness to pay for better delivery, and progress made on the path to sustainability. A "*customer-oriented*" approach was taken.

Phase I: Research Design

Critical Urban Public Services in India were identified through Literature Survey and interaction with experts in this field. Three critical Urban Public Services were chosen for this study from an exhaustive and long list. The three services were standard services where recipients could not influence the quality of public service. A survey tool was prepared to measure public opinion of Urban Public Services Delivery. A pilot test was conducted before the roll-out of the final questionnaire. The questionnaire had two sections:

Section I: Measuring overall User Satisfaction and Dissatisfaction with the Urban Public Service Delivery, Rank, and Willingness to Pay for better service delivery.
Section II: Assessing the Focus on Sustainability in the three Urban Public Service Delivery.

Each item on the questionnaire was assessed either on a 5-point Likert scale or through multiple-choice questions. The time taken to fill in the survey tool was between 7 and 10 minutes

Table 1 Population of the four Metropolis Cities in 2011

S.No	City	Population (Approx.)
1	Delhi	16,314,838
2	Kolkata	14,112,536
3	Mumbai	18,414,288
4	Bangalore	8,499,399

Source Press Information Bureau, Government of India [26]

Table 2 Sample distribution by city

City	No of respondents	Percentage (%)
Delhi/NCR	130	42
Mumbai	66	22
Bangalore	56	18
Kolkata	55	18
Total	307	

Source Computed by the Authors as per the Public Services Survey

Phase II: Administration

The survey was administered simultaneously across four metropolitan cities from 28th December 2022 to 20th February 2023. All survey respondents were more than 18 years old and residents of Delhi/NCR (National Capital Region), Bangalore, Kolkata, or Mumbai. The sampling technique was stratified random sample—stratified on city, gender, and age. The sample details are presented in Tables 2 and 3.

The total number of respondents was 307. Within each metropolitan city, there were respondents from all parts of the city, including men and women, who were from three age groups. Care was taken to ensure that we captured the voice of senior citizens. In fact, 22% of respondents were more than 55 years old (Table 4). This enabled us to capture the feedback of the elderly. Some senior citizens required assistance in filling in the survey tool which was provided to them.

The profile of a typical respondent is as follows:

1. *An adult resident of Delhi/NCR, Mumbai, Bangalore, or Kolkata.*
2. *Most respondents filled the questionnaire on Google Forms.*
3. *Educated and middle-class residents of the metropolitans.*

The sample size generated a 95% confidence level and $a \pm 10$ confidence interval.

Table 3 Percentage of respondents by gender

Female	53%
Male	47%

Source Computed by the Authors as per the Public Services Survey

Table 4 Percentage of respondents by age

18–25 years	12%
25–55 years	66%
55 years & above	22%

Source Computed by the Authors as per the Public Services Survey

Phase III: Data Analysis

The analysis and interpretation of the responses were done by calculating the percentage satisfaction and dissatisfaction score, the averages, standard deviations, and proportion percentages of the options. Pearson product-moment correlation coefficient was used to measure the linear relationship between two variables—the overall satisfaction scores and willingness to pay for better public services delivery. Test of proportion (Z score) was used to assess whether two populations differ significantly on specific characteristics at a 5% level of significance in a two-tailed test. The assumption was that all variables follow a standard normal distribution and a difference of more than 5% level of significance.

The results of the Public Opinion Survey are presented in the next section.

7 Results

The results of the public opinion survey are presented in two sections. Section I presents the analysis of the satisfaction/dissatisfaction levels, rank, and willingness to pay for the three Urban Public Services and Section II focuses on Sustainability.

Section I: **Level of Satisfaction/Dissatisfaction, Rank, and Willingness to Pay Better for Urban Public Services Delivery**

- The highest satisfaction score and the lowest dissatisfaction score overall for all four metropolitan cities is in **Water Supply** (Fig. 1a). The Satisfaction score on Water Supply was clearly ahead of Public Transport and Waste Management.
- The lowest satisfaction score was in Public Transport (23%).
- The highest dissatisfaction score is in Waste Management (28%).

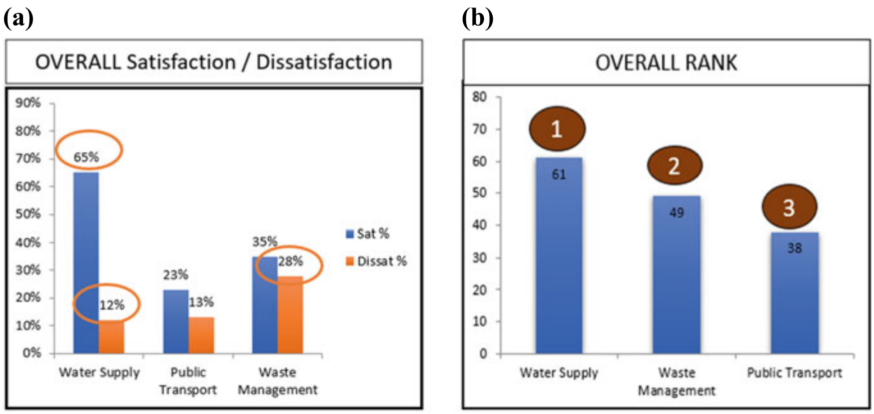

Fig. 1 Satisfaction and Dissatisfaction Scores and Rank of Urban Public Service Delivery in all Four Metropolitan Cities (**a**, **b**). *Source* Computed by the Authors as per the Public Services Survey

- In Fig. 1b, the three urban public services studied were ranked as follows:
    a. Water Supply
    b. Waste Management
    c. Public Transport.

- 42% of respondents are *not willing to pay* for better Water Supply (Fig. 2a). This could be related to the high satisfaction score on Water Supply.
- 81% of respondents are *willing to pay more* for better Public Transport (Fig. 2b), and 79% are willing to pay more for better Waste Management (Fig. 2c). *The need for better services in these areas is very high, as indicated by the respondents.*

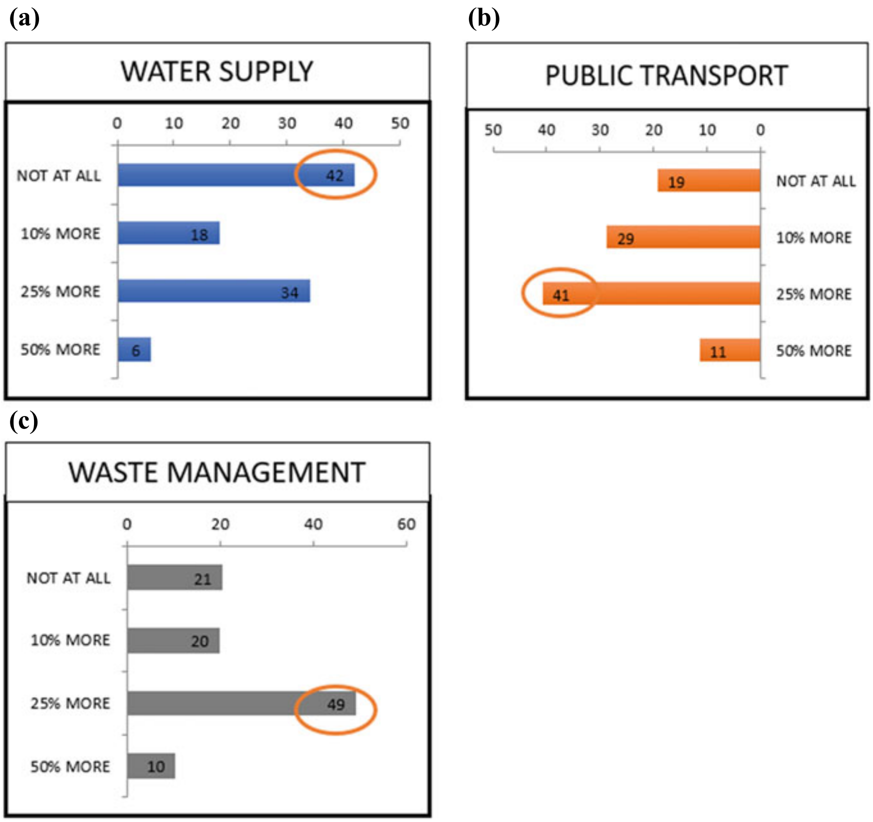

Fig. 2 Willingness to pay for better Urban Public Services Delivery across four Metropolitan Cities (**a**), (**b**), (**c**). *Source* Computed by the Authors as per the Public Services Survey

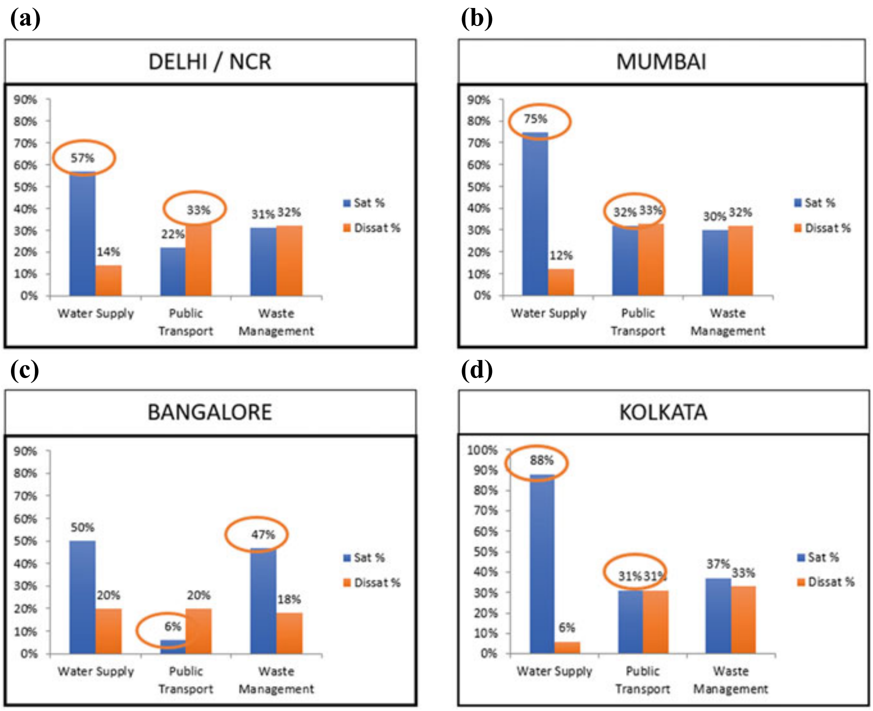

Fig. 3 Satisfaction and dissatisfaction scores in the four Metropolitan Cities and Rank of the Urban Public Services (**a**–**d**). *Source* Computed by the Authors as per the Public Services Survey

- Water Supply
  - The satisfaction score of Water Supply Service Delivery is the highest across all four metropolitan cities. The highest score in Kolkata (Fig. 3d) was the highest at 88%.
  - The dissatisfaction score in Water Supply is the lowest. In fact, in Kolkata (Fig. 3d), it is merely 6%.
- Public Transport
  - The satisfaction score in Public Transport is only 6% in Bangalore (Fig. 3c), much lower than that in New Delhi (Fig. 3a), Mumbai (Fig. 3b), and Kolkata (Fig. 3d).
  - The dissatisfaction score is higher than the satisfaction score in all four metropolitan cities.
- Waste Management
  - The satisfaction score is the highest in Bangalore at 47%.
  - In Delhi/NCR (Fig. 3a) and Mumbai (Fig. 3b), the dissatisfaction score is more than the satisfaction scores.

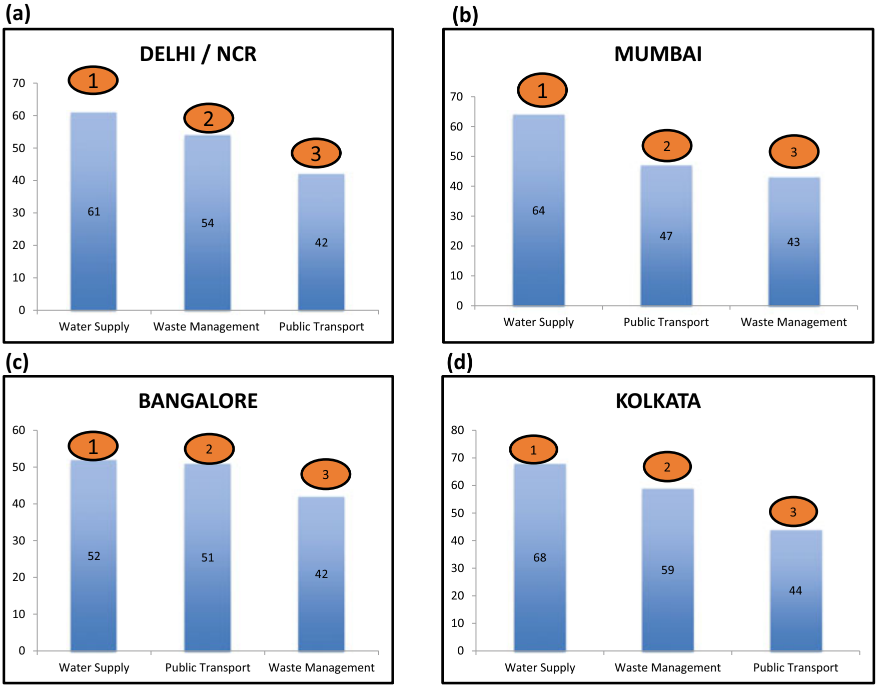

Fig. 4 Rank of Public Services in four Metropolitan Cities (**a**–**d**). *Source* Computed by the Authors as per the Public Services Survey

- Respondents were requested to rank the best-structured and the worst structured Public service. Water Supply is ranked first among all four Metropolitan cities studied.
- Waste Management was ranked third in Mumbai and Bangalore.
- Public Transport was ranked third in Delhi/NCR and Kolkata.

- The willingness to pay for better Water Supply is highest in Delhi/NCR (Fig. 5a), followed by Bangalore (Fig. 5c).
- In Mumbai (Fig. 5b)—45% of respondents, and in Kolkata (Fig. 5d)—47% of respondents would not like to pay more.

- 85% of respondents in Mumbai (Fig. 6b), 84% of respondents in Bangalore (Fig. 6c), 80% in Kolkata (Fig. 6d), and 77% in Delhi/NCR (Fig. 6a) would like to pay more for better Public Transport. This appears to be an urgent need.

- Most respondents are willing to pay more for a better Waste Management Delivery process. The scores in the four cities are—Bangalore (Fig. 7c)—84%, Mumbai (Fig. 7b)—82%, Delhi/NCR (Fig. 7a)—79%, and Kolkata (Fig. 7d)—73%.

Fig. 5 Willingness to pay for better Water Supply (in %) (**a**–**d**). *Source* Computed by the Authors as per the Public Services Survey

8 Comparison Between the Four Metropolitan Cities

In a two-tailed test, the Test of Proportions (Z score) was used to examine whether two populations differ significantly on specific characteristics at a 5% significance level. All scores that vary significantly have been highlighted. This indicates that the difference between the scores in the cities is significant (Tables 5 and 6).

[The strength of association is low if the coefficient of correlation is between 0.1 and 0.3, moderate between 0.3 and 0.5, and strong between 0.5 and 1.0]

- The correlation between satisfaction and willingness to pay has been tabulated above.
- The correlation is strong in Public Transport and Waste Management in Delhi/NCR, Public Transport in Mumbai, and Waste Management in Kolkata.
- The correlation is moderate in Water Supply, Public Transport, and Waste Management in Bangalore. Strong in Public Transport in Mumbai, strong Kolkata, strong in Waste Management and Public Transport.

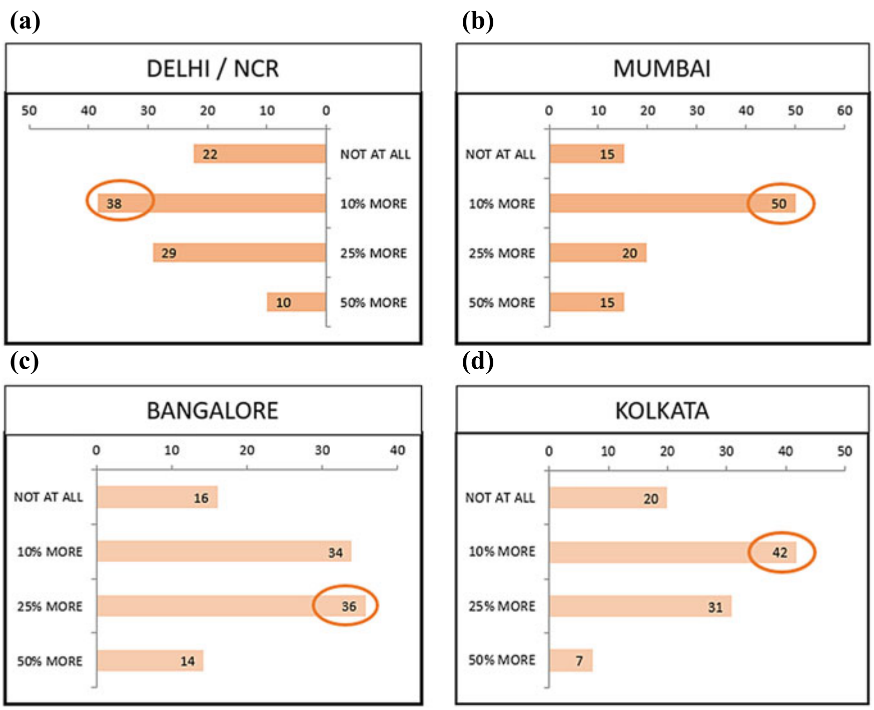

Fig. 6 Willingness to pay for better Public Transport (in %) (**a**–**d**). *Source* Computed by the Authors as per the Public Services Survey

Section II: **Focus on Sustainability in Water Supply, Public Transport and Waste Management**

1. **Sustainability Measure across the Four Metropolitan Cities and a Comparison between the Cities**

   A. **Water Supply**
   Rainwater harvesting and water reuse are ancient and cost-effective methods. In 2001, Tamil Nadu was the first state that enforced Rainwater harvesting. In the questionnaire, awareness and implementation of Rainwater Harvesting was assessed.

   - The overall results of Fig. 8a were positive—56% of respondents were aware of Rainwater Harvesting and water reuse projects in their neighborhood.
   - Bangalore (Fig. 8b) had the highest number of respondents who were aware (84%).
   - Delhi/NCR (Fig. 8b) had 51% of respondents who were unaware.

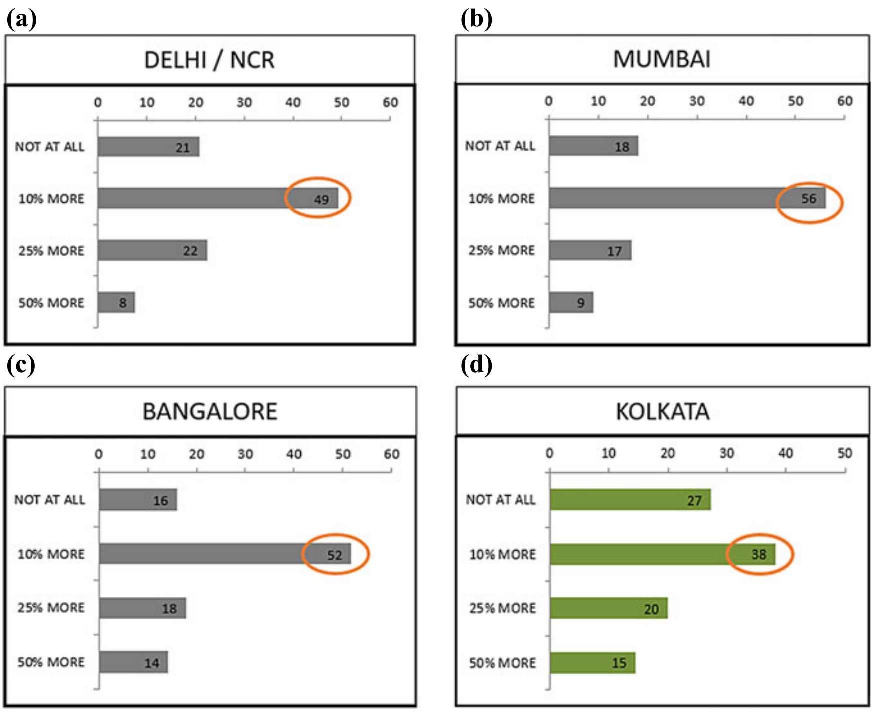

Fig. 7 Willingness to pay for better Waste Management (in %) (**a–d**). *Source* Computed by the Authors as per the Public Services Survey

Table 5 Inter-city Comparisons on Water Supply, Public Transport and Waste Management

Cities	Water supply	Public transport	Waste management
Delhi & Mumbai	**−2.37**	−1.4400	−0.15
Delhi & Bangalore	0.87	**2.8100**	**−2.5**
Delhi & Kolkata	**−3.79**	−1.240	−0.74
Mumbai & Bangalore	**2.77**	**4.830**	**−2.04**
Mumbai & Kolkata	−1.79	0.110	−0.53
Bangalore & Kolkata	**−4.23**	**−3.500**	1.45

Source Computed by the Authors as per the Public Services Survey

B. **Public Transport**

The question asked here was whether respondents use Public Transport. The respondent profile in this survey included the educated middle class (more than 18 years of age).

Table 6 Pearson's Product Moment Correlation Coefficient between Satisfaction and Willingness to Pay

Area	Description	Correlation	Degree
Water supply	Overall	−0.4663	Moderate
Public transport	Overall	−0.5334	Moderate
Waste management	Overall	−0.3766	Moderate
Water supply	Delhi/NCR	−0.4558	Moderate
Public transport	Delhi/NCR	−0.5645	Strong
Waste management	Delhi/NCR	−0. 6632	Strong
Water supply	Mumbai	−0.2336	Low
Public transport	Mumbai	−0.5438	Strong
Waste management	Mumbai	−0.3328	Moderate
Water supply	Bangalore	−0.4552	Moderate
Public transport	Bangalore	−0.4289	Moderate
Waste management	Bangalore	−0.3418	Moderate
Water supply	Kolkata	−0.1899	Low
Public transport	Kolkata	−0.3489	Low
Waste management	Kolkata	−0.5598	Strong

Source Computed by the Authors as per the Public Services Survey

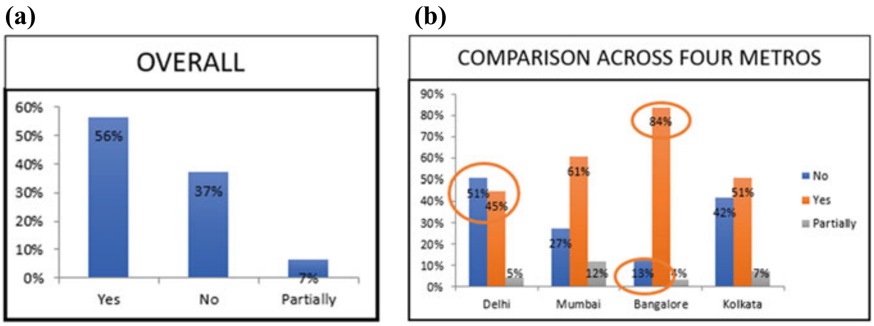

Fig. 8 Are you aware rain water harvesting & water re-use projects in your neighborhood? *Source* Computed by the Authors as per the Public Services Survey

- The results were unexpected. Overall, in Fig. 9a, across all four metropolitan cities, only 6% of respondents used Public Transport exclusively to commute.
- Respondents who use Public Transport only to commute were in single digits in all four metropolitan cities. Bangalore was 2%, Delhi/NCR 5%, and Mumbai and Kolkata were at 9% (see Fig. 9b).
- The use of Public Transport itself was a question mark.

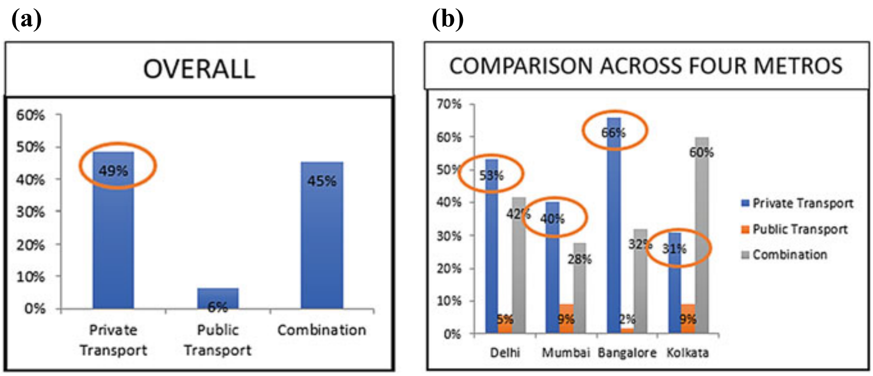

Fig. 9 How do you normally commute? *Source* Computed by the Authors as per the Public Services Survey

C. **Waste Management**

The question asked here was an elementary one on the respondents' awareness of the Solid Waste Management process in the city of their residence.

- In Fig. 10a, the results were surprising because 46% of respondents mentioned they were not aware. Furthermore, 29% were partially conscious, and only 25% of respondents seemed mindful of solid waste management.
- In Mumbai (Fig. 10b), only 17% were aware, and in Delhi/NCR (Fig. 10b), only 25% were aware of the solid waste management process.
- Therefore, it appears that the awareness about waste management process seems to be restricted to waste disposal from the household, from the user's perspective. This is the score for the educated urban middle class in metropolitan cities.

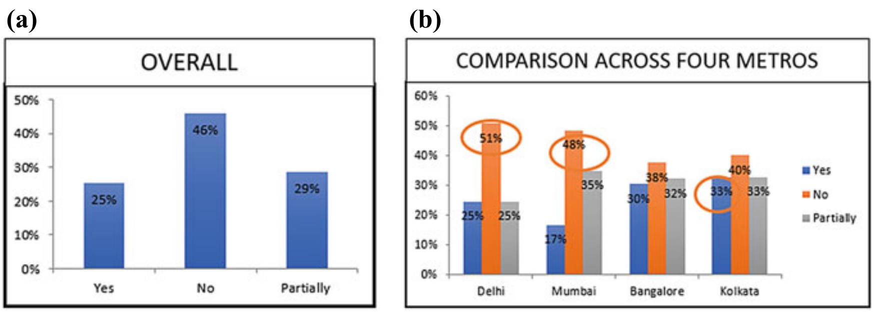

Fig. 10 Are you aware of the process that is followed for solid waste processing, treatment and disposal in your city? *Source* Computed by the Authors as per the Public Services Survey

9 Key Findings and Conclusion

9.1 Key Findings

Urbanization transforms a nation and drives economic growth but also leads to overcrowding, sanitation issues, water shortages, health hazards, among others. Metropolitan cities in India are expanding perpetually through unplanned urbanization, often unacknowledged and unaddressed. Furthermore, in India, households depend entirely on the government for essential public service delivery, and the state is accountable to the residents for this service. The link between residents, elected political leaders, and personnel who provide these services is the key to effective and efficient public service delivery. This can be done by institutionalizing political leaders' and service providers' accountability and empowering users [5]. Urban inhabitants often feel that their voice needs to be heard. This study is a step towards understanding the residents' needs related to three basic but essential public services of metropolitan cities. In a democratic polity, users' needs should be central when formulating public policies [12] and at the same time, citizens are equally eager to influence and participate actively in the design and execution of public services [10].

The findings of our study are summarized first on the basis of public services and then with respect to the four metropolitan cities. The study is focused on three critical aspects—the satisfaction and dissatisfaction of the users, the focus on sustainability, and the willingness of residents to pay more for better services.

(A) ***Urban Public Services***

1. Water Supply was ranked first and had the highest satisfaction score. Similarly, in the journey towards sustainability, water supply demonstrated positive results. In Bangalore, 81% of respondents were aware of Rainwater Harvesting and water reuse projects. However, despite the highest satisfaction score, 58% of users were willing to pay more for better water supply service delivery.
2. Public Transport had the lowest satisfaction scores. In Bangalore, the satisfaction score was as low as 6%. More than 81% of respondents were willing to pay more for better public transport in all the metropolitan cities under study. Users bypass their interface with the dismal existing system of Public Transport through alternatives such as private transport. The journey towards sustainable and equitable public transport is difficult to achieve when only 6% of users in this respondent profile were exclusively dependent on Public Transport in all four metropolitan cities studied. The only way to progress in Public Transport would be to make public transport attractive and reduce the quality differential with private transport. A robust public transportation system is at the heart of urban mobility and fulfilling living needs.

3. Waste Management had the highest dissatisfaction score of 28%. More than 79% of respondents were willing to pay more for better waste management services. Regarding sustainability, 46% of respondents (even in this respondent profile which included urban educated middle-class residents of metropolitan cities) needed to be made aware of the solid waste management process in their city of residence. The emphasis is merely on the collection and disposal of waste from households. Treatment and disposal after it moves out of homes is a neglected area. According to a study, despite residents segregating household waste at source, it is all dumped together in the primary landfill [28]. Waste management systems have remained unchanged for years. Sustainability is a far cry from the current situation, and there is an urgent need to bring new technology and public awareness into this area.

(B) Comparison across the Four Metropolitan Cities

1. Delhi/NCR has the highest dissatisfaction score for Public Transport and Waste Management. Sustainability scores indicate that only 5% of users were exclusively dependent on Public Transport and 50% of users were unaware of the solid waste management process followed in the city. Similarly, in Rainwater harvesting and water reuse, the score in Delhi/NCR was the lowest among the four metropolitan cities. Residents were willing to pay more for better services in all three Public Services. In fact, in the area of Water Supply—residents of Delhi/NCR were willing to pay more as compared to the other metropolitan cities.
2. In Mumbai, the satisfaction score of water supply was high (75%). Public Transport was ranked second, and the willingness to pay for better Public Transport and Waste Management was high. Sustainability scores indicated that the percentage of respondents exclusively dependent on public transport was only 9%, and 48% needed to be made aware of the solid waste management processes.
3. Kolkata had the highest satisfaction score on Water Supply (88%). Waste Management was ranked second among the three public services studied. The willingness to pay for better public transport and waste management was high. Sustainability scores indicated that only 9% of respondents depended exclusively on Public Transport, and 40% needed to know their city's solid waste management processes better.
4. Bangalore had the lowest satisfaction score on water supply (50%) among the four metropolitan cities. However, in the area of sustainability, Bangalore had the highest rainwater harvesting awareness and reuse score (84%). The satisfaction score on Public Transport in Bangalore was (6%). The sustainability score in the area of Public Transport and Waste management indicates that only 2% of respondents were exclusively dependent on Public Transport and 38% of respondents need to be made aware of the solid waste management processes followed. Willingness to pay for better services was

84% in Public Transport and Waste Management and 69% in the area of Water supply, respectively.

10 Conclusions

The experience with public services in India over the last 75 years after Independence has been a mixed bag. Governments invested heavily in constructing dams, canals, and water treatment plants for provision of safe drinking water. In 2014, the "Swachh Bharat Abhiyan" was launched, which has helped somewhat to improve the then dismal situation. In Public Transport, the government has invested in constructing roads, highways, railways, and airports and implemented metro rail and bus rapid transit systems in several cities.

The 74th Constitutional Amendment Act of 1992 provided Federal recognition for Local Government. The objective was to achieve democratic decentralization and constitutional endorsement of local self-government authorities. It aspired to be connected to the needs and realities of the grassroots level. More than three decades later, a closer analysis reveals that urban local bodies still need to be autonomous financially or functionally. The states appear hesitant to decentralize or empower Urban Local Bodies [25].

The Government of India recognizes the importance of sustainable urbanization. It is a signatory to several International Treaties and Agreements such as the UN World Conference on Disaster Risk Reduction in Sendai, Japan, in 2015, the Paris Agreement (UN Climate Change Conference) in 2015, the Quito Declaration on Sustainable Cities and Human Settlements for All in 2015, and the International Solar Alliance in 2015. Recently, global urban guidelines have been pressing urban governments towards meeting the Sustainable Development Goals. However, the focus is still on the goals and needs to shift towards attaining them [29]. To achieve Sustainable Development goals, it is essential to have multi-agency cooperation and partnerships between all stakeholders, good governance, and political will [36], which is connected to SDG 17 (Partnerships for the Golas).

The study also explores the aspect of "willingness to pay." The need for better services in Public Transport and Waste Management is clearly indicated, and respondents are willing to pay more for better services. Service relationships with users differ when the private sector interacts with users and can meet user expectations, whether perceived or actual. User feedback and interaction are weak when there is no choice, and gradually, users get accustomed to low service quality standards [13]. Specialized service delivery models and increased citizen involvement may help transition to an environmentally sustainable future [24]. Modernizing and adopting the latest technologies is necessary for better service delivery [33].

Suggestions, Limitations, and Future Scope of Study

The critical question is whether the policymakers are prepared to plan or manage the projected urbanization demand. Urban areas struggle to achieve "basic services for all." We cannot leave it to the chances of survival through 'laissez-faire'. Therefore, it is time for the three pillars of Urban Planning—the public sector, the education and research sector, and the private sector to come together. The road to success involves user collaboration, cooperation, and concerted efforts. The anticipated reaction to blame the supplier of the public service delivery for all the systemic problems is inappropriate since users have a pivotal role to play too. Lack of appropriate general behaviour and laws not being strictly enforced are significant reasons for the current sorry state of public services.

Finally, for future researchers, some areas need to be explored. First and foremost, the opinion of the lower income group is required to get a complete picture. The idea needs to be analyzed based on demographic profiles such as age, gender, household units with senior citizens or young children or members with disabilities, and whether the residence is part of a gated community, independent colony, or government colony. Another exciting area of research could be to explore whether the burden of managing inefficiencies in Public Services rests with women in urban households. Furthermore, in the current context where the Government of India plans to develop Smart Cities that will be sustainable and resident-friendly, there is a need to conduct such studies in these cities. In addition, the study needs to include other public services such as healthcare, security, education, electricity, etc. Also, there is a need to understand the perspective of all the stakeholders, the role of technology and processes to make the system more robust, and finally benchmark them with the best practices internationally.

The study highlights the importance of communicating directly with citizens and the necessity of user feedback to policymakers. Active citizen participation and engagement are the first steps towards delivering efficient public services and understanding users' needs. The study also highlights the willingness of residents to pay more for better services.

References

1. Avis WR (2016) Urban Governance. GSDRC, University of Birmingham. https://gsdrc.org/topic-guides/urban-governance/
2. Baer WC (1985) Just what is an urban service, anyway? J Politics 47(3):881–898
3. Banda IN (2013) Institutional mechanisms for water supply to informal settlements in Zambia: a grounded theory approach. University of Cape Town. https://open.uct.ac.za/bitstream/handle/11427/5071/thesis_ebe_2013_banda_ian_nzali.pdf?sequence=1&isAllowed=y
4. Bell E, Fourton C, Sowels N (2021) Public Services in the UK: the ongoing challenges of delivery and public accountability. French J Br Stud 26(2)
5. Blair H (2018) Citizen participation and political accountability for public service delivery in India: remapping the World Bank's routes. J South Asian Dev 13(1):54–81
6. Boex J, Malik AA, Brookins D, Edwards B (2016) Dynamic cities? The role of urban local governments in improving urban service delivery performance in Africa and Asia. Urban Institute. https://www.urban.org/sites/default/files/publication/82531/2000858-Dynamic-Cities-The-Role-of-Urban-Local-Governments-in-Improving-Delivery-Performance-in-Africa-and-Asia.pdf

7. Das P, Nayak C (2017) Urban service delivery: a case study of Major States in India. Soc Sci Humanit J 5:276–284
8. Downes S, Shah J (2022) Are cities holding India back from reaching its ambitious net zero targets? Ideas for India. https://www.ideasforindia.in/topics/urbanisation/are-cities-holding-india-back-from-reaching-its-ambitious-net-zero-targets.html
9. Duflo E, Galiani S, Mobarak M (2012) Improving access to urban services for the poor: open issues and a framework for a future research agenda. Abdul Latif Jameel Poverty Action Lab. https://www.povertyactionlab.org/sites/default/files/research-paper/USI%20Review%20Paper.pdf
10. Fitzgerald MR, Durant RF (1980) Citizen evaluations and urban management: service delivery in an era of protest. Public Adm Rev 40(6):585–659
11. Glaser BG, Strauss AL (1967) The discovery of grounded theory. Strategies for qualitative research
12. Hero RE (1986) The urban service delivery literature: some questions & considerations. Polity 18(4):659–677
13. Humphreys PC (1998) Improving public service delivery, vol 7. Institute of Public Administration
14. Jha R, Udas-Mankikar S (2019) India's urban challenges: recommendations for the new government (2019–2024). Observer Research Foundation, p 90
15. Khalil S, Salihu A (2012) Model for efficient service delivery in public service. J Public Adm Gov 2(3):85
16. Krishnan A (2021) Urban service delivery: what is limiting ULBS in Kerala from giving their best?. Centre for Public Policy Research. https://www.cppr.in/articles/urban-service-delivery-what-is-limiting-ulbs-in-kerala-from-giving-their-best
17. Majekodunmi A (2012) The state of local government and service delivery in Nigeria: challenges and prospects. Afr Public Serv Deliv Perform Rev 1(3):84–98
18. Ministry of Jal Shakti (2022) Investment in water supply and sanitation. https://pib.gov.in/PressReleasePage.aspx?PRID=1885713
19. Ministry of Urban Development (2016) Municipal solid waste management manual. Government of India. https://mohua.gov.in/upload/uploadfiles/files/Part2.pdf
20. Muzondi L (2014) Urbanization and service delivery planning: analysis of water and sanitation management systems in the City of Harare, Zimbabwe. Mediterr J Soc Sci 5(20)
21. Nanda A (2016) Urban Local Government in India: challenges and prospects. Anudhyan: Int J Soc Sci. https://rnlkwc.ac.in/pdf/anudhyan/volume1/Urban-Local-Government-in-India-Challenges-and-Prospects-Dr-Annapurna-Nanda.pdf
22. National Institute of Rural Development & Panchayat Raj (2018) A study on delivery of public services by Gram Panchayats and Village Councils. Government of India. https://www.panchayat.gov.in/documents/448457/0/Study+on+Delivery+of+Public+Services+by+GPs+and+Village+Councils.pdf/5ce54231-7597-6e9d-564e-c27266aab8b9?t=1669965979668
23. Ndevu ZJ (2019) Trust and organisational performance: a grounded theory approach for a South African district municipality. SA J Hum Resour Manag 17
24. Oates L (2021) Sustainability transitions in the Global South: a multilevel perspective on urban service delivery. Reg Stud Reg Sci 8(1):426–433
25. Prasad DR, Pardhasaradhi Y (2020) Twenty-five years of the constitution seventy-fourth amendment act (74th CAA) 1992: promise and performance. Indian J Public Adm 66(2):159–178
26. Press Information Bureau (2011) India Stats: million plus cities in India as per Census 2011. Government of India. http://pibmumbai.gov.in/scripts/detail.asp?releaseId=E2011IS3
27. PwC (2007) The road ahead for public service delivery delivering on the customer promise. https://www.pwc.com/gx/en/psrc/pdf/the_road_ahead_for_public_service_delivery.pdf
28. Sarmistha U (2021) Challenges of solid waste management: the case of Patna city. Ideas for India(website). https://www.ideasforindia.in/topics/urbanisation/challenges-of-solid-waste-management-the-case-of-patna-city.html
29. Satterthwaite D (2016) A new urban agenda? Environ Urban 28(1):3–12

30. Sinha R (2014) Institutional reform and public services: the case of Delhi. London School of Economics. https://blogs.lse.ac.uk/southasia/2014/06/23/institutional-reform-and-public-services-the-case-of-delhi/
31. Srdjevic Z, Funamizu N, Srdjevic B, Bajcetic R (2017) Grounded theory methodology and public participation in water management. Euro Water 60:381–386
32. TA Europe (2019) The Bankruptcy of Carillion—Lessons learned and the role of LTAs in future PPP projects. https://taeurope.com/2019/06/bankruptcy-carillion/
33. Tang X, Terblanche D (2012) Strategy for urban service delivery adapting to changing climate and environment—Building resilient and climate smart cities. World Meteorological Organisation. https://sustainabledevelopment.un.org/content/documents/6833final-%20urban%20service%20delivery%20Tang%20.pdf
34. Tummers L, Bekkers V, Vink E, Musheno M (2015) Coping during public service delivery: a conceptualization and systematic review of the literature. J Public Adm Res Theory 25(4):1099–1126
35. Urquhart C, Lehmann H, Myers M (2010) Putting the theory back into grounded theory: guidelines for grounded theory studies in information systems. Inform Syst J 20:357–381
36. Valencia SC, Simon D, Croese S, Nordqvist J, Oloko M, Sharma T, Taylor Buck N, Versace I (2019) Adapting the Sustainable Development Goals and the New Urban Agenda to the city level: initial reflections from a comparative research project. Int J Urban Sustain Dev 11(1):4–23
37. Western Australian Auditor General's Report (2020) Waste Management—Service delivery. https://audit.wa.gov.au/wp-content/uploads/2020/08/Report_3_Waste-Management-%E2%80%93-Service-Delivery.pdf
38. World Bank (2017) Sustainability assessment of rural water service delivery models findings of a multi-country review. https://documents1.worldbank.org/curated/en/271221503692975915/pdf/Sustainability-assessment-of-rural-water-service-delivery-models-findings-of-a-multi-country-review.pdf
39. World Bank (2022) Service upgrade-The GovTech approach to citizen-centered services. https://thedocs.worldbank.org/en/doc/c7837e4efad1f6d6a1d97d20f2e1fb15-0350062022/original/Service-Upgrade-The-GovTech-Approach-to-Citizen-Centered-Services.pdf

Net Zero Built Environment Agenda, Progression, Opportunities and Challenges

A Review of Sustainability Initiatives by Indian Real Estate Investment Trust (REIT)

Abbishek Sharma, Deepak Bajaj, and Ashish Gupta

1 Introduction

In recent years, REITs have drawn a lot of interest as real estate investment vehicles for institutional and retail investors. The global REIT market size is expected to grow from 3.69 T USD in 2021 to 6.13 T USD by 2030.[1] REITs have grown to be a popular option for people wishing to invest in real estate without owning physical properties since they aim to give investors liquidity, diversity, and transparency. The emphasis on ESG factors in commercial real estate has grown in significance as the globe moves towards a more sustainable future. It is well-known that the real estate industry has a significant negative impact on the environment [5] and 60% of the carbon emission in the cities is due to real estate activities [23]. To address the problem of climate change, world leaders reached the historic Paris Agreement in 2015 to limit the global temperature increase to 1.5°. This led to the global shift towards a Net Zero target by 2050 [30]. Green buildings are intended to have minimal detrimental effects on the environment while also boosting the occupiers' well-being. The average percentage of green assets in the REIT portfolio is still low. But it is expected that in the near future large number of buildings will go for green certification [15]. Newell and Marzuki [28] mentioned that in the emerging real estate markets the standards of real estate market transparency and environmental sustainability vary considerably.

[1] https://www.researchandmarkets.com/reports/5805536/global-real-estate-market-size-share-growth

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There is substantial disagreement regarding the market's potential transition to net zero [20]. To secure their long-term viability towards sustainability, REITs must now incorporate ESG considerations into their decision-making process.

2 Literature Review

As per the Companies Act [10], every listed entity in the stock market is required to disclose its commitment to CSR initiatives. The collected data is analysed and presented in a comparative format to identify each REIT's ESG practises' strengths and limitations. It is imperative to note that the literature surrounding environmental and sustainability initiatives in property investment is concentrated in more mature real estate markets like the USA and Australia. Ellison and Sayce [16] suggested sustainability factors pertinent to the commercial real estate investment industry. It was determined that there are not enough properties on the market to satisfy the investors' expectations regarding their corporate responsibility policies. Quantifying the relationship between sustainability and the worth of the investment property, Ellison et al. [17] clarified that obsolete assets which were using inefficient air conditioning systems will have to be upgraded due to changing occupier needs. Also, it is evidenced that an eco-friendly building provides the benefit of better rent and sale price premium [20]. On the contrary, Siew [32] highlighted that price changes are unpredictable and that ESG REITs do not necessarily outperform other types of REITs. Despite its major impact on global greenhouse gas emissions, the study conducted by Fan et al. [19] highlighted the challenge of promoting material ESG practices in the real estate sector.

Newell and Manaf [27] investigated the sustainability practices in Malaysian real estate. They analysed the annual reports and websites of publicly traded real estate companies. It resulted that some of the property companies have sustainability as their top agenda but still considering the size of the market there is scope for improvement. Continuing with the research on Malaysian REITs, Aini and Sayce [1] examine the implementation of environmental and social practices of property investors in Malaysia as revealed through published company material. They covered 13 active REITs in Malaysia in this study. The findings suggested either investors in Malaysia have been very slow in adopting ESG initiatives or that it is moving in a different direction than that of developed countries. The Asia Business Council [3] also emphasised why green buildings are critical to Asia's Future. It concluded that governments have now become more vigilant and proactive in drafting policies for designing energy-efficient buildings. However, it was evident that collaboration is required among businesses to meet sustainability goals. It is suggested that property investors should now engage with governments to influence outcomes and implement policies towards a lower-carbon world [31]. Bauer et al. [4] created an environmental scorecard based on the environmental performance of publicly traded and private real estate funds. According to the findings, the environmental performance of the global real estate investment industry can be significantly enhanced. Analysing a sample of

REITs from North America, Asia, and Europe for the years 2011–2014 suggests that there is a great deal of latent potential, particularly in the REIT community, to improve the sustainability performance of corporate real estate portfolios [21]. Westermann et al. [35] investigated the relationship between corporate social responsibility and the investment performance of Australian REITs. During market downturns or economic crises, CSR practises may produce higher risk-adjusted returns for A-REITs. This was consistent with the findings of Cajias et al. [8] who concluded that companies with a high level of ESG concerns have reduced market values. Wiley et al. [36] also mentioned that green buildings have higher occupancy and rent. Cortesi et al. [11] conducted a partial least squares analysis of the perceived impact of sustainable real estate design on well-being. It suggested a link between the design elements and health, wellness, and well-being.

According to the findings by Eichholtz et al. [14], spreads on loans for environmentally certified structures are lower than those for conventional loans. Chacon et al. [9] investigate the effects of ESG performance on the valuation, cash flow, and risk of an organisation. In this study, GRESB ESG performance data from 2019 to 2021 for global equity REITs was used. It suggested that REIT management may overinvest in ESG activities at the expense of shareholder value, particularly in times of market stress. Newell et al. [29] conducted interviews with sixty stakeholders to examine ESG issues in real estate investment. It was stated that ESG benchmarks must be improved. More attention must be paid to the impact of climate risk. In addition, enhancements to the Global Real Estate Sustainability Benchmark and a heightened focus on the Task Force for Climate-Related Financial Disclosures have emerged as significant initiatives. In addition, differences in ESG benchmarks across regions were observed.

3 Research Objective

As the world is moving towards responsible business practices, it has compelled real estate developers also to reassess their operations. With the amount of construction and heavy operations, the real estate industry has a significant negative impact on the environment. I-REITs are the pioneer in the Indian real estate industry to publicly disclose their ESG practices. The need to analyse the ESG initiatives of I-REITs is important because of the following; firstly, the Indian real estate industry guzzles to produce greenhouse emissions. Therefore, it is imperative to understand the impact created by the I-REITs on the environment. Secondly, I-REITs contribute to the upliftment of society through their contribution towards social causes and inclusivity. Thirdly, ethics and governance play a crucial role in building the trust of retail investors in a new investment class like REIT.

The objective of this research is to conduct a comparative analysis of the ESG practices of I-REITs by studying their approach towards sustainability, social responsibilities, and ethical governance practices. It identifies the areas of strength and scope for improvement for the I-REITs. This analysis will help the investors, policymakers and various other stakeholders to understand the seriousness of I-REITs being a socially responsible corporate. This research focuses on the need to study ESG practices of I-REITs and contribute to the existing knowledge and literature by filling the research gap in the field of sustainability.

4 Research Methodology

This study is qualified as qualitative in nature. In the broader category of ESG, further twenty parameters were identified starting from the ESG Vision of the REIT, their ESG Plan, Reporting standards, ESG Governance committee, Green Certified portfolio, ESG plan for new acquisitions, Renewable energy consumption, Solar power, Electric vehicles, Water usage and recycling, Waste management, Biodiversity, Organic farming, Sourcing of raw material, Community engagement, Number of independent directors, CSR spend, Number of women at the board or at management level, Diversity in the workforce and the number of hours spent in the employee training. The secondary data for this research is collected in the month of December 2022 to January 2023. During this period there were only three active REITs in India), namely Embassy REIT, Mindspace REIT, and Brookfield REIT. Secondary data was collected from the official I-REIT websites, publicly available annual reports, and published ESG reports. The data was studied to understand the I-REIT contribution towards sustainability through Content Analysis.

5 REITs in India

I-REITs are playing a vital role in organising the Indian real estate sector. REIT brings transparency, professionalism, and structure. REITs have brought global investors to invest in India because of regulatory compliance.

REIT in India is a new concept. Arora [2] studied the factors contributing to the feasibility of REITs in India. It also explored the initial regulations laid out by the SEBI. Manoj [24] studied the REIT regulations and suggested remedies for improvement. As per Virani and Kaur [33], the regulations of the I-REIT were approved by SEBI in 2014. Further Das and Thomas [12] elaborated on the strategic evolution of REITs in India.

Currently, there are active three REITs in India (Table 1). The first REIT was listed by Embassy in April'19. Later Mindspace listed their IPO in August'20, followed by Brookfield in Feb'21 [34]. All three REITs have global investors like Blackstone and Brookfield a Sponsor.

Table 1 Snapshot of the listed REIT entities in India

	Embassy REIT	Mindspace REIT	Brookfield REIT
IPO	01 April 2019	07 August 2020	16 February 2021
Total portfolio	42.8 million sft	31.9 million sft	18.6 million sft
Completed portfolio	33.8 million sft	24.9 million sft	14.1 million sft
Asset class	Office, Hospitality, Solar park	Office	Office
No. of properties	12	10	5
Location	Bengaluru, Pune, Mumbai, and Noida	Mumbai, Hyderabad, Pune, and Chennai	Gurugram, Noida, Mumbai, and Kolkata

Source Compilation of various I-REIT websites and annual reports by the authors

5.1 Sustainability Framework (Table 2)

5.1.1 ESG Vision

The Indian Prime Minister's commitment to achieving net zero emissions by 2070 [13] presents a significant challenge for the real estate sector, which is expected to contribute 13% to the country's GDP by 2025 [22]. In this context, the role of REITs cannot be overstated. Therefore, it is essential to understand the vision of REITs in relation to this commitment.

Embassy REIT, Mindspace REIT, and Brookfield REIT have each taken significant steps towards sustainability. Embassy REIT has committed to achieving net zero carbon emissions across its operational portfolio by 2040, while Mindspace REIT has pledged to use only renewable energy by 2050. Brookfield REIT is committed to achieving net zero greenhouse gas emissions by 2040.

5.1.2 ESG Plan

However, these REITs' commitments are not merely aspirational goals. There is a definitive plan in place. Embassy's ESG framework comprises three broad ideas: responsible business, resilient planet, and revitalised communities, further subdivided into 19 programs covering various aspects of ESG. These programs include (01) Energy and Emissions (02) Water Stewardship (03) Waste (04) Biodiversity (05) ESG Performance of Suppliers (06) Local Sourcing (07) Certified Materials (08) Employee Practices and Engagement (09) Training and Development (10) Health, Safety and Well-being (11) Corporate Social Responsibility (CSR) (12) Corporate Connect (13) Customer Centricity (14) Sustainable Finance (15) Asset Acquisition and Site Selection (16) Disclosures (17) Corporate Governance (18) Regulatory Compliance and (19) Risk Management. It is a comprehensive plan covering elaborative aspects of ESG.

Mindspace focuses on three pillars of resource conservation and efficiency, employee and community relations, and responsible business conduct, with eight focus areas, including: (01) Carbon Neutral Operations (02) Futuristic Buildings (03) Human Capital Development (04) Community and Tenant Relationships (05) Health and Safety (06) Human right and ethical conduct (07) Responsible Sourcing & Supplier Engagement (08) Responsible Portfolio.

Brookfield follows four pillars of ESG reporting, which include leading on sustainable solutions, partnering for thriving communities, empowering its people, and promoting trust through governance. However, Brookfield has not dissected the plan into smaller targets.

5.1.3 Reporting Framework

All three REITs follow respectable guidelines in reporting their ESG results as compared to their actual plan. Embassy follows the ESG reporting standards laid by Global Reporting Initiatives (GRI) Standards (2020), while Mindspace has multiple and comprehensive reporting standards. These include the Global Reporting Initiative (GRI) Standards, the National Voluntary Guidelines on Social, Environmental, and Economic Responsibilities of Business in India, the Principles of the United Nations Global Compact on Environment, Human Rights, Labour, and Anti-Corruption, and the Sustainable Development Goals of the United Nations. When it comes to ESG reporting, Brookfield relies on the GRESB score.

5.1.4 ESG Governance

A CSR (Corporate Social Responsibility) Committee of the Board, consisting of three or more directors, out of which at least one director shall be independent, must be established by every company with a net worth of INR 500 crore or more, or a turnover of INR 1,000 crore or more, or a net profit of INR 500 crore or more during the immediately preceding financial year, in accordance with Section 135 (1) of the Companies Act [10]. The senior leadership of all three of the aforementioned REITs i.e. Embassy REIT, Mindspace REIT, and Brookfield REIT has shown their dedication to ESG governance.

5.1.5 Certified Portfolio

The Embassy REIT has been committed to sustainability and has made significant progress in this area. Over 90% of its operational portfolio is USGBC/IGBC LEED certified. The REIT has set a target to achieve a 100% USGBC LEED rating for operations and maintenance for its entire portfolio by FY'23. This indicates a strong commitment to sustainable practices and environmental responsibility.

Mindspace has also demonstrated a similar commitment to sustainable practices. As of now, 18.73 MSF (75% of their total footprint) is certified as ‘Green Building’. The REIT has set a target to have 95% of its portfolio certified with a minimum Gold rating by 2025.

Similarly, Brookfield has 74% of its portfolio under sustainability certification. This demonstrates a strong commitment to sustainable practices and responsible investing.

All three REITs are pursuing sustainability certifications that demonstrate their commitment to environmental stewardship. Their efforts towards obtaining these certifications signify their adherence to industry best practices and governance standards. The REITs’ efforts to achieve these sustainability targets are a testament to their commitment to ESG governance.

5.1.6 CSR Spend

According to their respective annual reports, Embassy has disclosed a CSR spend of INR 112 million, while Brookfield has disclosed INR 6.81 million. Mindspace, on the other hand, has earmarked INR 48 million in separate escrow accounts earmarked for the CSR projects. These figures demonstrate the commitment of each of the three REITs to corporate social responsibility and sustainability initiatives.

5.1.7 New Acquisition

As part of their commitment towards achieving net zero emissions, Embassy has set a requirement that any new asset they acquire must be brought under a net zero regime within 5 years of acquisition. Meanwhile, Mindspace has established certain criteria for asset acquisition, though these criteria are not explicitly defined in their annual reports. On the other hand, Brookfield has not disclosed any specific criteria for the acquisition of new assets under their ESG framework.

5.2 Renewable energy (Table 3)

5.2.1 Renewable Energy Consumption

Based on the available data, it is evident that Embassy has taken a significant step towards sustainability by powering 55% of its current portfolio with renewable energy. Furthermore, they target to achieve 75% renewable energy by 2025. On the other hand, Mindspace has a comparatively lower percentage of renewable energy consumption at 2.9%. However, their target to increase it to 35% by 2025 and 50% by 2030 shows a promising commitment towards sustainability. In contrast, Brookfield has only 1.4% of its portfolio powered by renewable energy, but the Kensington property in Mumbai operates on 100% green power, which is a positive development. Overall, it is evident that companies are gradually moving towards sustainable energy, but there is still a long way to go to achieve complete sustainability.

5.2.2 Solar Power

Embassy has made a significant investment in a 100 MW solar park in Bellary. Meanwhile, Mindspace's Madhapur location has a solar plant capable of generating 1.6 MW of energy. Brookfield has also taken steps towards renewable energy with the installation of rooftop solar panels.

5.2.3 Electric Vehicles

As part of its commitment to sustainability, Embassy ensures that all its projects incorporate electric vehicle (EV) charging points for at least 5% of the total parking capacity. Mindspace has taken significant strides in this regard, with over 950 EV charging points installed across its portfolio. While Brookfield has not disclosed specific data on EV charging points, their tech parks are equipped with such facilities.

5.3 Recycling (Table 4)

5.3.1 Water

According to the available data, Embassy has reduced freshwater usage by 53% through the re-use of treated water. Mindspace has achieved a 35% reduction in freshwater usage through the same method. Brookfield has reported a 21% reduction in freshwater usage, but further details are not available.

5.3.2 Waste Management

Embassy has a total annual waste generation of 735 tonnes, with a capacity of 13.2 tonnes of Organic Waste Convertor. Mindspace generates an annual waste of 1,374 tonnes, while Brookfield generates an annual waste of 2,348 tonnes.

5.4 Biodiversity (Table 5)

5.4.1 Biological Diversity

Embassy has gone beyond pet shelters in its parks and has also established a butterfly park and Miyawaki plantation at Manyata Business Park in Bengaluru. Similarly, Mindspace has also created a butterfly park at its Airoli location. In contrast, Brookfield focuses on the maintenance of green areas near its campuses in Noida, Sector 135 and New Town, Kolkata. Overall, each of these REITs has made an effort to incorporate green spaces and initiatives in their projects, providing benefits to both the environment and the communities they serve.

5.4.2 Organic Farming

Mindspace has made efforts towards promoting organic farming in urban areas, specifically at Mindspace Airoli East. However, there is no disclosure of any initiatives related to organic farming from Embassy and Brookfield.

5.5 Sourcing (Table 6)

Embassy, Mindspace, and Brookfield have all recognised the importance of local sourcing in reducing carbon footprints during transportation. Embassy has set a target of sourcing at least 30% of materials locally by FY'25, within a 1,000 km radius of their sites. Mindspace has set a goal of sourcing 25% of total civil material value locally and increasing it to 40% by 2026. Brookfield has not disclosed specific numbers but has stated that they procure building materials from local value chains to minimise transportation emissions.

5.6 Community Engagement (Table 7)

Embassy has undertaken various development activities such as student education, water sanitization, nutrition, and health, among others. On the other hand, Mindspace has focused on student education, nutrition and health, and biodiversity, among other initiatives. Brookfield has undertaken development activities that primarily focus on student education and women empowerment.

5.7 *Corporate Governance (Table 8)*

5.7.1 Independent Board of Directors

In compliance with SEBI regulations, a REIT is mandated to have at least 50% of its board of directors as independent directors. Among the three REITs in India, Embassy and Brookfield have met this requirement by maintaining a 50% independent board of directors. On the other hand, Mindspace has exceeded the regulation by having 66.67% of its board of directors as independent directors, indicating a higher level of adherence to corporate governance standards.

5.7.2 Women Board/Management Level

As per the data available, Embassy has 12.5% women representation at the board and management level. Mindspace, on the other hand, has a higher representation of women at 27% at the board and management level. They have set targets to increase this percentage to 29% by 2023 and more than 30% by 2025. Brookfield has 25% women representation at the board and management level.

5.7.3 Diversity

Embassy has 23% women in its workforce. Mindspace has 16% women in its workforce. However, Brookfield has not disclosed its gender diversity data.

5.7.4 Employee Training

According to the available information, Embassy provides an average of 13 hours of training per employee per year, including ESG training. Mindspace invests 10 hours on average for ESG training per employee, with a plan to increase the training hours to more than 10 by 2025. They also spend an average of INR 3,400 per employee for the training. Brookfield provides an average of 25.5 hours of training per employee for behavioural training and an additional average of 30 hours for technical training. However, there is no specific information available on ESG training for Brookfield.

Table 2 Summary of the sustainability framework by I-REITs

	Embassy REIT	Mindspace REIT	Brookfield REIT
Vision	Committed to Net zero carbon emissions by 2040 across our operational portfolio.	Committed to utilising 100% electricity from renewable sources by 2050	Achieve Net zero by 2040 or sooner
ESG plan	Three pillars: 1. Responsible business 2. Resilient planet 3. Revitalised communities ESG Framework comprises 19 programs under the three pillars	Three pillars: 1. Resource conservation and efficiency 2. Employee and community relations 3. Responsible business conduct There are 8 focus areas	Four pillars: 1. Lead on sustainable solutions 2. Partner for thriving communities 3. Empower our people 4. Promote trust through Governance
Reporting standards	Global Reporting Initiative (GRI) Standards (2020)	1. GRI standards 2. National voluntary guidelines on social, environmental and economic responsibilities of business 3. UN global compact principle on the environment, human rights, labour and anti-corruption 4. UN's sustainable development goals.	1. GRI Standards. 2. On track to receive GRESB score (a leading global benchmark for ESG reporting) for FY'22.
ESG governance	Defined committee having senior leadership	Defined committee having senior leadership	Defined committee having senior leadership
Certified portfolio	Over 90% of the operational portfolio is USGBC/IGBC LEED certified Target to get 100% of the portfolio USGBC LEED rated for operations and maintenance by FY'23	18.73 MSF (75%) total 'Green Building' certified footprint By 2025, 95% of the total portfolio is to be LEED/IGBC certified with a minimum Gold rating	74% of the portfolio is under sustainability certification
CSR spend	INR 112 million	INR 48 million	INR 6.81 million
New acquisition	Aim to bring the asset under the purview of our net zero commitment within 5 years	Setting ESG criteria for new acquisition	No specific criteria defined

Source Compilation of various I-REIT websites and annual reports by the authors

Table 3 Summary of the renewable initiatives by I-REITs

	Embassy REIT	Mindspace REIT	Brookfield REIT
Renewal energy consumption	2022: 55% 2025: Commitment to achieve 75% renewable energy usage	2022: 2.9% 2025: Commitment to achieve 35% renewable energy usage 2030: Commitment to achieve 50% renewable energy usage	2022: 1.4% Kensington is operating with 100% green power
Solar power	Invested in 100 MW Solar park in Bellary	Solar plant with 1.6 MW capacity to generate renewable power at Mindspace, Madhapur	Installed rooftop solar panels
Electric vehicle (EV)	All projects are designed to incorporate EV charging points for at least 5% of the total parking capacity	Installed over 950 EV charging points across the portfolio	No specific criteria defined

Source Compilation of various I-REIT websites and annual reports by the authors

Table 4 Summary of the recycling initiatives by I-REITs

	Embassy REIT	Mindspace REIT	Brookfield REIT
Water	53% reduction in freshwater usage by re-use of treated water	35% reduction in freshwater usage by re-use of treated water	21% reduction in freshwater usage by re-use of treated water
Waste management	Total waste: 735 tonnes. Capacity of 13.2 tonnes of organic waste converter	Total waste: 1,374 tonnes	Total waste: 2,348 tonnes

Source Compilation of various I-REIT websites and annual reports by the authors

Table 5 Summary of the biodiversity initiatives by I-REITs

	Embassy REIT	Mindspace REIT	Brookfield REIT
Biodiversity	Pet shelter Butterfly Park at Manyata Miyawaki plantation at Manyata	Butterfly Park at Mindspace, Airoli	Maintenance of green areas in Noida and Kolkata
Organic farming	No disclosure	Invest their efforts into nurturing organic urbanised farming at Mindspace Airoli East	No disclosure

Source Compilation of various I-REIT websites and annual reports by the authors

Table 6 Summary of the sourcing initiatives by I-REITs

	Embassy REIT	Mindspace REIT	Brookfield REIT
Sourcing	Defined a 1,000 km radius around the respective sites to evaluate the availability of local materials FY'25: Plan for at least 30% locally sourced materials	2023: Plan for 25% of the total value of civil material 2026: Plan for 40% of the total value of civil material	Procurement of building materials from value chains that manufacture locally

Source Compilation of various I-REIT websites and annual reports by the authors

Table 7 Summary of the community engagement initiatives by I-REITs

	Embassy REIT	Mindspace REIT	Brookfield REIT
Community engagement	Undertaken development activities including student education, nutrition, water sanitization and health, etc.	Undertaken development activities including student education, nutrition and health, biodiversity, etc.	Undertaken development activities including student education and women empowerment

Source Compilation of various I-REIT websites and annual reports by the authors

Table 8 Summary of the corporate governance initiatives by I-REITs

	Embassy REIT	Mindspace REIT	Brookfield REIT
Independent board of directors	50%	66.67%	50%
Women at the board/ management level	12%	2022: 27% 2023: 29% (planned) 2025: 30%+ (planned)	25%
Diversity	23% of women workforce	16% of women workforce	No disclosure
Employee training	Avg. 13 training hours per employee per annum	2023: 10 Hrs. average ESG training hours per employee 2025: 10+ Hrs. average ESG training hours per employee Avg. amount spent on ESF training per FTE is INR 3400	Behavioural training: 25.5 Hrs. of training per employee Technical training: 30 Hrs. of training per employee

Source Compilation of various I-REIT websites and annual reports by the authors

6 Conclusion

Globally REITs are gaining significance as real estate investment vehicles and are frontrunners in the adoption of sustainable practices and ESG norms. The three I-REITs have demonstrated a strong commitment to sustainability and have set benchmarks for the real estate industry in India. Their adherence to ESG reporting guidelines signifies their commitment to transparency and accountability towards their stakeholders. This paper provides an idea of the progress made by Indian REITs towards sustainability in their business operations and investment strategies. Each REIT has a strong commitment to reducing its impact on the environment, promoting sustainable communities, and improving the well-being of its tenants and employees. Notably, Embassy REIT stands out in terms of its ESG initiatives, especially in terms of Environment sustainability. Embassy REIT is chasing an ambitious goal of net zero by 2040. It has a high percentage of LEED-certified assets and invested in mega solar plants. Embassy's extensive ESG framework demonstrates its holistic approach. Their sustainable effort reduces the environmental impact as well as creates a positive social impact in society. It is a model for sustainable real estate and a benchmark for other REITs in India. The findings suggest that while there is variation in the ESG practices among the three REITs but collectively they have made a positive impact on the environment and society. It highlights the significance of ESG practices in terms of green funding and sustainable practices that drive positive change for the built environment. Investors and policymakers can further contribute to a responsible real estate sector by incorporating these findings into the decision-making for future investments.

7 Recommendation

Currently, all three I-REITs have their own standards towards ESG reporting. There is no official benchmark to compare. Therefore, it is recommended that common minimum ESG standards should be implemented by the government or industry bodies. The reporting mechanism should be cohesive and consistent for the real estate industry. This will raise the benchmark for I-REITs and establish credibility and transparency among investors. It will further help to raise the awareness of REITs in the Indian capital market and drive a positive change towards sustainability. As a limitation of this study, it is based on the secondary data available in the public domain which may be subject to interpretation.

References

1. Aini AM, Sayce S (2010) Disclosing environmental and sustainability practices and initiatives in the annual reporting process of property investors: evidence from Malaysia. Presented at the (2010)
2. Arora R (2014) Establishing a Conducive Environment of REITs (Real Estate Investment Trusts) in India
3. Asia Business Council (2008) Building energy efficiency : Why green buildings are key to asia's future building energy efficiency . Why green buildings are key to asia's future
4. Bauer R, Eichholtz P, Kok N, Quigley JM (2011) How green is your property portfolio? the global real estate sustainability benchmark. Rotman Int J Pension Manag 4:34–43
5. BNP Paribus Real Estate. What does real estate have to gain by investing in sustainability?. https://www.realestate.bnpparibas.com/what-does-real-estate-have-gain-investing-sustainability
6. Brookfield (2021) ESG report 2021
7. Brookfield (2022) Annual report 2021-22
8. Cajias M, Fuerst F, McAllister P, Nanda A (2014) Do responsible real estate companies outperform their peers? Int J Strateg Prop Manag 18:11–27. https://doi.org/10.3846/1648715X.2013.866601
9. Chacon R, Feng Z, Wu Z (2022) Does investing in ESG pay off? Evidence from REITs around the COVID-19 Pandemic. SSRN Electron J:1–38. https://doi.org/10.2139/ssrn.4147749
10. Companies Act 2013 (2018) Section 135 indian company act on corporate social responsibility
11. Cortesi A, Vardopoulos I, Salvati L (2022) A partial least squares analysis of the perceived impact of sustainable real estate design upon Wellbeing. Urban Sci. 6:69. https://doi.org/10.3390/urbansci6040069
12. Das P, Thomas CRJ (2016) Strategic development of REITs in India. J Real Estate Lit 24:103–131. https://doi.org/10.1080/10835547.2016.12090416
13. Economic Times: India's ambitious 2070 zero emission target needs $10 trillion investment. https://energy.economictimes.indiatimes.com/news/renewable/indias-ambitious-2070-zero-emission-target-needs-10-trillion-investment/96512902#:~:text=The economic benefits of India,Getting Asia to Net Zero.
14. Eichholtz P, Holtermans R, Kok N, Yönder E (2019) Environmental performance and the cost of debt: Evidence from commercial mortgages and REIT bonds R. J Bank Financ 102:19–32. https://doi.org/10.1016/j.jbankfin.2019.02.015
15. Eichholtz P, Kok N, Yonder E (2012) Portfolio greenness and the financial performance of REITs. J Int Money Financ 31:1911–1929. https://doi.org/10.1016/j.jimonfin.2012.05.014
16. Ellison L, Sayce S (2007) Assessing sustainability in the existing commercial property stock: Establishing sustainability criteria relevant for the commercial property investment sector. Prop Manag 25:287–304. https://doi.org/10.1108/02637470710753648
17. Ellison L, Sayce S, Smith J (2007) Socially responsible property investment: Quantifying the relationship between sustainability and investment property worth. J Prop Res. 24:191–219. https://doi.org/10.1080/09599910701599266
18. Embassy REIT (2022) ESG report
19. Fan KY, Shen J, Hui EC (2022) ESG materiality and responsible investment: Evidence from real estate investment trusts Kwok Yuen Fan, Jianfu Shen, Eddie Chi-man Hui This version 2022-11-25. pp 1–52
20. Franz Fuerst PM (2022) Green noise or green value? Measuring the effects of environmental certification on office values
21. Fuerst F (2015) The financial rewards of sustainability: a global performance study of real estate investment trusts. SSRN Electron J:1–22. https://doi.org/10.2139/ssrn.2619434
22. IBEF Indian real estate industry. https://www.ibef.org/industry/real-estate-india
23. JLL (2022) Decarbonizing cities and real estate
24. Manoj (2014) Real estate investment trusts (REITs) in india: relevance and significance in emerging scenario. 3:945–954

25. Mindspace (2022a) Annual report
26. Mindspace (2022b) ESG report
27. Newell G, Manaf Z (2008) The significance of sustainability practices by the Malaysian property sector. Local Econ 23:152–167. https://doi.org/10.1080/02690940802197242
28. Newell G, Marzuki MJ (2022) The increasing importance of environmental sustainability in global real estate investment markets. J Prop Invest Financ 40:411–429. https://doi.org/10.1108/JPIF-01-2022-0005
29. Newell G, Nanda A, Moss A (2023) Improving the benchmarking of ESG in real estate investment. J Prop Invest Financ. https://doi.org/10.1108/jpif-10-2021-0084
30. Oberthür S, Groen L (2018) Explaining goal achievement in international negotiations: the EU and the Paris Agreement on climate change. J Eur Public Policy 25:708–727. https://doi.org/10.1080/13501763.2017.1291708
31. Pike J (2020) The future of sustainable real estate investments in a post-COVID-19 world. J Eur Real Estate Res 13:455–460. https://doi.org/10.1108/JERER-07-2020-0042
32. Siew RYJ (2015) Predicting the behaviour of Australian ESG REITs using Markov chain analysis. J Financ Manag Prop Constr 20:252–267. https://doi.org/10.1108/jfmpc.2008.37613aaa.002
33. Virani S, Kaur P (2015) Real estate investment trusts (REITs)—An innovative approach to real estate sector. Annu Res J SCMS, Pune. 3:155–165
34. Walia S, Sarkar S, Mohanty B, Pal S (2023) Analysis of the emergence and initial performance of REITs in India. J Prop Invest Financ. https://doi.org/10.1108/JPIF-12-2022-0084
35. Westermann S, Niblock SJ, Kortt MA (2022) Does it pay to be responsible? Evidence on corporate social responsibility and the investment performance of Australian REITs. Asia-Pacific J Account Econ 29:1102–1119. https://doi.org/10.1080/16081625.2019.1673188
36. Wiley JA, Benefield JD, Johnson KH (2010) Green design and the market for commercial office space. J Real Estate Financ Econ 41:228–243. https://doi.org/10.1007/s11146-008-9142-2

Evolution of Green Office Buildings in the Business Districts of Indian Cities

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1 Introduction

The cities are the engine of economic growth, responsible for 85% of the global gross domestic production [28]. Economic growth fuels built environment construction and related activities in the cities, which are responsible for high carbon emissions and energy consumption. With only two percent of the landmass, the cities are responsible for 70% of carbon emissions and over two-thirds of energy consumption (C40, University of Leeds, University of NSW, & Arup 2018). Moreover, the world construction industry consumes 40% of natural resources and creates 50% of solid waste, along with significant environmental challenges in the cities,for its six percent contribution to the global GDP [27]. That is an unsustainable and expensive proposition for the growth and future of our cities [23].

The city-level economic activity resulted in built environment construction with defined spaces for work, live, play, and leisure. Urban history and geography from the developed economies suggested the city's hub of economic activity in the center of the city and named it as a central business district (CBD). Around this CBD hub, the spokes of economic activity along the transit routes from CBD led to the formation of suburban business districts (SBD) [2]. The developed economies literature represented the sub-market as the smallest unit of economic activity at a city level leading to real estate development, the largest unit at the city level being business districts mostly represented as CBD and SBD. In developing countries, rarely any standard urban geography terms are used by all market participants while defining business locations at the city level. Different cities and markets used different terms to represent the same context and there is no standard terminology used. The current

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research looks at city evolution in developing countries like India to understand if standard urban geography terms can be used in the context of developing cities or not.

The literature provides built environment-related environmental challenges solutions through green and low-carbon building development in the cities of the world. In the developed world most of the city's built environment is already under operation whereas in developing, emerging economies like India two-thirds of commercial buildings needed by 2030 are yet to be built [21]. Looking at already existing environmental challenges in developing country cities, the need for new stock to be green and low in carbon emission throughout its lifecycle is high [25].

The Indian literature suggested that cities have been reluctant to green investments due to a lack of awareness, dis-belief in environmental benefits, and perception of being "out of responsibility zone" when environment and resources are deliberated upon [6, 15, 26]. For the success of urbanization in developing countries, the city stakeholders and broader markets need environmental awareness and feel accountable for constructing a sustainable built environment. As per the [30], India is at a unique tipping point in its urban development journey with 300 million new urban residents to be added by 2050 and related built environment construction. This urbanization better be green and low carbon to increase the quality of living and this paper studies the evolution of Indian cities in terms of green building development. The current paper also studies the penetration of green buildings in the cities of India mainly the commercial hubs like Mumbai, Bangalore, and NCR region.

Developed economies literature suggests that at the city level, buildings, neighborhoods, business districts, and community development spaces should all be designed, constructed, and operated green [5, 7, 24]. Indian cities have had green buildings for more than a decade now but there has been no study at the city level of green building penetration in the context of urban geography. For that matter city development patterns in developing countries like India have rarely been compared with developed countries cities which this paper attempts to do.

2 Background on Indian Cities, Business Districts, and Green Buildings

Indian cities contribute nearly 70% of the GDP and every minute 25–30 people move to cities for better employment and quality of life [30]. The growth driver in cities is the services sectors which need commercial buildings whereas industry sectors like IT/ITeS, Banking and Financial Services, Telecom, Pharmaceuticals, E-commerce, Retail, and Media need working space. Also, many people move for better education, medical facilities, and overall quality of life leading to built environment construction and growth of cities.

The three biggest commercial business centers in India are Mumbai, NCR Region, and Bangalore and these cities have grown by more than 350% in built-up area over the last four decades of development [20]. These three cities are mega cities with a population of more than 10 million but more importantly, they contribute the highest to the GDP of India compared to other cities. Typically, these megacities and regions now have upcoming cities and satellite towns within the metropolitan region. Mumbai Metropolitan Region (MMR) now consists of the cities of Thane, Mumbai, and Navi Mumbai. NCR region has Delhi, Gurgaon, Noida, Greater Noida, Manesar and Ghaziabad, and others. Typically, these cities have grown in the outskirts of older cities where transit-oriented developments happened over the last forty years.

The commercial buildings are typically located in the business districts but in the case of Indian cities, there are different names given by the market participants based on the commercial activity location size, spread, and density of the location and activity. The market participants typically use terms like business district, business region, micro-market, business district-zone, CBD, Secondary business districts, Peripheral business districts, and Emerging business district (EBD) with no standard definition in the urban geography context.

Green buildings in India came into existence in 2001 when the Confederation of Indian Industries (CII) formed Indian Green Building Council (IGBC) to fight resource challenges and environmental issues at the building level. The first green building came out in 2003 which was IGBC's own headquartered building. During this time a few influential companies in IT/ITeS, Banking, and Financial Services which were environmentally aware and innovative went ahead for rated green commercial buildings. After a gradual start from 2014 onwards there has been an acceleration in the number of buildings registering and achieving certifications. Currently, more than 2000 certificated green commercial buildings exist in cities of India.

3 Literature Review

India has witnessed strong demand for resources and supply shortages over more than two decades of urbanization, resulting in Indian Government coming up with Energy Conservation Act (ECA) on 1st October 2001 [17]. The increasing urbanization and forecasted growth of the built environment in new and existing cities make the built environment the second-largest consumer of energy and by 2030 the sector will be the largest energy consumer [14]. To manage energy inefficiencies and focus on energy-conscious design and encourage standard practices Bureau of Energy Efficiency (BEE), a legislative body under ECA and the Ministry of Power came into existence [16, 17]. BEE came up with star rating systems for buildings to achieve energy efficiency and also the formation of Energy Conservation Building Code (ECBC) which have been modified and fast-tracked in 2017 [23]. It is noted that the initial driver of green buildings in India was the energy efficiency and increasing electricity costs and supply shortages 1, 9].

Green building evolution and diffusion patterns have been researched widely in developed countries [10, 11, 13], and developing economies lack literature and found to have regional imbalances in green building evolution and diffusion [19, 31]. Currently, there exists no literature representing the evolution of cities and green buildings in the cities of developing countries like India comparing it with developed countries' city patterns and green building evolution.

4 Data and Research Methods

To understand the city-level development of business districts and the evolution of green buildings in three Indian cities the paper conducted secondary data analysis. The data sources were the JLL Property Database, International Property Consultants reports, USGBC Green Building database of India, Green Building Information Gateway, IGBC newsletters, and ICICI Property Services reports on commercial real estate. A total of 317 green buildings were identified from the LEED green building database operational in three cities of Mumbai, Bangalore, and NCR region. The database building's longitude and latitude information from the database led to finding micro-markets, business district zones, and business districts of these green buildings. The data was classified and tabulated further as represented in the sections ahead. The similarities and dissimilarities of commercial real estate development in these cities are further analyzed for drawing conclusions.

5 City-Level Business District Classification in India

Usually, in developed countries, the center of the city is the hub of commercial activity, named CBD. Around this CBD hub, there are spokes of secondary commercial development, typically called suburban business districts. In contrast the emerging economies like India, there are typically three layers of development in each metropolitan region. As mentioned earlier the mega cities in India have grown by more than 300% over the four decades of development and still, there are active development happening in the fringes. Traditionally there are old CBD regions around which fully developed business districts came up, which together with CBD form the first layer called Primary Business Districts (PBD). With transit-oriented development from PBD to the fringes of the cities, many other business districts came up along the transit routes, forming the second layer called Secondary Business Districts (SBD) by the market participants (Fig. 1). The economic growth and demand for real estate have resulted in the cities undergoing expansion and development at fringes and peripheries, forming the third layer known as peripheral business districts. Many times, these peripheral regions become cities in themselves e.g., Thane near Mumbai. Developing countries like India have active real estate development happening in the peripheral regions. The market participants also call it Emerging Business Districts (EBD) to highlight the potential of real estate development in this region.

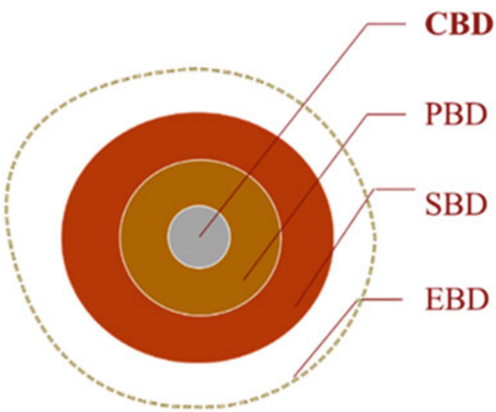

Fig. 1 Indian cities or metropolitan region with three layers of development, *Source* [23]

The market participants like International Property Consultants (IPC), financial institutions, and brokerage firms define micro-markets as the smallest unit of commercial and real estate activity at the city level. From the smallest units onwards, there are different terminologies used to represent business districts at the city level and the paper further represents the classification for the cities of Mumbai, NCR, and Bangalore metropolitan regions. The penetration of green buildings in these cities is also presented in respective tables.

5.1 Mumbai Metropolitan Region (MMR)

The Mumbai metropolitan region consists of three cities namely Mumbai, Thane, and Navi Mumbai; and is a preferred commercial hub for companies conducting trade business in the Southeast Asia region. It is also the financial and entertainment capital of India, contributing the highest GDP among Indian cities [29]. The below table represented the smallest unit micro-market representing economic activity connected with the broader city-level classification along with the percentage of certified green buildings till 2020. As per Table 1, the whole MMR region can be classified into three categories,the first being PBD where the very first business district in history Ballard Estate existed. In the 1950s Mumbai's southern tip near the ocean, called the Nariman Point micro-market, became the central business district (CBD). The micro-markets of Ballard Estate, Nariman Point, and Cuffe Parade are now collectively called the old CBD region. The classification in the table below considers PBDs, which include the old CBD region and the region around it (developed by the late 1970s), plus the Central Mumbai zone of Lower Parel, Prabhadevi, Mahalaxmi, and Worli. In the late 1970s, the Bandra Kurla Complex (BKC) region was developed from marshy lands into a prime business region near the international airport; it is also considered as a PBD in the analysis. BKC became the new CBD of Mumbai in the year 2010. North of BKC, along the Eastern and Western express highway, a transit-oriented suburb development started in the year 2000 which has Secondary Business Districts (SBDs) along the highway named as the eastern and western suburbs. Toward the end of the Eastern Express Highway, a satellite town, Thane, became a city; it has been considered an SBD in the analysis. Navi Mumbai, a planned development envisaged as the “other” Mumbai (on the east side of Mumbai, across the mile long Vashi Bridge), was initiated in the late 1990s. This small town grew into a major city and is the region’s Emerging Business District (EBD); it is also called a peripheral business district by market participants. This emerging business district is still under development and will soon have an international airport of its own.

Most of the buildings in the Mumbai region which were rated green were mostly Gold or Platinum rated with less than 1% stock which are silver rated or certified. The higher-rated green buildings signal the sustainability and responsible environmental image of the companies developing or occupying these spaces. As per the Figure below, we plotted gold and platinum-rated buildings around Mumbai airport (Fig. 2).

Table 1 Commercial business districts and micro-markets of MMR

City-level location classification	City/town	Major business district	Green building (%)	Micro-markets within business district
PBD	Mumbai	CBD and Off CBD	4.50	Nariman Point, Cuffe Parade, Ballard Estate, Fort, Churchgate
	Mumbai	BKC and Off BKC	17.90	BKC, Bandra (East), Kalina, Kalanagar, Vakola, Kurla (West)
SBD	Mumbai	Central Mumbai	16.90	Parel, Lower Parel, Dadar, Prabhadevi, Worli, Byculla, Central, Mahalaxmi, Elphinstone Road, Sion
	Mumbai	Western Suburbs	31.40	Santacruz (East), Ville Parle, Andheri, Jogeshwari, Goregoan, Malad, Borivali
	Mumbai	Eastern Suburbs	10.11	Ghatkopar, Vikhroli, Kanjurmarg, Powai, Bhandup, Chembur, Mulund (West)
	Thane	Thane	6.75	Chiraknagar, Wagle estate, Naupada, Kalwa, Kolshet, Majiwada, Manpada, Mumbra, Vartak Nagar
EBD	Navi Mumbai	Navi Mumbai	12.35	Airoli, Vashi, Ghansoli, Rabale, Belapur, Juna Sheva, Taloja, Mahape, Kalamboli, Pawne, Turbhe, Kopar Khairane, Vashi, Sanpada, Nerul, Ulwe, Dronagiri, Karanjade, Kamothe, New Panvel

The table below shows the three major business districts, seven business district zones, and many micro-markets in each zone. In the dataset, SBDs and PBDs contain 48.3 and 39.3% of the total green buildings, respectively, and the emerging region of Navi Mumbai has 12.35% of the certified building dataset. *Source*—[8, 12, 22, 23]

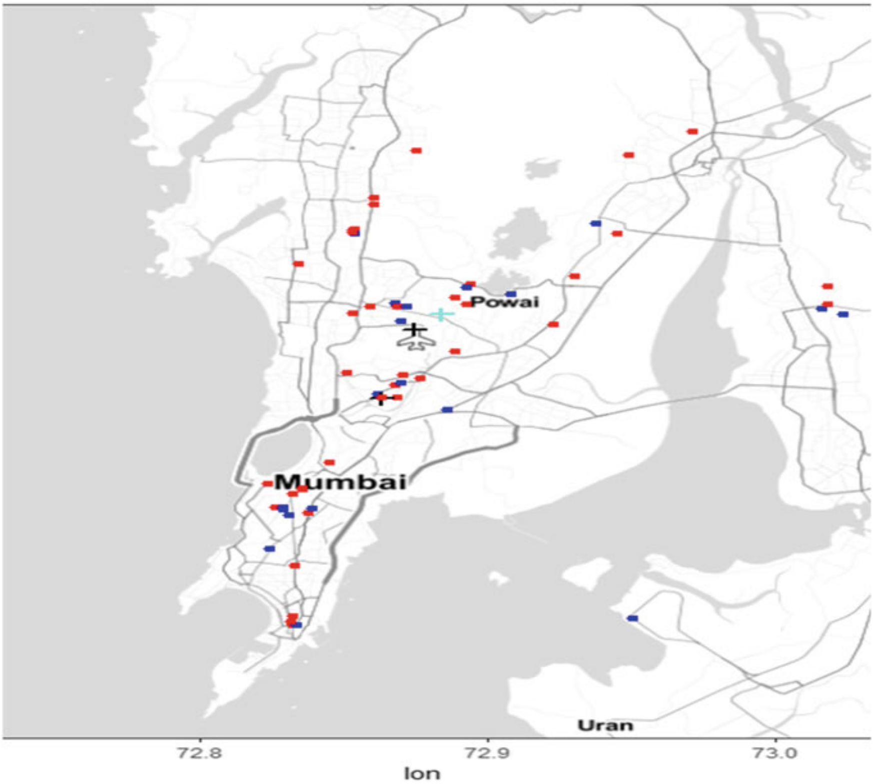

Fig. 2 Blue dots represent platinum-rated buildings, and the red dots represent gold-rated buildings in and around the Mumbai airport region. The region has an international and domestic airport at the same location with different terminals represented in a plus sign. *Source*—[23]

5.2 NCR Region

The National Capital Region (NCR) contributes the second-largest GDP among all the major cities of India. The city is the Indian political and administrative capital and headquarters to the central government, ministries, central and state public sector companies, international embassies, and institutions of repute present in India. The major cities in the region are Delhi, Noida, Gurgaon, and Greater Noida, which have been further classified into various micro-markets as per Table 2. The NCR region's commercial real estate market can be divided into three major business districts, per the progression of this region with time. The original city of Delhi witnessed the concentric growth model as the development began in 1957 when the Delhi Development Authority (DDA) was formed and that started the development of the region. The Connaught Place has been the original CBD of Delhi and the nearby regions like Lodhi estate, Chanakyapuri, and CGO complex have various government, public sector, and international embassies headquarters located in the area. These micro-markets form the Primary Business District (PBD) for the region. As time passed by, outer Delhi started getting developed from rural land to urban land; people started coming in search of new livelihood and services sector, establishing the region as a base. The real struggle of horizontal to vertical development continued till 2000, later as per Master Plan 2021 Connaught Place is defined as the first CBD of the city identified as the hub of business and cultural activities located at the prime location. Gurgaon near the airport of Delhi attracted a lot of IT/ITeS and BPO/KPO industry and developed into a millennium city by 2010. Toward the other end of the city, New Okhla Industrial Development Association (NOIDA) came into existence and the development of the Noida Greater Noida expressway enabled further development to spread toward the Greater Noida region. In 2019, Connaught Place was among the most expensive office market around the globe. Slowly other areas like Lodhi Estate, Gole Market, Chanakyapuri, and CGO complex were being treated as CBD because of high leasing activity and high rentals which became the PBD of Delhi NCR. However, the CBD mostly lacks out to the SBDs on Grade A building supply and precinct-level infrastructure. Therefore, across key Indian office markets, Secondary Business District (SBDs) are emerging as the most favorable having the availability of accessible space and reasonable pricing.

Global organizations, institutions, and foundations like the World Bank and the United Nations, and many more have their regional headquarters and south-east Asian offices in the NCR region. It is home to many IT/ITeS, Telecom, Media, Consulting companies, educational institutes, auto, auto parts, and related ancillary manufacturing industries. As shown in Table 2, most of the commercial buildings are in the secondary business districts resulting from transit-oriented development in the region until 2011. With a higher available land-bank, compared to the Mumbai region, the regional area coverage has multiplied by more than five times in the last 40 years. The region has a mix of higher and lower-rated buildings and most of the green buildings are newer, taller, and more prominent in size compared to conventional buildings.

5.3 Bangalore Region

Bangalore is the biggest commercial real estate market in India which is also the software and start-up capital of India. In Asia, The Bangalore region is the second-largest Grade A office space market after Tokyo and is consistently among top performing office markets [4]. The city attracts companies from all over the world, most of them being in technology, electronics, fintech, e-commerce, defense, and startups. The city has abundant availability of skilled human capital in the region. The Bangalore region's commercial real estate market can be divided into three major business districts, per the progression of this region with time. The original city of Bangalore, which has PBD and parts of SBD initially had public sector companies and education institutions which led to an influx of people. In the 1970s and 80 s industrialization and manufacturing led to job creation with the creation of road infrastructure in

Table 2 Commercial business districts and micro-markets of the NCR region

City-level location classification	City/town	Major business district	Green building (%)	Micro-markets within business district
PBD	Delhi	CBD and Off CBD	2.43	Connaught Place, Lodhi Estate, Gole Market, Chanakyapuri, CGO Complex
SBD	Delhi	Delhi—SBD	5.04	Saket, Jasola, Bikaji Kama Place, Vasant Vihar, Munirika, South Extension, Nehru Place, Okhla Industrial Area & Mohan Cooperative Industrial Estate, Vasant Kunj
	Gurgaon	Institutional Sectors	4.51	Sec 44, Sec 45, Sec32, Sec 18, Sec 30, Sec31, Sec39, Sec 41
	Gurgaon	Golf Course Area	2.97	Golf Course Road, Golf Course Extension Road, Golf Course Sohna Road, Sector 42, Sector 54, Sector 43
	Gurgaon	Udyog Vihar—Gurgaon	1.58	Udyog Vihar Phase I- Sector 20, Udyog Vihar Phase III - Sector 20, Sector 21
	Gurgaon	DLF Cybercity-Gurgaon	59.26	Sector 24, Sector 25, DLF Phase 2, DLF Phase 3, Sector 25A
	Gurgaon	MG Road	0.00	MG Road-Gurgaon
	Gurgaon	Mehrauli Gurgaon Road	0.26	Anamika Enclave-Sec 14, Sikanderpur–Sec 26
	Noida	Industrial Sectors	0.36	Sec 1–9, Sec 11, Sec 57–60, Sec 63–65
	Noida	Central Noida	1.25	Sector 24, Sector 25, Sector 18, Sector–16,16A
	Noida	Noida Commercial	3.52	Sec 18, Sec 16, Sec 62
EBD	Delhi	Delhi-Outskirts	0.15	Netaji Subhash Place, Aerocity, Shivaji Marg-West Delhi, Rohini–West Delhi
	Gurgaon	NH8 (till Manesar)	8.99	IMT Manesar, Sector 26A, Sector 36
	Gurgaon	Gurgaon – Faridabad Road	0.80	Gwal Pahari, Sec 48, Sec 52, Sec 56, Sec 49, Sec 67, Sec 51, Sec 69, Sec 65
	Noida Greater Noida	Noida Expressway	5.90	Noida Greater Noida Expressway
	Greater Noida	Greater Noida	3.00	Greater Noida

From Table 2, we can see that many of these commercial buildings (79.53%) are in SBD, highlighting the development of business districts along the transit routes of Delhi. *Source*—[8, 12, 22, 23]

SBD leading to the formation of micro-market business districts. The original CBD witnessed companies moving to SBD and later most of the retail spaces came up in the CBD region. The accelerated growth of the Bangalore region started in the 1990s when IT and Electronic companies made Bangalore the location of choice with an abundant talent pool of employees and land/infrastructure available for growth. Bangalore Development Authority constructed the Outer Ring Road (ORR) from 1996 to 2002 which spurred real estate growth and development in the region. The ORR unlocked the land, and many IT Parks and IT SEZs are located on ORR. ORR is responsible for nearly 32% of Bangalore's IT revenue. The airport in Bangalore which was located in SBD East known as HAL Airport became too congested and a new airport on the north side of ORR came into existence in May 2008. Kempegowda International Airport located in Devanahalli opened real estate development around the airport area and many micro-markets have emerged in the northern region and are still under development. Similarly, many regions' outskirts of ORR are witnessing development with the provision of various infrastructure facilities (Table 3).

6 Findings and Conclusion

The various business districts, commercial real estate micro-markets, and 317 green buildings analyzed from the three metropolitan regions give us the similarities and dissimilarities which exist in commercial real estate markets and the penetration of green buildings. Firstly, all three metropolitan regions have three layers of development as shown in Fig. 1 and there is high real estate development activity in Emerging Business Districts (EBD). Interestingly Mumbai and Bangalore metropolitan regions have the highest-rated Platinum green buildings concentration in EBDs compared to other districts. The highest-rated green buildings in EBD's will act as counter magnets to pull tenants and corporates from PBD and SBD to the outskirts of the cities and decongest the central part. In Bangalore most of the office buildings are in EBD compared to SBD. Here it's important to note that Bangalore office buildings are mostly IT Parks and IT SEZ's which have been built with lower height and higher ground coverage compared to Mumbai region's buildings giving space a campus feel. Mumbai region has mostly commercial buildings and not IT Parks, which are taller with low ground coverage and small plot sizes. In terms of age the Bangalore buildings were mostly new compared to Mumbai and NCR region buildings were somewhere in between.

In the case of the NCR region, we see the highest concentration of commercial buildings which are green or Grade A buildings in the SBD region. Also, the highest-rated platinum buildings are mostly located in SBD unlike the other two regions. Bangalore had the highest concentration of green buildings in EBD region emphasizing the growth brought by the outer ring road over the last decade.

For stakeholders of city planning and administration, the emerging business districts offer the opportunity of better planned sustainable development. The Navi Mumbai success shows that if peripheral business districts are planned sustainably

Table 3 Commercial business districts and micro-markets of bangalore region

City-level location classification	City/town	Major business district	Green building (%)	Micro-markets within business district
PBD	Bangalore	CBD and Off CBD	6.56	MG Road, Residency Road, Richmond Road, Lavelle Road, Infantry Road, Cunningham Road, Langford Road, Wood Road, St. Marks Road, Vitthal Mallya Road, Miller Road. Ambedkar Nagar, Ashok Nagar, Shivaji Nagar, Vasanth Nagar, Ulsoor (Off CBD)
SBD	Bangalore	SBD East	6.43	New Tippasandra, Indiranagar, Koramangala, Domlur, HAL Airport Area, CV Raman Nagar, Maruthi Sevanagar, Benniganahalli, Cox town
	Bangalore	SBD West	0.40	Jagajeevanram Nagar
	Bangalore	SBD South	2.82	Jayanagar, J.P. Nagar, Bannerghatta Road, Bommanahalli, Bilekhalli, HSR Layout, Bellandur Road, Mangammanapalya,
	Bangalore	ORR	0.83	Hebbal-Nagavara ORR, KR Puram—Hebbal ORR, KR Puram—Marathahalli ORR, Sarjapur—Marathahalli ORR
	Bangalore	SBD South East	11.93	Bellandur, Kadubeesanahalli (All inside ORR)
	Bangalore	SBD South West	0.60	Mailasandra Village, Koramangala, Raja Rajeshwari Nagar, Raja Rajeshwari Nagar-Mysore Road, Raja Rajeshwari Nagar—Bangalore-Mysore Highway, Vasanthapura
EBD	Bangalore	North Bangalore	7.34	Abbigere, Thanisandra (Thanisandra Road), Bellary Road, Tumkur Road (Between Dasarahalli and Nagasandra metro station), Nagavara, Byatarayanapura, Kattigenahalli, Amruthnagar, Kattingalahalli, Yelahanka, New Yelahanka Town

(continued)

Table 3 (continued)

City-level location classification	City/town	Major business district	Green building (%)	Micro-markets within business district
	Bangalore	EBD North East	3.71	Konadasapura, Devanahalli (Airport Area), Bhattaramarenahalli
	Bangalore	EBD East	20.86	Krishnarajapuram (KR Puram), Whitefield, Brookefield, Hoodi, Mahadevapura
	Bangalore	EBD South	6.44	Electronic City Phase I, Electronic City Phase II, Electronic City Phase III, Hosur Road, Kanakpura Road, Singasandra, Bommasandra, Chandapura
	Bangalore	EBD South East	32.07	Kaikondrahalli, Devarabeesanahalli, Kadubeesanhalli, Bellandur (Outside ORR)

Source—[8, 12, 22, 23]

with green buildings, they will be able to attract tenants and employers from the congested CBD and SBD regions, making cities more sustainable for the future. The cities that are planned well and have regulations around sustainable construction practices will attract companies and investments. The data analyzes only LEED-certified green buildings in these cities and other rating systems green buildings don't form part of this analysis and conclusion should be drawn reflecting this limitation.

Overall green buildings are still not a significant stock of office buildings in Indian business districts. The best cities of the world have now nearly 40% of green building stock (CBRE CBRE Australia [3] and emerging economies cities need regulatory and policy initiative to create significant green stock. Recently the regulator of Indian markets has asked the top 1000 companies to report their carbon emissions and ESG initiatives SEBI [18]. The reporting and regulatory norms will encourage corporates to operate through green spaces. That is a future direction that our cities may have to take to attract investments and economic growth.

References

1. ASCI and NRDC (2014) Greener construction saves money: incentives for energy efficient buildings across India. pp 1–8
2. Braun T, Bienert S (2015) Is Green (still) a matter of prime ? Stylized facts about the location of commercial green buildings. J Sustain R Estate 7(1):160–182

3. CBRE Australia (2018) "Green" Building certifications on the rise in major international markets. https://www.cbre.com.au/global/about/media-center/green-building-certifications-on-the-rise-in-major-international-markets
4. Colliers International (2020) Bengaluru tops net office absorption in H1 2020 across major APAC markets. Colliers-APAC Office Markets. https://www2.colliers.com/en-IN/News/APAC-Office-Markets
5. Ghaffarianhoseini A, AlWaer H, Ghaffarianhoseini A, Clements-Croome D, Berardi U, Raahemifar K, Tookey J (2018) Intelligent or smart cities and buildings: a critical exposition and a way forward. Intell Build Int 10(2):122–129. https://doi.org/10.1080/17508975.2017.1394810
6. Govindan K, Kaliyan M, Kannan D, Haq AN (2014) Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. Int J Prod Econ, 147 (PART B):555–568. https://doi.org/10.1016/j.ijpe.2013.08.018
7. Houghton A, Castillo-Salgado C (2019) Associations between green building design strategies and community health resilience to extreme heat events: a systematic review of the evidence. Int J Environ Res Public Health 16(4):663. https://doi.org/10.3390/ijerph16040663
8. ICICI Property Services (2012) Mumbai commercial real estate overview, September 2012 (Issue September)
9. JLL (2012) Greenomics: Cost efficiency of green buildings in India. http://www.joneslanglasalle.com/ResearchLevel1/research_greenomics_cost_efficiency_of_green_buildings_in_india.pdf
10. Johansson O (2011) The spatial diffusion of green building technologies : The case of Leadership in Energy and Environmental Design (LEED) in the United States. Int J Technol Manag Sustain Dev 10(3):251–266. https://doi.org/10.1386/tmsd.10.3.251
11. Kaza N, Lester TW, Rodriguez DA (2013) The Spatio-temporal clustering of green buildings in the United States. Urban Studies 50(16):3262–3282. https://doi.org/10.1177/0042098013484540
12. Knight Frank (2013) Advisory report 2013 India's top business districts
13. Kontokosta CE (2011) Greening the regulatory landscape: the spatial and temporal diffusion of green building policies in U. S. Cities. J Sustain R Estate, 3(1):68–90. https://doi.org/10.5555/jsre.3.1.hx085737n8325333
14. Kumar S, Kapoor R, Rawal R, Seth S, Walia A (2003) Developing an energy conservation building code implementation strategy in India
15. Mathiyazhagan K, Govindan K, NoorulHaq A, Geng Y (2013) An ISM approach for the barrier analysis in implementing green supply chain management. J Clean Prod 47(May):283–297. https://doi.org/10.1016/j.jclepro.2012.10.042
16. Ministry of Power (2001) The energy conservation act. The Gazette of India, 60(2), 22. http://powermin.nic.in/sites/default/files/uploads/ecact2001.pdf
17. Sanjay Seth (2008) Regulatory framework for energy efficiency in energy efficiency initiatives in commercial buildings ministry of power, Government of India overview of India's Commercial building sector growth in the indian building sector electricity growth in commerc. pp 0–3
18. SEBI (2021) Business responsibility and sustainable reporting by listed entities. Sebi Gov In. https://www.sebi.gov.in/legal/circulars/may-2021/business-responsibility-and-sustainability-reporting-by-listed-entities_50096.html
19. Smith RM (2015) "Green" building in India: a comparative and spatial analysis of the LEED-India and GRIHA rating systems. Asian Geogr 32(2):73–84. https://doi.org/10.1080/10225706.2015.1020065
20. Times of India (2019) Mumbai metropolitan region's built-up area up 350% in 40 years. https://timesofindia.indiatimes.com/city/mumbai/mumbai-metropolitan-regions-built-up-area-up-350-in-40-years-study/articleshow/70918285.cms#:~:text=The urban footprint has spread,Navi Mumbai on the other
21. USAID Eco-III Project (2011) Strategy roadmap for net zero energy buildings in India. In: United States Agency for International Development

22. USGBC (2019) USGBC projects database. https://www.usgbc.org/projects
23. Verma S (2020) Green value inferences of rated green buildings in India [Doctoral Thesis]. Amity University Noida
24. Verma S, Mandal SN, Bajaj D (2019) Green building systems in the NCR region of India. Test Eng Manag, 81(11–12):6527–6536. http://www.testmagzine.biz/index.php/testmagzine/article/view/929
25. Verma S, Mandal SN, Robinson S, Bajaj D (2022) Diffusion patterns and drivers of higher-rated green buildings in the Mumbai region, India: a developing economy perspective. Intell Build Int 14(4):393–413. https://doi.org/10.1080/17508975.2020.1803787
26. Verma S, Mandal SN, Robinson S, Bajaj D, Saxena A (2021) Investment appraisal and financial benefits of corporate green buildings: a developing economy case study. Built Environ Proj Asset Manag 11(2):392–408. https://doi.org/10.1108/BEPAM-06-2020-0108
27. WEF & BCG (2016) Shaping the future of construction a breakthrough in mindset and technology. https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report__.pdf
28. World Economic Forum (2018) Circular economy in cities evolving the model for a sustainable urban future. World Econ Forum White Pap, 29. http://www3.weforum.org/docs/White_paper_Circular_Economy_in_Cities_report_2018.pdf
29. World Economic Forum (2019) Why the world should be watching India's fast-growing cities. We Forum Agenda's. https://www.weforum.org/agenda/2019/01/india-urbanization-why-the-world-should-watch/
30. World Economic Forum (2020) Climate emergency: how our cities can inspire change. Weforum.Org. https://www.weforum.org/agenda/2020/01/smart-and-the-city-working-title/
31. Zou Y, Zhao W, Zhong R (2017) The spatial distribution of green buildings in China: Regional imbalance, economic fundamentals, and policy incentives. Appl Geogr 88:38–47. https://doi.org/10.1016/j.apgeog.2017.08.022

Fueling India's Net-Zero Transition

Kruti Upadhyay

1 Introduction

Carbon emissions were expected to reach the highest-ever level in 2023, however, it is yet to reach peak levels. As many as 195 countries have agreed to the Paris Agreement, there was not sufficient decrease in coal production, and some of the countries are looking to increase their oil and gas production because of the Ukraine war situation [1]. Efforts on transition are picking up pace as 140 countries that contribute 91% of the GHG emissions have proposed or committed to net-zero goals [2]. However, the latest research by IMF shows that existing climate goals will be able to achieve only 11% emission reduction by 2030 which is way below the expected emissions reduction levels [3]. World will require approximately $0.7 trillion in annual added investment to tackle climate change-related challenges [4]. Private sector is expected to play an important role in accelerating the transition [3]. Support needs to be provided for the commercially viable projects that may have to access capital markets and require financing from the investment funds for long tenure to increase private sector financial flows to such projects. Private investors are cautious when financing such kinds of projects as they mostly have higher up-front cost as compared to the conventional projects and are comparatively newer for the stakeholders as well. Thus, scarce public finance needs to be prudently used for attracting private financing for relevant projects.

Realizing the urgency to take necessary action to deal with climate change world over different types of financing funds and facilities (now on referred as mechanism) have been set up. Currently, India has three mechanisms which can play a vital role in financing the transition—National Investment and Infrastructure Fund (NIIF), The National Adaptation Fund for Climate Change (NAFCC), and National Bank for Financing Infrastructure and Development (NaBFID). NIIF was set up in 2015 to

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decrease the level of perceived risks and catalyze investments in the infrastructure sector by blending public and private finances [5]. NAFCC is a Central Sector Scheme established in 2015–16 to help finance the adaptation projects that can alleviate the detrimental effects done by climate change. NAFCC as per its objective only supports adaption efforts [6]. NaBFID is a fairly new development financial institution that was established in March 2021 to spur the growth of long-term infrastructure development in the country [7]. NaBFID is expected to start its disbursements in 2023 [8]. Thus, for this article, the author has considered NIIF only.

Article compares the NIIF with other global counterparts such as DBSA Climate Finance Facility, SDG Indonesia One Green Finance Facility, and ASEAN Catalytic Green Finance Facility using case study method. The author has highlighted some of the best practices of these mechanisms which can be further used to accelerate financial resource mobilization through existing mechanisms. Finding suggests that there is existing expertise, knowledge, procedure, transparency and governance structure that can be further utilized by NIIF for financing the NZT projects by setting the priority, separate inhouse unit or establishing a focus fund.

This article is divided into six sections: current status of India in terms of tackling climate change and net-zero transition efforts; literature review; method used and the data relevant to the study, results and discussions, policy implications and the last one is on conclusions.

2 Literature Review

Existing literature focuses on estimating financial requirements, identifying the origins of funding, assessing international policy responses, and learning from pilot projects in the field of climate finance [1, 9, 10]. There are studies which focus on the multitude of climate finance initiatives, with certain scholars examining the factors influencing how multilateral agencies and development finance institutions provide climate finance [11–13].

Existing literature points out that many climate financing mechanisms encounter challenges related to project availability, fund size, geographical scope and allocation, implementation, and stakeholder management [14–16]. Scholars also recognize the importance of utilizing domestic resources' existing capacity to address climate change and promote greener development [17]. Griffith-Jones and colleagues emphasize that domestically established financial institutions can play a crucial role in achieving Nationally Determined Contributions (NDCs) by directly financing projects essential for meeting set goals [13].

The closest two works which author came across for this research paper are focused on national climate funds and these papers have tried to understand and evaluate the existing funds and their effectiveness using different parameters. First paper [18] enhances comprehension of climate finance by recording the climate finance activities at the national level. It introduces a unique database generated from an extensive survey of national climate funds in 38 developing countries. The paper documents the attributes—such as scope, mandate, location, financing, legal basis, and role within the climate finance architecture—of these funds and lays the groundwork for empirical investigations into the variations among national climate funds and their potential impact on effectiveness [18]. The proposed study goes beyond literature by applying case study method to study the select mechanisms and how their learnings can be used for accelerating the NZT efforts.

In Sheriffdeen and colleagues' study [19], they identify five key elements that contribute to the effectiveness of national climate finance institutions. The primary objective of this research was to create a comprehensive method, along with its corresponding indicators, for evaluating the efficiency of National Climate Change Financial Institutions (NCFIs). These components include the legal and regulatory framework, fund mobilization and sustainability, fund governance and allocation, monitoring and evaluation, and accountability and transparency. The researchers emphasize the importance of climate finance for sustainable development, acknowledging the need for substantial financial investments. They also highlight the challenge faced by many developing countries, as they often lack the institutional capacity and expertise necessary to actively engage in the climate finance arena. Developed method was put to use in evaluating the effectiveness of Indonesia's main national climate change financial institution, known as The Indonesian Climate Change Trust Fund (ICCTF) [19]. This research study fills a gap by providing specific insights into how financing mechanisms can be harnessed to address the current financing gap for NZT costs. Proposed research takes a step further in the evaluation and suggests a financing mechanism design that can used to leverage existing mechanisms or establish fresh mechanisms for financing NZT in Indian context.

3 Method and Data Collection

GoI has committed for NZT by 2070. This research aims to examine whether the existing financing mechanisms currently available to GoI align with international practices and to offer recommendations for utilizing the current institutional structures more effectively. To evaluate this, existing international financing mechanisms need to be compared. Thus, to compare these mechanisms proposed research needs an in-depth qualitative approach like case study approach. As per Robert Yin, case study method can be useful to answer questions starting with "What"—generally delving into the defining attributes or consequences of a phenomenon and process questions, often beginning with "how," explore how individuals or groups achieve specific goals, without focusing on intensity, duration, or frequency. Case study method helps in providing explanation of the cause-and-effect relationships in real-life interventions that may be very complex to evaluate through strategies like surveyor experimental strategies. The case study method proves valuable when exploring situations where the evaluated intervention does not have clear, singular set of outcomes [20].

Proposed research aims to understand what kind of financing mechanism can be useful for accelerating NZT in India and how that mechanism can be implemented.

The author has selected a combination of the most common features which form the basis of the mechanisms while making sure that important features are covered in the data collection. Table 1 captures characteristic list developed by reviewing the papers [18, 19, 21–25] which have used them for comparing and contrasting funds through case study method. These characteristics have been used as parameters for the comparison of the mechanisms.

The author collected data on specifically 3 mechanisms, namely the DBSA Climate Finance Facility in South Africa, the SDG Indonesia One Green Finance Facility in Indonesia, and the ASEAN Catalytic Green Finance Facility operating in ASEAN countries. These mechanisms are located and work in developing nations. All the regions have almost similar types of climate vulnerabilities and challenges which India has. All of them are also actively considering to address these challenges through various sources of climate finance. All these mechanisms were established post 2015—Paris Agreement. They all have specific objective for which they were developed—the climate financing, SDGs and green infrastructure. Also, these mechanisms have very diverse set of instruments and comprehensive structures which allows project borrowers to explore different options and modalities. They have detailed set of guidelines and governance structures. Thus, these mechanisms can provide valuable insights through comparison for Indian mechanism National Investment and Infrastructure Fund (NIIF) in India.

Author has gathered information from various data sources. Primary sources are various existing financing mechanism documents such as mechanism design, investment principles, operations guidelines, brochures, case studies on the selected mechanisms, and peer-reviewed journal articles. However, as these documents had

Table 1 Parameters for comparing the selected mechanisms

Parameters	Description
Instruments offered [25]	There are a wide variety of instruments from basic to very advanced categories which are used by these mechanisms to promote the projects focused on NZT
Project sector funded [25]	Sectors or project categories supported by them
Geographic allocation [25]	Geographical location of the projects which are supported by such mechanisms
Legal structure [23]	Describes how the mechanism has been structured from a legal entity perspective
Source of funding [24]	Different sources of funding e.g. government, multilateral agencies, etc.
Approval/ evaluation criteria [24]	Set of parameters that needs to be fulfilled for getting support from these mechanisms
Governance structure [24]	Governance structures incentivize the board and members to achieve the objectives set for the mechanism by monitoring the operations and performance of the mechanism

some missing data, we conducted additional research by examining relevant official websites of Development Bank of South Africa, PT Sarana Multi Infrastruktur, and Asian Development Bank to ensure the database's completeness. The author also utilized these websites and annual reports of the mechanism themselves to gather information about their characteristics.

4 Overview of Selected Mechanisms

This paper has focused on selected financing mechanisms that have been specifically set up to support the projects which are dealing with climate change, green infrastructure, or projects focused on reducing GHG emissions. This section gives an overview of the selected funds and facilities.

4.1 Development Bank of Southern Africa (DBSA) Climate Finance Facility (CFF), South Africa

CFF was established to give a push to climate-related infrastructure projects and to attract private investments in these projects. CFF focuses on the Southern African Development Community (SADC) region. CFF has been supporting projects through long-term subordinate debt and credit enhancement mechanisms like first loss or tenor extension, and subordination. CFF is supported by Coalition for Green Capital (CGC) and DBSA. Both of them bring in complementing expertise—DBSA as a local champion and CGC as an expert on green banks. CFF had an initial capitalization target of $110 million which was secured in March 2019. CFF makes investments in local currency and is expected to catalyze five Rands from the private sector for every rand invested by CFF [26].

Instead of creating a standalone entity this facility is housed in the DBSA. However, CFF is expected to be a self-sustaining distinct entity from DBSA with its own separate balance sheet and be able to achieve revenue levels to support the repayment to its funders and meet the facility's operating expenses [26]. CFF has been leveraging the existing expertise of the DBSA's investment committee and Board of directors for operation oversight and designing investment criteria for providing support to the projects which can help in low carbon transition and also attract private sector investments [26].

CFF does not fund projects which can receive funding from commercial banks solely. To receive the funding from CFF, the project has to be economically and technically feasible and is interesting for the market as well, however, due to some barriers or financing gaps limited capital is available [12]. As per the DBSA's Integrated Annual Report 2022, the facility has 6 projects in the pipeline and 2 projects have been approved for financing [27].

CFF is first of its kind mechanism on the African continent. This facility through its subordinate loans aims to improve the risk-return profile of viable projects and attract private investments. CFF design is based on the green bank model. This facility is also expected to be an inspiration for emerging nations by demonstrating proof-of-concept for the nations who wants to handle market barriers and rapidly attract the much-needed private sector investments required for achieving the net-zero ambition [12, 13].

4.2 Association of Southeast Asian Nations (ASEAN) Catalytic Green Finance Facility (ACGF), ASEAN Countries

This facility was established in 2019 to prepare and finance projects that reduce GHG emissions and create climate-resilient infrastructure in the ASEAN region by catalyzing financial support from private, commercial, and institutional participants. ACGF supports projects by providing loans to the projects from the equity allocation of AIF and combines technical assistance and co-financing from the ADB and other DFI partners. ACGF aims to de-risk the projects and to increase their bankability to make the project attractive enough for the crowding in private finance. This facility was set up under ASEAN Infrastructure Fund (AIF) [28].

ACGF has very well-defined eligibility criteria for the project to be eligible to receive funding from the facility—green, bankable, and private capital catalyzation. ACGF provides financing to **green** projects—from sectors such as energy, urban, transport, water, and multisector projects which have a significant impact on meeting climate goals and help to improve environmental sustainability as well. The project that has the potential of showing increased **bankability** after receiving support. The project has a possible capacity or roadmap to **catalyze** a minimum of 10% of financing from private, institutional, or commercial sources in the first eight years [29].

Initially, ACGF leveraged expertise of existing ADB AIF administration team. ACGF Facility manager is responsible for the functioning of the facility with the support of the AIF administration team and project structuring team. AIF board of directors are responsible for reviewing the annual project pipeline and approving the projects for receiving financing from AIF [30]. Currently, the Southeast Asia Department Innovation Hub of ADB is managing the implementation of ACGF. The AIF administration team and Interdepartmental Working Group oversee the operations of ACGF [29].

As per the latest annual report of ACGF, six projects which fulfilled the ACGF criteria received approval for getting included in the AIF financing pipeline. It is estimated that these six projects will be able to reduce GHG emissions by approximately 408,434 tCO_2e annually [31]. These projects could achieve considerable leverage with AIF commitment of $70 million for a total project cost of $3.2 billion. ADB and other co-financing partners provided financing worth $1.9 billion (leverage ratio

1:27—for every dollar financed from AIF—ACGF was able to raise $27 from ADB) and $464 million (leverage ratio 1:6.62) respectively [31]. ACGF is also working on another important area of capacity and knowledge building on green financing to be able to develop bankable green project pipelines and identify better project opportunities [29].

4.3 SDG Indonesia One (SIO) Green Finance Facility (GFF), Indonesia

The government of Indonesia established SDG Indonesia One (SIO) was established in 2018 through PT Sarana Multi Infrastruktur (PT SMI) for accelerating infrastructure project development efforts to meet Sustainable Development Goals. SIO is an integrated platform based on four pillars: de-risking facilities, development facilities, financing facilities, and equity funds [32]. SIO was established to push blended finance to attract private sector funding and it was able to receive blended finance commitment worth $2.5 billion for SDG-related projects [33]. As of 2021, SIO was able to attract approximately $3.24 billion from various financing sources such as multilateral agencies, bilateral donors, philanthropy, climate funds, sovereign wealth funds, institutional investors, and commercial banks [34].

In February 2022, Green Finance Facility (GFF) was set up under SIO to generate both public and private funding for bankable green infrastructure projects which can boost sustainable economic recovery. ADB provided a loan worth $150 million for supporting this facility's development. Green has been an important necessity for the project as it is the common theme that can help Indonesia reach SDGs and NZT simultaneously [35].

There are specific criteria that need to be met by the project to receive funding from this facility. The project needs to demonstrate measurable impact in terms of either being green or achieving SDGs. The project should be able to achieve the bankability criteria of debt service coverage ratio of 1.05 at least and have a positive net present value post receiving support from the facility. The project should be capable of catalyzing a minimum of 30% of subproject cost through private, institutional, and commercial (PIC) capital for each green subproject and 20% of subproject cost for non-green SDG subproject [36].

PT SMI is responsible for setting up basic principles and guidelines, developing the subproject pipeline, and putting monitoring systems in place for the operations of GFF. PT SMI is also responsible for the operation and business of this facility. PT SMI board of directors are responsible for providing financial approval to subprojects [35]. As per the estimates of [35], GFF is expected to reach to leverage ratio of 1:8—from $150 million of ADB support, GFF is estimated to catalyze $1.13 billion from other sources.

4.4 National Investment and Infrastructure Fund (NIIF), India

NIIF was established in 2015 by the Indian Government with an objective to provide much-needed financing support to the Indian infrastructure sector by attracting equity investments from both local and international sources. NIIF is a trust fund with three sub-funds—the Master Fund, the Fund of Funds (FoF), and the Strategic Opportunities Fund. NIIF was set up with a corpus of $6 billion with 49% of stake holding (almost $3 billion) from the GoI and spread across all three funds [9].

Master fund has been set up with the objective of constructing a portfolio with brownfield projects from select infrastructure sectors through investment platforms.[1] NIIF recognizes that this kind of portfolio allocation can be viewed as a more comfortable option for foreign investors and NIIF can play a vital role as a local partner with all the required expertise. Fund of Funds has been established with the objective to fund managers with a sound track record who are doing fundraising for infrastructure sectors such as green infrastructure (renewables, clean transport, water, and waste), affordable housing, social infrastructure sectors, and other core infrastructure sectors. Strategic Opportunities Fund has been set up with the objective to make investments in businesses and assets focused on the infrastructure sector that require investments with a long-term view. This fund can invest in greenfield projects and projects with a higher risk-return profile as compared to the master fund [9].

The investment committee appointed by the NIIF Limited board is responsible for making investments and existing related decisions. Governing council provides required guidance to NIIF Board Ltd. Governing council is chaired by the Minister of Finance, India. Other members of governing council are from the policy, business, and finance communities. A fund-specific advisory board is responsible for supervising the specific fund. These fund-specific advisory boards are appointed by NIIF Trustee Limited [9]. All three sub-funds are registered as Category II Alternative Investment Funds under the domestic regulator Securities and Exchange Board of India as per Regulation 2(1) (b) of the Securities and Exchange Board of India (SEBI) (Alternative Investment Funds) Regulations, 2012 [37].

As such NIIF does not have any predefined targets like a private capital multiplier. However, [11], mention that NIIF has been designed in such a way that it can deliver high resource mobilization and can have a multiplier effect up to 15–20 times. NIIF (Fund II) in 2019 acquired 58.89% equity stake in IDFC Infrastructure Finance Limited and post that the entity was renamed to NIIF Infrastructure Finance Limited. Through equity allocation from Strategic Opportunities Fund, NIIF aims to support them in becoming one of the largest companies in the field of infrastructure debt financing [38].

[1] Platform is a company that can be partially or fully owned by the fund that can acquire a collection of operational infrastructure projects in a specific sector.

5 Results and Discussions

In the methodology section Table 1 captures the common features of the different mechanisms. Table 2 has captured the information on those parameters for DBSA CFF, ACGF, SIO GFF and NIIF. Depending on the project or sector requirements each mechanism provides different types of instruments. These instruments broadly include equity, loans, grants, TAs and credit enhancements.

Table 2 Comparison of different mechanisms

Mechanism	DBSA CFF	ACGF	SIO GFF	NIIF
Instruments offered	First loss or tenor extension, subordination	Loan, technical assistance, capacity building	Debt	Equity
Project sector funded	Climate-related infrastructure projects	Green projects	Green and SDG-impacting infrastructure projects (GSIP)	Infrastructure
Geographic allocation	Southern African Development community region	ASEAN countries	Indonesia	India
Legal structure	Trust	Trust	Trust	Trust
Source of funding	DBSA and GCF	ADB, AFD, AIF, EIB, EU, KfW, Republic of Korea	ADB and Indonesian Government	Government of India and commercial investors
Evaluation criteria	Project has to be economically and technically feasible and is interesting for the market but unable to receive funding	Catalytic, green and leveraging	Green and SDG, bankability and catalyze PIC investments	Different sub-funds have different strategies—projects can be rejected based on both financial and ESG criteria
Governance structure	DBSA's investment committee and Board of directors	AIF board reviews and approves project for AIF/ACGF pipeline	PTSMI board of directors responsible for projects approvals	IC appointed by the NIIFL board is for approvals and governing council to guide the NIIFL board

Source Authors compilation

5.1 Mechanism Specific Learnings

Traditionally, in the ASEAN region if the project has received funds through public or sovereign guarantees then it implied that investments would also receive complete support from the development partners or governments. However, ACGF is such kind of financing mechanism that has specific criteria related to bankability and resource mobilization and has the capacity to use different financial instruments to match the project requirements, which would help to demonstrate to the government the efficient utilization of available resources and properly designed project for catalyzing the financing from private sources [39].

Both DBSA CFF and ACGF aim to ensure that the project will be considered on a priority basis if the project has higher chances/ outcomes of contributing to achieving the net-zero ambitions set by any country [26, 28]. Even though CFF was created as part of DBSA but it was the ring-fenced and distinct unit to make sure that it added value by working on its predefined purpose of attracting private investments for the projects helping reduction in GHG emissions [26]. SIO GFF highlights that the priority of the facility may change over the years depending on national priorities and goals. Originally set up only for SDGs this facility has further expanded itself by ensuring the dual objective achievement by financing projects which can advance both SDGs and NZT as well.

NIIF comes with the added advantage that is being able to play the role of facilitator for foreign investors through its expertise in understanding local markets and providing much-needed support for generating more resources through such partnerships [11]. NIIF works as an independent commercial authority and does not have any obligation to make investments in the policy-driven projects that are proposed by GoI. However, there is a dedicated team from NIIF that helps state and central government in setting up PPP projects if that is a feasible option instead of financing the project through a highly limited resource of public financing [11].

5.2 NIIF's Role in Fueling India's NZT

India is currently standing at a point where as a nation it wants to grow both economically and socially while ensuring that the progress achieved does not affect the environment negatively. To deal with the situation at hand a combination of policies, improved institutional structures, and financing capacity [17].

There are instances when NIIF has been looked up to as a flagbearer for the next round of infrastructure development growth which can put India on the center stage of the world [17]. NIIF has been specifically established to target the infrastructure sector and one of its mandates is to invest in projects that have long tenure. Thus, NIIF is able to solve the issue of asset-liability mismatch. NIIF has a very-well defined structure and the kind of projects each sub-fund aims to finance. This can further help in predefining the type of projects that can qualify as projects supporting greenhouse gas reductions and helping in NZT.

NIIF has been playing a dual role as both an equity and debt provider (through its equity investments in debt provider). Even though NIIF has strong ESG policies in place and makes the different stakeholders follow them as applicable, there is no specific team or unit which categorically focuses only on the projects that help in achieving NZT. Considering the kind of expertise and strong governance required to accelerate the financing of projects for achieving NZT goals is readily available with NIIF and there is a visible void as well which can be filled by scaling up NIIF's operation.

One way of doing this is, NIIF can give more priority to the projects which demonstrate commitment to NZT by furthering the ambition of India by financing them through a dedicated unit. A similar type of arrangement can be seen in the case of all other three mechanisms discussed above where they have set up a dedicated unit to deal with a specific type of project category for example green or SDG-related projects. Another way can be by carving out fund allocation from the Fund of Funds where again funds demonstrating commitments to NZT can be given priority over other funds. Last but not the least, setting up a fourth fund under the NIIF umbrella that is dedicated to supporting the projects that can help achieve NZT. There can be additional funding that can be requested from the Indian government, or a portion to start with from the Strategic Opportunity Funds can be diverted to this fund. This fourth fund—let's name it NZT fund for the simplicity of the paper can be run as a pilot project and it then can raise further rounds in the future depending on the successful implementation of the pilot and the requirement of the financial resource mobilization. Just like ACGF initially fund can be set up for 3 years and then can receive further approval to continue working. Another important aspect is the ring-fencing and distant entity features can be leveraged by NIIF for attracting the right set of investors just like DBSA CFF. Like mechanisms discussed above ACGF and SIO, NIIF can also play an important role by de-risking the projects which can demonstrate the improved risk-return profile after receiving support from NIIF. This goes with the ideology of NIIF that initially let the investors invest in brownfield projects which are less risky and then they can explore the opportunities in the greenfield projects which are comparatively riskier.

It is necessary that when such kind of new financing mechanism is getting implemented there is a conducive regulatory environment and required government support is made available at both state and central levels for gaining investor confidence. Such kinds of initiatives also require clear policy signals for example—a policy that encourages a shift towards green projects and disincentivizes brown projects. Better information or data flow to the investors can help the investors to be more confident about project implementation and their investment performance. NIIF has a strong governance structure and regulations-related disclosures in place.

6 Policy Implications

Addressing the NZT (Net-Zero Transition) gap requires two key actions: raising additional finance and embracing lower-cost technologies for efficient project delivery. These measures are vital to bridge the financial shortfall and ensure adequate funding and implementation of NZT projects. Establishing a dedicated NZT mechanism can aid developing countries in the first action of raising additional finance, providing a structured pipeline of projects, not limited to a single endeavor.

Creating separate financing mechanisms encourages the development and utilization of capacity to deploy funds specifically for NZT objectives. Banks are cautious about assuming the entire burden of construction risks and may be reluctant to offer extended repayment periods. Lastly, achieving timely, efficient, and cost-effective project delivery necessitates a combination of private and public funding. Hence, blending capital from various sources becomes crucial to avoid investment gaps.

Financing mechanisms also aid in managing the transition and physical risks associated with climate change, supporting the structuring, financing, and addressing of policy implications in NZT projects. This reassures investors interested in dedicating funds solely to NZT, rather than broader avenues like infrastructure sectors.

This research also offers valuable insights to existing national or domestic funds and mechanisms by highlighting opportunities for enhancing investor-friendliness while maintaining climate change standards and providing financing. It encourages necessary adjustments for mechanisms to remain attractive to investors while prioritizing NZT-related goals.

7 Conclusion

This paper aims to compare and contrast existing financing mechanisms to outline a best practice for achieving India's NZT goal. The author analyzes the DBSA Climate Finance Facility (South Africa), the ASEAN Catalytic Green Finance Facility (ASEAN countries), the SIO Green Finance Facility (Indonesia), and the NIIF (National Investment and Infrastructure Fund, India). The comparison reveals that an effective mechanism can be established by combining appropriate financial instruments, project criteria, prioritization, existing capacity, and financial resources. The NIIF already possesses many of these features, making it a potential catalyst for reaching the NZT goal.

This research provides policymakers with a comprehensive overview of effectively planning, attracting, managing, and utilizing climate finance at the national level in India. It emphasizes the importance of financing NZT when a solid commitment to delivering the targets exists, but there is no dedicated mechanism for the ambitious NZT goal.

Addressing the climate crisis and achieving NZT require the mobilization of private capital, even though various stakeholders are actively responding to the challenge. However, an investment gap still needs to be addressed, offering developing nations like India an opportunity to transition to a greener economy.

The Union Budget highlights India's reliance on domestic financing sources for NZT and the need for international support. Financing mechanisms can play a vital role in mobilizing international resources by acting as reliable local partners and financing infrastructure projects crucial for NZT, attracting resources from different stakeholders.

The paper advocates for establishing a unit within or by NIIF that catalyzes financial resources for NZT. By adopting relevant features from the discussed mechanisms and tailoring them to India's requirements, this unit can effectively contribute to achieving the NZT goal.

References

1. Klasen A, Wanjiru R, Henderson J, Philipps J (2022) Export finance and the green transition. Glob. Policy 13:710–720. https://doi.org/10.1111/1758-5899.13121
2. Georgieva K (2022) Getting back on track to net zero: three critical priorities for COP27. In: IMF Blog (2022). https://www.imf.org/en/Blogs/Articles/2022/11/04/getting-back-on-track-to-net-zero-three-critical-priorities-for-cop27. Accessed 25 Jan 2023
3. Black S, Chateau J, Jaumotte F et al (2022) CLIMATE CLIMATE getting on track to net zero accelerating a Global just transition in this decade getting on track to net zero: accelerating a global just transition in this decade IMF Staff Climate Note 2022/010. Washington, DC
4. Jain M, Bhattacharya S (2019) Unlock India's green funding potential. In: The pioneer. https://www.dailypioneer.com/2019/columnists/unlock-india---s-green-funding-potential.html. Accessed 25 Jan 2023
5. NIIF. Infrastructure and private equity investment | about us. In: National Investment and Infrastructure Fund (2021). https://www.niifindia.in/about. Accessed 25 Jan 2023
6. PIB Delhi. National adaptation fund for climate change | MoEFCC. Delhi (2018)
7. RBI. NaBFID—All India financial institution (AIFI). In: Reserve Bank of India (2022). https://www.rbi.org.in/Scripts/BS_PressReleaseDisplay.aspx?prid=53392. Accessed 25 Jan 2023
8. The Hindu Business Line. NaBFID likely to begin project disbursements, bond issues in FY23. In: The Hindu Business Line (2022). https://www.thehindubusinessline.com/money-and-banking/nabfid-likely-to-begin-project-disbursements-bond-issues-in-fy23/article66087782.ece. Accessed 25 Jan 2023
9. Divakaran S, Halland H, Lorenzato G et al (2022) Strategic investment funds. In: Strategic investment funds: establishment and operations (2022). https://doi.org/10.1596/978-1-4648-1870-7
10. Chaturvedi V, Malyan A (2021) Implications of a net-zero target for India's sectoral energy transitions and climate policy, New Delhi
11. Halland H, Dixon AD, In SY et al (2018) Governing blended finance: an institutional investor perspective. SSRN Electron J. https://doi.org/10.2139/SSRN.3264922
12. Lindfield M, Asseline F, Jenny H et al (2021) Catalyzing climate finance lessons learned from the Shandong green development fund. ADB sustainable development working paper series, No. 75
13. Griffith-Jones S, Attridge S, Gouett M (2020) Securing climate finance through national development banks

14. Cameron A, Claeys G, Midoes C, Tagliapietra S (2020) How good is the European Commission's just transition fund proposal? Bruegel Policy Contribution (4)
15. Habir MT (2021) Indonesia's First Sovereign Wealth Fund (INA): opportunities and challenges. ISEAS Yusof Ishak Institute
16. Sarkki S, Ludvig A, Nijnik M, Kopiy S (2022) Embracing policy paradoxes: EU's just transition fund and the aim "to leave no one behind." Int. Environ. Agreem. 22:761–792. https://doi.org/10.1007/S10784-022-09584-5/TABLES/7
17. Sinha J, Saran S, Sharma M et al (2020) Getting to the green frontier
18. Bhandary RR (2022) National climate funds: a new dataset on national financing vehicles for climate change. Climate Policy 22:401–410. https://doi.org/10.1080/14693062.2022.2027223/SUPPL_FILE/TCPO_A_2027223_SM2178.XLSX
19. Sheriffdeen M, Nurrochmat DR, Perdinan, Di Gregorio M (2020) Indicators to evaluate the institutional effectiveness of national climate financing mechanisms. Forest Soc 4:358–378. https://doi.org/10.24259/FS.V4I2.10309
20. Yin RK (2013) Applications of case study research. Appl Soc Res Methods Ser 34:173. https://doi.org/10.1097/FCH.0b013e31822dda9e
21. Bahoo S, Hassan MK, Paltrinieri A, Khan A (2019) A model of the Islamic sovereign wealth fund. Islam Econ Stud 27:2–22. https://doi.org/10.1108/IES-05-2019-0003
22. Güzel F, Acar M, Şekeroğlu G (2017) Sovereign wealth funds: a comparison of the Turkish sovereign wealth fund with the world samples. Period Eng Nat Sci (PEN) 5:165–175. https://doi.org/10.21533/PEN.V5I2.107
23. Al-Hassan A, Papaioannou M, Skancke M, Chih Sung C (2013) Sovereign wealth funds: aspects of governance structures and investment management IMF working paper monetary and capital markets department sovereign wealth funds: aspects of governance structures and investment management. Working Paper No. 2013/231
24. Gelb A, Tordo S, Halland H et al (2014) Sovereign wealth funds and long-term development finance: risks and opportunities. Policy Research Working Paper; No. 6776. World Bank, Washington, DC
25. Fatemi A, Fooladi I, Kayhani N (2011) Sovereign wealth funds: an exploratory study of their behavior. J Entrep Financ 15:64–90. https://doi.org/10.57229/2373-1761.1012
26. Convergence (2019) Climate finance facility case study
27. DBSA (2022) The 2022 integrated annual report
28. ACGF (2020) ASEAN catalytic green finance facility: investment principles and eligibility criteria. ASEAN Catalytic Green Finance Facility
29. ADB (2022) ASEAN catalytic green finance facility 2021 financing for a Green Recovery in Southeast Asia ASEAN Catalytic Green Finance Facility (ACGF)
30. ADB (2020) ASEAN catalytic green finance facility operations plan 2019–2021
31. ADB (2023) ASEAN catalytic green finance facility 2022: building Southeast Asia's green project pipelines
32. Halimatussadiah A, Adriansyah M, Afifi FAR (2022) Enhancing Philanthropy's Role in SDGs financing in Indonesia: the importance of achieving SDGs, the role of philanthropists, and stakeholders collaboration
33. Halimatussadiah A (2020) Mainstreaming the sustainable development goals into national planning, budgetary and financing processes: Indonesian experience. MPDD Working Paper Series WP/20/06 United Nations Economic and Social Commission for Asia and the Pacific (ESCAP)
34. CBI (2022) Green infrastructure investment opportunity (GIIO) Indonesia: green Recovery 2022 Report
35. ADB (2022) Sustainable development goals Indonesia one-green finance facility (Phase 1) (RRP INO 54152-001) Republic of Indonesia: sustainable development goals Indonesia one-green finance facility (Phase 1) Project Administration Manual. Manila
36. ADB (2022) SDG Indonesia one: green finance facility. Manila

37. SEBI (2023) Registered alternative investment funds. In: The securities and exchange Board of India. https://www.sebi.gov.in/sebiweb/other/OtherAction.do?doRecognisedFpi=yes&intmId=16. Accessed 8 Feb 2023
38. NIIF IFL (2023) About Us | NIIF IFL. In: NIIF Infrastructure Financing Limited. https://www.niififl.in/Home/about_us. Accessed 7 Feb 2023
39. GCF (2021) FP156: ASEAN catalytic green finance facility (ACGF): green recovery program

Net-Zero Development in Educational Campuses—A Case Study of Nalanda University Campus at Rajgir

Swati Sinha and J. S. Sudarsan

1 Introduction

The concept of sustainability has gained significant attention globally. It has become imperative to develop sustainable campuses and communities to reduce the environmental impact of human activities.

The main cause of the building sector's ongoing energy consumption growth is the rapid construction of new structures relative to the retirement of existing ones [1]. India's per capita energy consumption has grown as a result of better urban living conditions and modern methods of energy utilization from homes to the industrial sector [2]. This energy demand can be lowered by adopting sustainable and energy-efficient methods/techniques for our daily needs. One of the best methods to limit our energy requirements in a building environment is by moving toward net-zero buildings.

2 Net-Zero Energy Buildings/Campuses

Net-zero energy buildings are the buildings which have exported energy equal to or greater than the imported energy [3–5].

$$\text{Net engry} = \left(\text{Export}_{\text{energy}}\right) - \left(\text{Import}_{\text{energy}}\right) \geq 0$$

They can be categorized in the following ways:

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1. Site net-zero energy building: this produces greater than or equal to the energy which it utilizes per year.
2. Source net-zero energy building: this includes the primary energy which is used per year at the source. It should be greater than or equal to the secondary source.
3. Emission net-zero energy building: they produce less than or equal to the emission produced by other emission producing sources.
4. Cost net-zero energy building: this includes the cost of the energy paid. It should be less than or equal to the bill received in otherwise case.

NZEBs are typically thought to be extremely energy-efficient structures that employ renewable energy technology to create the same amount of energy they use over the course of a year [6, 7].

Consequently, the NZEB strategy of any place may vary based on the temperature, the grid's (green) power supplies, and the infrastructure of the heating and cooling systems [8]. A long-term plan that can boost energy efficiency levels and utilize renewable energy sources is required to satisfy the energy needs of any building. The primary objective is to create energy-efficient buildings using sustainable materials and techniques, or NZEBs, by using energy conservation measures during construction [1]. Buildings with net-zero energy are not isolated entities. They always exist as a homogenous entity [9]. Net-Zero implies that the total energy which is supposed to be used by the building/campus should be equal to the energy which is generated through sustainable ways which means that the balance energy used and produced will be zero or at least near net-zero [9, 10].

In order to successfully design a Net-Zero Energy building/campus, it is typically necessary to successfully integrate and optimize a number of architectural concepts and strategies, including building orientation with respect to the sun's path, natural ventilation, solar shading, day-lighting, solar heat gains, thermal comfort, the use of tried-and-true insulation techniques, energy-efficient glazing, air conditioning, and lighting systems, and the incorporation of renewable energy technologies for on-site power generation [11]. Although green buildings, also known as NZEBs, are still a relatively uncommon occurrence in India, politicians, architects, and builders are increasingly recognizing their advantages and advocating for them [6]. The national, state, and local governments are making efforts to include energy efficiency and renewable energy throughout the building design phase and achieving the net-zero target by 2070 by incorporating policy and design measures for the same.

3 Methodology

The paper talks about achieving net-zero status in an educational building from three aspects: energy, water, and waste (see Fig. 1). All the strategies which have been incorporated within the campus have been studied under each subheading. The working process and their contribution have been highlighted. The calculations have been done using standard formulae. The results indicate that with all systems

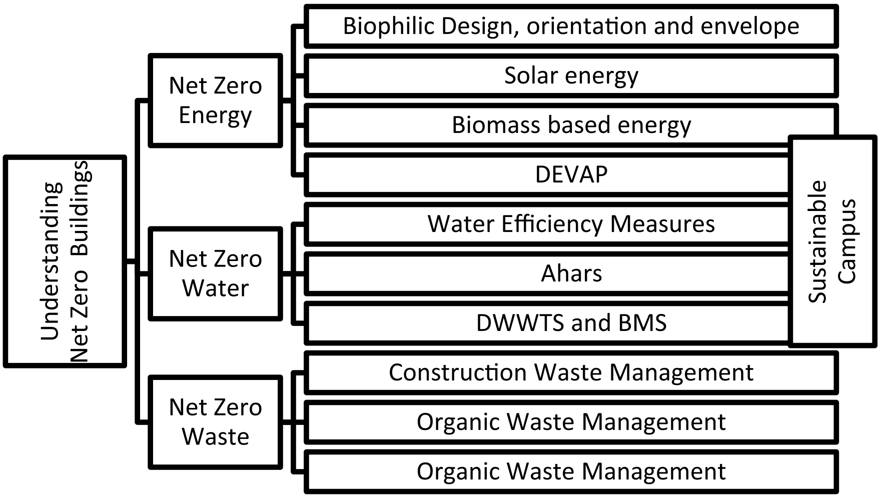

Fig. 1 Methodology

together in place, any campus/building can achieve the status of a self-sustaining campus/building.

4 India's First Net-Zero Energy, Waste, and Water University

Nalanda is renowned as one of the world's oldest known centers for learning. Located in the Rajgir district of Bihar, the region has moderate to high rainfall, hot summers, and chilly winters. On November 25, 2010, Nalanda University was established as a postgraduate, research-intensive international university. The university is a leader in embracing the transition to clean energy as a Net-Zero in energy, water, and waste campus. Nalanda University has pledged to adhere to strict environmental standards and has created a design that would blend in with the surrounding ecology and rural setting. Therefore, despite being a contemporary university, it will maintain its illustrious natural heritage. It will be India's first campus to achieve net-zero energy, waste, and water when it is fully operational [12].

If Nalanda University had employed standard building procedures, it is predicted that it would have used 58,240 MWh of power annually and released GHG emissions equal to almost 52,415 million metric tonnes of carbon dioxide [13]. When compared to conventional building designs, the university expects to lower the energy consumption intensity of the campus by 63% by using the net-zero strategy.

The paper discusses the following strategies to achieve net-zero (Fig. 2).

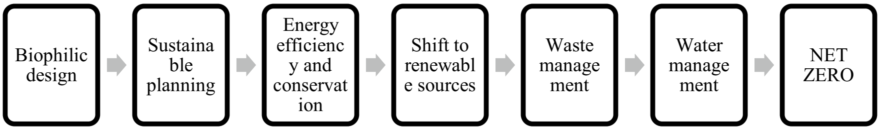

Fig. 2 Strategies used by the university to achieve carbon zero

Strategies Used by Nalanda University

4.1 Biophilic Design

An innovative strategy is being used by Nalanda University to integrate the entire campus into a vast ecosystem and achieve carbon neutrality and zero waste campus. Eventually, the Nalanda University campus will be the first net-zero campus in the country, implying all of the institution's energy will be produced on-site.

Reducing energy demand through smart planning is an important aspect of sustainable design. Here are some ways in which smart planning of Nalanda University is helping to reduce energy demand in buildings.

Building orientation: It plays a great role in reducing energy consumption by maximizing the use of natural light and passive solar heating and cooling. Orienting a building to capture natural light and heat from the sun can help to lessen the need for heating and lighting systems that are artificial. The orientation of a building has a significant impact on its energy efficiency, comfort, and overall performance. It also affects the amount of sunlight and heat that enters the building, the amount of shading provided by nearby trees or other structures, and the direction and strength of prevailing winds [14].

The orientation of the buildings at Nalanda University takes into account the specific geographic location, climate conditions, and surrounding topography of the site. By considering factors such as solar angles, prevailing winds, and the site's relationship to nearby bodies of water or green spaces, the buildings are designed to harmonize with the natural environment and optimize energy performance.

The buildings are designed to take advantage of solar orientation, which involves aligning them in a way that maximizes exposure to sunlight. The main facades, such as windows and openings, are typically oriented toward the south in the Northern Hemisphere to capture the maximum amount of natural light throughout the day. This orientation helps reduce reliance on artificial lighting and enhances the overall energy efficiency of the buildings. Building orientation also considers the placement of shading devices such as overhangs, louvers, and sunshades to mitigate excessive solar heat gain during hot seasons. These shading elements help block direct sunlight from entering the building when the sun is at its highest point, reducing the need for mechanical cooling systems and improving occupant comfort.

Nalanda University's building orientation takes into account prevailing wind directions to optimize natural ventilation. By aligning buildings and openings perpendicular to the dominant wind direction, a "venturi effect" can be created, allowing for the natural flow of air through the buildings. This helps cool the indoor spaces and reduce the reliance on mechanical ventilation systems.

The campus design incorporates courtyards and open spaces strategically to facilitate natural ventilation, create microclimates, and enhance the thermal comfort of the buildings. These open areas allow for increased airflow, promoting natural cooling and providing pleasant outdoor spaces for occupants. The optimal orientation of the buildings helps to maximize daylight, minimize heat gain, maximize natural ventilation, minimize energy consumption and related costs by minimizing the need for artificial lighting, heating, and cooling. This in turn provides a more comfortable and healthier indoor environment for its occupants without compromising the building's energy efficiency and performance.

Green spaces: The campus has extensive green spaces, including a botanical garden and a fruit orchard, which not only provide aesthetic value but also help to reduce heat island effects and improve air quality. The project has been planned to leave less carbon footprint and is surrounded by more than 9 m^2/capita of green space which comes less than 1.19 tonnes per person annually, which is less than the average for all of India [15].

Merged planning with outside landscape: The integration of the outside landscape with the planning of Nalanda University promotes human well-being and a connection to nature. Access to green spaces, parks, and outdoor recreational areas enhances the quality of life for students, faculty, and visitors. These natural environments provide opportunities for relaxation, physical activity, and a sense of tranquility, positively impacting mental and physical health. Here are some ways in which merging planning with outside landscape can help in sustainability:

- *Passive cooling and heating*: The integration of the outside landscape into the planning of Nalanda University helps regulate the microclimate on campus. Trees, shrubs, and green spaces provide shade and cooling effects, reducing the heat island effect and mitigating the impact of urban heat. This natural cooling effect can help lower the energy demand for air conditioning and improve the comfort of outdoor spaces.
- *Stormwater management*: The merged planning approach considers effective stormwater management strategies. Green spaces, permeable surfaces, and bioswales are incorporated to capture and manage rainwater runoff. This helps to prevent flooding, reduce erosion, and recharge groundwater reserves. By minimizing stormwater runoff, Nalanda University mitigates the strain on local drainage systems and promotes sustainable water management.
- *Biodiversity and Aesthetics*: The merged planning approach at Nalanda University takes into account the preservation and enhancement of the natural ecosystem. The campus design incorporates green spaces, gardens, and native plant species, creating habitats for local flora and fauna. By preserving and promoting biodiversity, the university contributes to the overall ecological balance and helps protect

the surrounding natural environment. It also integrates sustainable land use practices, such as preserving open spaces, agricultural areas, and natural features. By avoiding unnecessary land development and minimizing soil disturbance, the university helps conserve natural resources and protects the integrity of the local ecosystem.
- *Improved air quality*: By removing pollutants from the air and generating oxygen, trees and other plants can contribute to better local air quality, creating a more hospitable and healthier environment.

4.2 Sustainable Building Planning

The Nalanda ruins that are still standing served as inspiration for the architectural style. The design aims to blur the line between inside and outside. The interiors are constructed entirely of modern materials while the exterior is solid, and brick clad. The initial layer of insulation from the heat from the outside is provided by a substantial, hefty bulk that houses all of the functions and circulation spaces in the periphery. To ensure optimal orientation, well-shaded facades, adequate building envelops, and optimized daylight levels, all buildings are simulated using energy simulation software. These factors limit heat gain in the building by 30%.

Efficient building envelope: An efficient building envelope which includes walls, windows, and roofs helps to reduce energy demand by minimizing heat loss and gain. Insulation, high-performance windows, and airtight construction of the university help to improve the efficiency of the building envelope.

Use of light wells: The university has extensively used light wells to maximize natural lighting, enhance natural ventilation, improve thermal comfort and also create visual interest for the students.

Passive cooling techniques: The buildings were designed with features such as double roofs, courtyards, and shading devices to minimize the use of air conditioning.

4.3 Energy Efficiency and Renewable Energy Technology Solutions

Use of energy simulation software: The university employed energy simulation software for predicting energy consumption, identifying energy-saving strategies, optimizing building design, evaluating the performance of existing buildings, and certifying sustainable buildings [16].

Renewable energy sources: The campus is powered by a 2.7 MW solar power plant, which offers roughly 90% of the university's energy needs. The campus also uses a bio-gas plant to convert organic waste into energy which can help to reduce energy demand and reliance on non-renewable energy sources.

Efficient lighting and HVAC systems: Low operating expenses and reduced energy consumption may both be achieved with the use of high-efficiency lighting and HVAC systems. For example, LED lighting is advised to reduce energy consumption by up to 75% compared to traditional lighting.

Solar Energy: To reduce the need for energy storage, the campus will use solar energy during the day and energy produced by renewable sources at night. Net metering gives the strategy a solid fallback as well. The reduction in energy demand must come first, followed by the use of renewable energy to meet the demand. There will be less demand overall thanks to several advancements in plumbing, air conditioning, and architectural design. The emphasis shifts to using renewable energy sources to produce needed energy once the demand has been lowered [17]. 4450 kWP Solar PV and 1330 kW CHP engine have been installed for the same.

Biomass-based energy: As a predominantly agricultural state, Bihar has a lot of biomass (rice husk) in stock. A sizable plot of land is available for growing algae at the university. The utilization of solar PV and the production of electricity from biomass, such as rice husk and algae, have been proposed by Nalanda University. This dual strategy makes use of biomass-based electricity generated at night and solar energy during the day. With these two energy sources, the university aspires to generate all of its own electricity on-site from renewable resources. Having a backup renewable energy source also reduces the need for batteries for storage. If necessary, extra energy can also be transferred to the grid. The facilities installed on the campus can also be used by nearby villages.

The table below gives a snapshot of all the resources used with their details (Table 1).

Cooling Solution: The region's hot and humid climate made it difficult to find low energy cooling systems. Consequently, the cooling system comprises of a three-stage cooling approach that includes air conditioning, chemical dehumidification, and evaporative cooling. Waste heat from the production of energy fuels the dehumidification process. This three-stage method reduces cooling load by 40% compared to traditional air cooling. The three components of this approach have been implemented separately at other sites, but they will come together for the first time in this project.

The DEVAP (a low energy cooling) system [18], which is situated within the climatic towers, then provides additional micro cooling to the interior spaces. The goal of design development was to make the energy demand as low as possible (Fig. 3).

4.4 Construction Waste Management

A research from Building and Demolition Recycle predicts that by 2025, there will be 2.2 billion tonnes of construction debris produced annually worldwide. The majority

Table 1 Resources used on the campus

Type of resource	Availability	Costs	Location	Result/usage
Wind	Can not be harnessed because of low intensity	Expensive installation and upkeep	North road	Inefficient due to low speed and also expensive
Geothermal	Easily accessible will operate independently from Nov to June but will require additional cooling using conventional methods	Built along with groundwork or basement	Earth ducts/ labyrinth under buildings	Easily maintainable and highly applicable
Solar hot water	Widely available because of wide span of the campus and the terraces	Low	Roofs	Quite suitable
Solar	Widely available except rainy months of July–Oct and mid-Dec-mid-Jan	High initial installation cost, but low maintenance and operations cost	On roofs and above water reservoirs	Suitable for 8 months, for rest of the months output is low
Biomass	Crops, vegetable, and fruit residue/compostable waste locally available	Operation and maintenance costs	Main entry road	Highly efficient, can also help villagers

Source Author's compilation

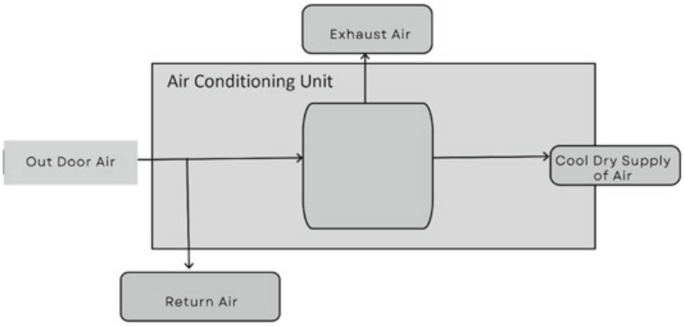

Fig. 3 Schematic of DEVAP AC. *Source* Author's compilation

of the garbage produced by a building project is dumped in a landfill, but 80% of it, also known as public fill, has the potential to be utilized as the raw material for new construction projects [19]. In an effort to lessen site-specific plastic pollution and prevent it from entering landfills, 5% of the plastic waste is employed in road construction. The project also made use of construction materials like hollow brick and recycled concrete to reduce our dependency on natural, virgin materials. Use of

Compressed Stabilized Earth Blocks (CSEB) will also reduce the waste on the site as most of the muck is being used for preparing CSEB [20].

The university has put in place a waste management system that recycles and separates garbage such as paper, plastic, and metal.

Organic Waste Management

The university has a bio-methanation facility [21] to handle all of the organic waste produced on the job site and during construction (Fig. 4). This process converts the waste materials to biogas which can be used by the occupants of the campus as an energy source and helps with energy security of the nearby villages [22].

4.5 Water Efficiency Measures

The Nalanda University development aims to attain net-zero water usage and strives to be self-sufficient in water use. In order to lessen the demand for portable water, rainfall will be collected and treated throughout the year. As part of the project, Kamal Sagar, "Ahars" (water storage system), and a water treatment system were made available. The campus will make use of the good rainfall and extensive catchment area at the project location to collect surface water in sizable artificial lakes. Before use, collected water is thoroughly treated. Decentralized wastewater treatment is also done for sewage treatment [23]. Landscaping and toilet flushing utilize this treated water for its requirement. The usage of low flow faucets and flush fittings also helps in reducing water wastage (Fig. 5).

The campus also has an extensive rainwater harvesting system that collects rainwater from rooftops and other surfaces and stores it in underground tanks for later use in landscaping and irrigation. Through these measures, the university achieves

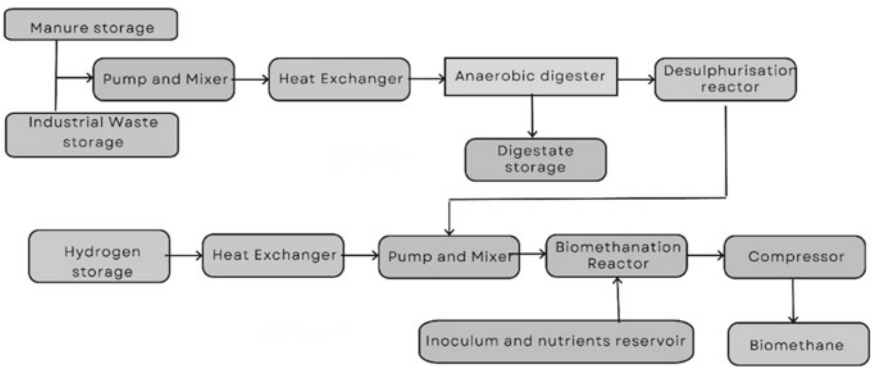

Fig. 4 Process flowsheet of the anaerobic digestion and biomethanation plant. *Source* Author's compilation

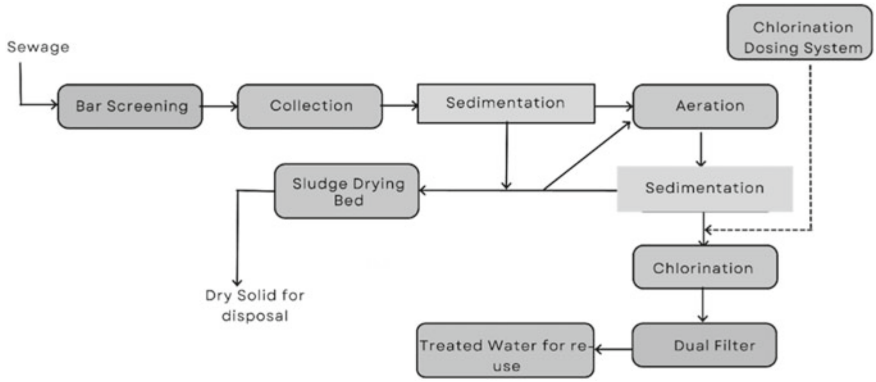

Fig. 5 Schematic diagram of wastewater treatment system. *Source* Author's compilation

100% self-sufficiency in terms of water use. Major usage zones have installed water meters that are integrated with Building Management System (BMS).

4.6 Sustainable Campus

Sustainable materials: The entire campus utilizes the excavated soil from the site as Compressed Stabilized Earth Blocks (CSEB) [13]. The CSEB is not only sustainable but also cheaper and more energy efficient as it is locally sourced which helps reduce the carbon footprint associated with transportation and extraction processes [24]. It generates 10.7 times less embodied carbon and around 12.5 times less carbon emission [14]. The university also uses hollow bricks and recycled concrete to reduce dependency on natural, virgin materials.

Sustainable transportation: Encouraging sustainable transportation options such as biking, walking, and public transit has helped reduce energy demand associated with transportation and promote a healthier and more sustainable community. The university has also installed solar recharging stations for battery-operated vehicles.

Utilizing resources as efficiently as possible, replacing the need for resource consumption through natural means, generating resources renewably, or minimizing the site's current environmental impact are all characteristics of sustainability. The most evident benefit of a green campus is the decrease in water and energy use that starts on the first day of occupancy which is clearly present in the case of this university. Some of the intangible benefits of green campuses include improved occupant health and well-being, greater air quality, the promotion of biodiversity, safety benefits, and resource conservation [25].

With everything set up, the university could achieve its goal of becoming self-sufficient and net-zero in terms of energy, as well as provide for the infrastructure of the nearby local villages and highlight its desire to serve as a leading example of sustainable building practices for the rest of the world.

5 Result and Discussion

The below table shows the total carbon emitted taking into account six emission inventories namely human, building, solid waste, transportation, electricity, and water consumption. The total estimated carbon comes to 38138275 kg/month (see Table 2) which can easily be countered by the strategies adopted in the campus. The amount of CO_2 which can be compensated by landscaping alone is 67800000 kg.

Similarly, other resources have been calculated using secondary data as a reference (see Table 3: Net-Zero Energy, Water, Waste).

The above table summarizes the reductions in the campus. There are 0–200% energy savings due to the use of passive strategies adopted. There are more than 30% water savings by adopting water-saving measures such as low faucet usage and recycling water. There is 98% reduction in wastage by using 3R concept.

Table 2 Carbon emission through various factors on campus [26]

Emission inventory	Emission factors	Quantity	Carbon emitted (kg/month)
Human factor	1.14 kg/person/day	7000 (planned)	239400
Building	28 kg/m^2 of brick work	3,41,000 m^2	9548000
Solid waste	0.125 kg/person/day	7000	875
Transportation	Petrol-2.3 Kg/l Diesel-2.7 Kg/l	0	0
Electricity	0.689 kg/kwh		
water consumption	0.376 kg/l	945000	28350000
Total carbon emitted			38138275

Amount of carbon absorbed within campus
No. of matured trees = 390 (existing) + 3000 (planned)
Average amount of carbon absorbed by a mature tree = 20000 kg/month [27]
Amount of carbon absorbed by campus greenery = 3390 × 20000 = 67800000 kg
Source Author's compilation

Table 3 Net-zero energy, water, waste

	Baseline	Reduction (%)	Systems	Generation	Systems	Net 0
Energy	160 kwh/m^2 (51 kBtu/sf)	72	Passive DEVAP cooling, microclimate, daylighting, DC power	28%	PV, Biofuel	0–200% + 5 kWh/m^2 variable by generation
Water	135 LPD/ person	31	Low flow fixtures, re-used water	69% rain capture	Rooftop, agricultural land	+30% +42 LPD/ Person variable
Waste	900 kgCO_2 e/ m^2 embodied	71	Natural materials	260 kgCO_2 e/ m^2 embodied	CSEB	98% reduction

Source Author's compilation

6 Conclusion

Nalanda University has implemented various strategies and techniques to achieve net-zero waste, water, and energy in its new campus. The university has installed a 1 MW solar power plant and is working toward increasing its capacity to 5 MW. The campus also uses energy-efficient lighting, heating, and cooling systems. Rainwater harvesting and wastewater treatment systems have been installed to reduce water consumption and promote water conservation. The university has also implemented a comprehensive waste management system, which includes waste segregation, composting, biogas plant, and recycling. The campus generates minimal waste, and the waste generated is managed efficiently, reducing its environmental impact. The university's commitment to sustainability has created awareness among its students and staff, promoting sustainable practices in their daily lives.

When fully functional, the Nalanda University will serve as an example for other educational institutions leading how to achieve the greatest levels of energy efficiency and climate-responsive design to minimize energy demand. It will undoubtedly spark the interest of experts and students alike, all across the world, particularly those working in the fields of climate change and carbon neutrality.

Recommendation

All the stakeholders can collectively take actions if India wants to achieve the promised net-zero status by 2070. The government specially can encourage and educate the masses about the initiative and the benefits of adopting net-zero concept in their daily lives. Carbon Pricing, which includes curbing emission by placing taxes or fees, Clean Energy Subsidies, Fossil Fuel Subsidy Reforms, etc. are some of the strategies which could be adopted by the authorities if they want to check from the financial point of view. Infrastructure Investments which adopt cleaner and greener resources, International Collaboration for R and D in the area, Net-metering schemes throughout the country, Tradable Green Certificates, etc. are some strategies which can be adopted from the governance point of view. All these efforts together can help address the net-zero challenges.

The government's "Sustainability for life" campaign is an added effort which if adopted religiously will help India achieve its target within the stipulated frame.

Limitations and Future Scope

Although implementing net-zero techniques has many advantages, there is still hesitation due to lack of knowledge, greater upfront costs, limited research and development, illiteracy and hesitation in implementing alternate strategies.

If one can get over all of these obstacles, the future will be more environmentally friendly in every way. Even the general populace can be made aware of the changes and urged to adopt healthier, greener behaviors with appropriate and timely government initiatives, which can make the transition to net-zero easier.

References

1. Torcellini P, Pless S, Deru M, Crawley D (2006) Zero energy buildings: a critical look at the definition
2. Sarraf S, Saboo SA, Gupta S, Deshmukh A (2011) Energy conservation and commercialization (ECO-III), ECO-III-1041, Final Report, USAID
3. Lu Y, Zhang XP, Huang Z, Lu J, Wang C (2019) Definition and design of zero energy buildings. In: Green energy advances
4. Jaysawal RK, Chakraborty S, Elangovan D, Padmanaban S (2022) Concept of net zero energy buildings (NZEB)—A literature review. Clean Eng Technol 11
5. Omrany H, Chang R, Soebarto V, Zhang Y, Ghaffarianhoseini A, Zuo J (2020) A bibliometric review of net zero energy building research 1995–2022. Energy Build 262
6. Jain M (2018) Enschede: University of Twente
7. Siregar DJ, Putra A (2019) IOP Conf Ser: Earth Environ Sci
8. Hermelink A, Schimschar S, Boermans T, Pagliano L, Zangheri P, Armani R, Voss K, Musall E (2013) Towards nearly zero-energy buildings. Definition of common principles under the EPBD. Final report, Netherlands: Ecofys, Koeln (Germany)
9. Sartori I, Napolitano A, Marszal AJ, Pless S, Torcellini P, Voss K (2010) Criteria for definition of net zero energy buildings. Graz
10. Torcellini P, Pless S, Deru M, Crawley D (2006) Zero energy buildings: a critical look at the definition. National Renewable Energy Laboratory Drury Crawley, U.S. Department of Energy
11. Kapoor R, Deshmukh A, Lal S (2011) Strategy roadmap for net zero energy buildings in India. USAID ECO-III Project, New Delhi, India
12. Nalanda University upcoming campus. https://nalandauniv.edu.in/campus-life/upcoming-campus/
13. Mendis MS (2018) Resource innovations. https://www.resource-innovations.com/resources/nalanda-university-s-net-zero-energy-vision. Accessed 2 May 2023
14. Sinha A (2020)Building orientation as the primary design consideration for climate responsive architecture in urban areas. Arch Urban Plan 16
15. Suparna Havelia AB (2020) Greening Nalanda University. GreenTree
16. Sudarsan JGH (2023)Application of BIM in conjunction with circular economy principles for sustainable construction. Environ Dev Sustain

17. D. S. P. S. S. Prachi Pandey (2022) Stepping towards energy efficient campus through a green rating system case study of faculty of architecture and planning, Lucknow. J Emerg Technol Innov Res (JETIR) 9(9):55–58
18. E. W. J. J. R. Kozubal (2012) Development and analysis of desiccant enhanced evaporative air conditioner prototype. Contract 303
19. Sudarsan JS, Abhyankar AA, Parashar A, Krishna SV (2022) Analysing construction and demolition waste practices: an Indian case study 221
20. Kuma MM, Dongmo K, Francois N, Nelson M, Alakeh MB, Emmanuel Y (2020) Compressed stabilized earth brick (CSEB) as building construction elements. IOSR J Mech Civil Eng 42–48
21. Lawson N, Alvarado-Morales M, Tsapekos P, Angelidaki I (2021)Techno-economic assessment of biological biogas upgrading based on Danish biogas plants. Energies 14:8252
22. Zhang K, Zhang YL, Ouyang X, Li JP, Liao JJ, You A, Yue X, Xie GJ, Liang JL, Li JT (2019)Genome-centered metagenomics analysis reveals the microbial interactions of a syntrophic consortium during methane generation in a decentralized wastewater treatment system. Appl Sci 10:135
23. Varma VG, Jha S, Raju LH, Kishore RL, Ranjith V (2022)A review on decentralized wastewater treatment systems in India. Chemosphere 300
24. Auroville Earth Institute (AVEI) (2005). https://www.earth-auroville.com/index.php. Accessed 4 May 2023
25. Parvez N, Agrawal A (2019) IGBC Green Campus rating system: an initiative to sustainable campuses in India. In: 53rd international conference of architectural science association 2019, Roorkee, India
26. Sudarsan JS, Jyesta W, Jaisal D (2019)Carbon footprint estimation of education building a drive towards sustainable development. Int J Eng Adv Technol (IJEAT) 9(1S4):611–614
27. You F, Hu D, Zhang H, Guo Z, Zhao Y, Wang B, Yuan Y (2011) Carbon emissions in the life cycle of urban building system in China-A case study of residential buildings. Ecol Complex 8:201–212

Climate Change Policy, Legal Framework and Financing

Identification of Green Rating Attributes for Metro Station: An Indian Case Study

Neha S. Gavit, Gayatri S. Vyas, and Chaitali K. Nikhar

1 Introduction

The twenty-first century's rapid urbanisation in developing nations is characterised by advances in technology. Over the next forty years, the urban population in developing countries is expected to grow by an average of five million people per month, making up 95% of the global urban growth. Urban population growth is a significant factor in developing nations like India, which are not far behind. Policymakers will have a difficult time addressing the issues associated with both infrastructure development and financial allocation if it is projected that the urban population will rise from 370 million in 2011 to 600 million by 2031 (metro rail news 2023). For the Metro Railways Service in India to address these issues, the European Transport Conference has provided a viable model. India's rapid urbanisation and population increase have necessitated the development of efficient and sustainable transportation networks. Metro rail projects have emerged as a popular mode of transportation in Indian cities, providing a safe and reliable means of commuting for the citizens (Panday and Bansal n.d.). However, with the increasing concerns for environmental sustainability, it is imperative to assess impact of such projects on environment and identify green rating attributes that can enhance their sustainability. This research paper focuses on identifying green rating attributes for metro stations in India, with a case study of a specific metro station. For metro systems around the world, several international green rating systems were created and put into place with a focus on energy efficiency, environmental impact, and sustainable practices. The next step is to improve and expand these rating systems to include broader environmental and social considerations; some systems use a combination of performance indicators, like SB Tool, LEED, Building Research Establishment Environmental Assessment Methodology (BREEAM), and the Green Rating Initiative (GRI). This study aims

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to provide a framework for assessing the sustainability of metro stations. Which can be used by policymakers, planners, and engineers involved in such projects [1].

A green rating system for metro stations is a framework for evaluating and improving the sustainability and environmental performance of metro stations [2]. A rating system of this type might provide a consistent approach for measuring the environmental impact of metro stations and influence design, construction, and operating decisions to minimize carbon footprints and boost energy efficiency (Gupta and Garg 2020). The paper will begin by providing an idea of the current condition of metro station in India as well as the importance of sustainability assessment. The case study of a metro project in India will be used to demonstrate the application of the framework for assessing the sustainability of metro station. The findings of this study will help India establish sustainable transportation networks and serve as a model for other developing countries facing similar challenges. The identification of green rating attributes for metro will help in promoting sustainable infrastructure development and mitigating the adverse impact of urbanization on the environment. The purpose of this study is to create a framework for metro stations. To fulfil this aim there are certain objectives:

2 Research Objectives

This research is based on three main assumptions: (1) An analysis of current practise should serve as the foundation for developing green metro station rating systems. (2) A framework for evaluation should be created that is appropriate for the regional setting (in this case, India). (3) Existing green rating systems for urban infrastructure need to be complemented by more specialized frameworks tailored specifically to metro stations, considering their complex nature, operational requirements, and the need to integrate sustainable practices effectively. The principal aim of this study was to identify and evaluate the most important green rating factors for metro stations; to carry out the pilot study through a survey questionnaire, to offer guidance to project designers in order to improve the sustainability of metro projects in India.

3 Literature Survey

The literature survey indicates the significance of aligning the Philippines' economic development objectives with the Sustainable Development Goals (SDGs), particularly in addressing Metro Manila's water security issues. Due to flaws in the region's infrastructure and society, the study emphasises the urgent need to reassess the region's water security. The frequency and duration of water shortages are expected to increase as climate change continues to impact natural cycles. The significance of adopting adaptive measures, taking into account the effects of climate change and incorporating sustainable development practises in order to guarantee water security in Metro Manila and support the larger SDG targets. It advocates for a comprehensive and replicable approach to addressing water issues and regional development issues throughout the country and beyond [3].

The primary goal of any green construction assessment tool is to evaluate various aspects of sustainable techniques during the planning, construction, and operation of a metro station and to incorporate the best practises in reducing the construction's negative environmental impact. The Environmental Assessment Method (BREEAM) developed by the Building Research Establishment in 1990 was the first green building performance assessment method. It can be used to rate any type of metro station and each is designed for a specific type of metro station. BREEAM is also used in country-specific formats, such as those developed for the Netherlands, Sweden, and Spain. Several other countries, including the United Kingdom, have developed green building environmental assessment rating systems, such as the Green Building Tool (GB Tool). Several other countries, including the United Kingdom, have developed green building environmental assessment rating systems, such as the Green Building Tool (GB Tool) and LEED in 1998. In 2006 the (IGBC) made the first attempt to devise a rating system for Indian buildings, based on a revision of the LEED 2000 [4].

The study identifies polished Kota stone tiles, toughened fiberglass ceilings, Kota stone wall tiles, and insulated fiberglass doors as the most feasible and sustainable materials for the metro station's design based on the application of the Fuzzy Factor Comparison Method. Building Information Modelling (BIM) was used by the researchers to evaluate the various building materials and design strategies. The results showed that using the suggested alternative resulted in an impressive 73% average embodied energy savings. The results showed that using the suggested alternative materials instead of the existing ones resulted in an impressive 73% average embodied energy savings. In addition, the paper proposes a framework for a real-time automated BIM-enabled energy management system for the metro rail station using Internet of Things (IoT) sensors. This framework demonstrated the potential for a 25% reduction in operational cooling load. Overall, the study offers a novel and integrated approach to improving the sustainability of infrastructure projects by combining the Fuzzy Factor Comparison Method, BIM, and IoT. The paper's findings and methodologies are critical contributions to the long-term viability of transport facilities such as metro rail stations [5].

Due to the metro station's significant environmental impact, it is crucial to make sure that they are planned and built sustainably. There is a need for a green metro station rating system in developing nations like India that is simple to use and equally simple for designers to understand [5]. From this literature the understating of green metro station, prominent attributes to becoming metro station green like site selection, energy efficiency, indoor environment quality, green transportation, etc. existing techniques for evaluating green metro stations were created by a few authors for localized purposes, and they are not always appropriate for use elsewhere. A green metro station rating system that is simple for metro users to understand and equally simple for designers to work with is needed in developing nations like India. The climatic variations within a specific certified period across the nation should be considered in a rating system for a developing country. In other words, certain existing environmental assessment systems may not be directly usable due to factors like climate, resource consumption, materials, governmental policies and regulations, population growth, public awareness, etc. The main objective of this study was to develop a framework for measuring the sustainability of metro stations based on key factors that are relevant in Indian construction. This methodology helps us to make the framework for metro station.

Initially, a literature review was carried out in the present study to understand the attributes that were considered. The data were collected to establish the most influential factors on the impact on the greenness of the metro by an analytical questionnaire survey of respondents involved in the everyday activities of metro stations in various regions of India.The questionnaire was developed so that respondents could rank their answers based on their personal preferences these data were analysed using quantitative analysis approach. The methodology of the present study was accomplished by following research flow study.

4 Identification of Attributes

For assessing the sustainability of metro stations in India, it is essential to identify green rating attributes. These characteristics are crucial in creating a thorough framework that can accurately evaluate the environmental impact and overall sustainability of these transport hubs. This study seeks to develop a methodological approach for assessing the sustainability of metro stations by identifying specific green rating attributes, such as energy efficiency, waste management, water conservation, sustainable materials, etc. These attributes identify for greenness of metro. A framework like this can be an invaluable resource for stakeholders, policymakers, and urban planners in helping them prioritise sustainable practises and develop metro stations responsibly in India. Without these relevant attributes, the evaluation process lacks the essential focus to address the critical aspects of sustainability, making the framework inadequate for guiding sustainable development efforts in the context of metro stations in India.

5 Research Methodology

A preliminary questionnaire covering selected attributes relevant to sustainability was compiled based on a literature search (see Table 1). Subsequently, a pilot study was conducted in which a limited number of experts (10) were asked to give their opinion on these factors and their relevance in the Indian context. The experts were asked to add, delete, or modify the preliminary list. The pilot survey made a final list of 41 attributes, which included two new attributes renewable energy integration and water-efficient fixtures—suggested by experts. A few attributes were left off because

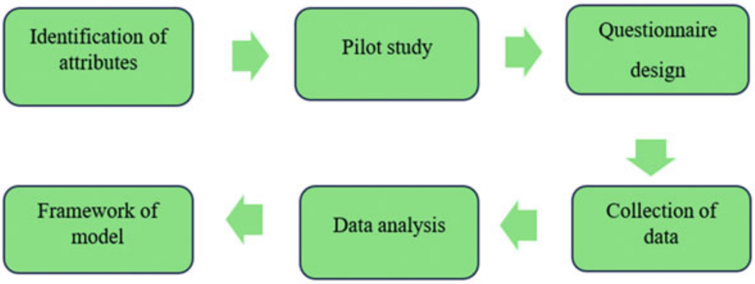

Fig. 1 Research methodology flowchart. *Source* Author

they were deemed unnecessary in the Indian context. The 41 attributes were designed to indicate the positive impact of the green metro station concept on costs, pollution, environmental impact, recycling of natural resources (such as water, air, and fossil fuels), energy consumption, air quality, etc. The attributes and their implications on the sustainability of metro stations are shown in Table 1, which also indicates the publication in which attributes were cited as important to the sustainability of a metro station. This research study is quantitatively where structured based. A 41-attribute questionnaire was prepared and circulated among professionals from construction sector. Respondents were required to indicate their agreement with the inclusion of each attribute in a green building rating system using a 5-point Likert scale ranging from 1—'strongly disagree' to 5—'strongly agree'. The survey was collected to individuals in various professions, for example, project managers and IGBC-accredited professionals who had worked on at green metro station sites. The targeted audience is around 100, including builders, architects, designers, and consultants. The respondents are leaders in the green construction field in India, so their opinions are of immense importance. The questionnaire was circulated to online and offline mode with 100 professionals, of whom 57 responded, a response rate of 63.33%. Ten responses were excluded from analysis because they were incomplete, giving a final sample of 57 valid responses distributed as follows: IGBC-accredited professionals (39), and project managers (18). Data analysis procedures are described in the following Sect. [6] (Fig. 1).

5.1 Reliability of Collected Data

In SPSS Version 26, one can calculate Cronbach alpha, which indicates the factors' suitability for additional analysis and the high degree of internal consistency among all the attributes. Cronbach alpha is calculated using SPSS Version 26 and this value denotes the factors' suitability for further analysis as well as the excellent internal consistency of all the attributes. Thus, based on the findings of the reliability analysis, the value is acceptable and the attributes' internal consistency is satisfactory [32].

Table 1 Attributes considered in the questionnaire survey (Source Author)

Sr. No	Key parameter	Attributes of metro stations	Implication on the greenness of metro	Source
A1	Site selection	Biodiversity	Creating green spaces through community gardens, pocket parks, and rain gardens	[7]
A2		Heat island effect	The heat island effect necessitates a higher cooling load for metropolitan environments, which increases air pollution, has a bigger influence on resource extraction and costs more	Kibert [8], [9]
A3		Land acquisition cost	Construction costs are high, but maintenance costs are lower	Mateus et al. [10]
A4		Metro station density	The use of mass construction reduces waste and pollution	[6], Elangovan [11]
A5		Sustainable site development	To improve worker's productivity during construction	Mateus et al. [10]
A6	Energy efficiency	Climate control	Systems reduce energy use and environmental impact	
A7		Collaboration with energy providers	Use smart grid technology or renewable energy to improve energy efficiency	Ma et al. [12], [13]
A8		Employee training	Employees should be trained on energy-efficient practices to reduce energy waste	[14]
A9		Energy audits	Regular energy audits are essential to improve energy efficiency	[14]
A10		Energy efficient station design	Metro stations should prioritize energy efficiency through natural ventilation, insulation, and lighting	[15]
A11		Energy efficient technology	LED lighting energy-efficient heating and cooling systems, and regenerative braking systems, minimize energy use	
A12	Sustainable materials	Local availability	Using locally sourced materials can reduce transportation and support local economies	Moriconi (n.d.), Ram et al. (2020)
A13		Longevity	Materials should have a long lifespan and withstand wear and tear	

(continued)

Table 1 (continued)

Sr. No	Key parameter	Attributes of metro stations	Implication on the greenness of metro	Source
A14		Recyclability	Materials should be recyclable at the end of their lifecycle to reduce waste and environmental impact	Moriconi (n.d.), Ram et al. (2020)
A15		Water and fire resistance	Materials should be fire-resistant to ensure safety of passengers and staff	[16]
A16		Sustainability certifications	Materials should have sustainability certifications to demonstrate environmental impact and performance	[17]
A17	Green transportation	Accessibility	Accessible to all passengers, including those with disabilities	Chen and Wang [18]
A18		Community integration	Integrated into the local community with local retail spaces and public spaces to encourage social interaction	[19]
A19		Integration with technology	The station should be equipped with the latest technology to provide passengers with the information and services they need to use the metro system efficiently and effectively	Gupta and Garg (2020), Kazanskiy and Popov [20]
A20		Integration with other mode of transportation	Provide green transportation options such as bike lanes, bicycles, and public transportation	Tuzkaya [21]
A21		Safety and comfort	The station should provide a comfortable environment with safety, fire suppression, and security systems	Hill and Bowen [22], Chen and Wang [18]
A22		Wayfinding	The station should have clear and intuitive wayfinding systems to help passengers navigate the area	Shi et al. (2020)
A23	Water conservation	Graywater recycling	Recycling wastewater can reduce the need for fresh water	Lee and Tansel [23], Mourad et al. [24]
A24		Leak detection and repair	Regular monitoring and repair can reduce water waste	[25]
A25		Sustainable procurement	Installing green roofs and walls can reduce water loss and improve air quality	[1]

(continued)

Table 1 (continued)

Sr. No	Key parameter	Attributes of metro stations	Implication on the greenness of metro	Source
A26		Water efficient fixtures	Water consumption can be reduced by using low-flow toilets, showerheads, and faucets.	Lee and Tansel [23]
A27		Water management	The station should have systems to conserve water, such as low-flow toilets, showers, and taps	Mohammed Shahanas and Bagavathi Sivakumar [1]
A28	Waste Management	Awareness campaigns	Signs and posters can raise awareness and encourage behaviour change	Saladié and Santos-Lacueva [26]
A29		Cleanliness	Cleanliness, frequency and quality of waste collection and disposal	[25]
A30		Partnership with local authorities	The partnership with local authorities and waste management companies ensures proper disposal and treatment of waste	
A31		Waste segregation	Waste segregation facilities for different types of waste	Malik et al. [27]
A32	Indoor environment quality	Green roofs and walls	Green roofs and walls can absorb rainwater, reduce heat island, and provide habitat for wildlife	Fernando Barriuso and Beatriz Urbano [28]
A33		Environmental monitoring	Monitoring systems to track local ecosystem impacts	
A34		Mechanical system	Fan energy savings, material waste reduction, pump energy savings, and material waste reduction	Prasanna Gandhi and Vishal Prajapati (2011)
A35		Pollution sources	Understanding sources of pollution is essential to improve air quality	[29], Hill and Bowen [22]
A36		Smoking restrictions	Smoking restrictions in metro stations can reduce second-hand smoke and improve air quality	[29], Hill and Bowen [22]
A37	Economy	Renewable energy integration	The metro should use renewable energy sources are being used to minimize demand on non-renewable energy sources	Hidoussi et al. (2019)
A38		Cost of material	Materials should be cost-effective while meeting sustainability criteria	

(continued)

Table 1 (continued)

Sr. No	Key parameter	Attributes of metro stations	Implication on the greenness of metro	Source
A39		Amenities	Make the station comfortable for travellers by providing amenities such as restrooms, seating areas, vending machines, and bike storage	[9]
A40	Infrastructure	Infrastructure	Composting facilities, recycling bins, and waste compactors are essential for waste management	[29], Hill and Bowen [22], Ram et al. (2020), Sharholy et al. [30]
A41		Acoustic performance	Materials should have good acoustic properties to reduce noise levels and improve sound quality	[31]

5.2 Questionnaire Validity and Significance Test

The Kaiser–Meyer–Olkin (KMO) test represented the ratio of squared correlation between variables to the squared partial correlation between variables. KMO is calculated using SPSS Version 26 and is a measure of the distribution of values to see if it is adequate for conducting factor analysis. Initially, KMO for the response study was found to be 0.661, that is, >0.5 and therefore acceptable for 41 attributes. A partial correlation between the variables was visible in the anti-image correlation matrix. The diagonal elements show that two attributes had values that were less than 0.5, which is the minimum amount that's required for factor analysis. When these factors were taken out, KMO increased to 0.669, which is regarded as "acceptable" in the industry (Field 2013). The anti-image correlation matrix showed a partial correlation between variables. Lastly, Bartlett's test of sphericity is used to measure the multivariate normality and correlations among variables. The significance of Bartlett's test of sphericity is observed to be 0.000 (<0.005), indicating that the data were suitable for factor analysis (Field 2013).

5.3 Principal Component Analysis (PCA)

A set of variables can be linearly transformed into a much smaller set of uncorrelated variables using the statistical technique known as PCA, which captures the majority of the information from the original set of variables. The original data set's dimensionality is decreased (Field 2013). Pearson and Hotelling revised PCA. The three main benefits of PCA are its ability to reduce a large dataset to a more manageable size while preserving as much of the original data as possible, its ability to solve the collinearity issue associated with regression, and its ability to reduce a large dataset to a more manageable size. In order to condense a large number of variables into a smaller set, PCA was used to ascertain the underlying relationships among the proposed attributes contributing to the sustainability of the building. Three steps of analysis were carried out: factor extraction, factor rotation, and factor removal from the anti-image correlation matrix. Finding the dominant attributes using PCA is the goal of factor extraction. For each individual variable, the diagonal anti-image correlation matrix serves as a measure of sampling adequacy (MSA) and factor rotation was used to make the attributes more understandable. PCA is aided by the measured standard variable known as eigenvalue.

In summary, the results of reliability analysis test, KMO and Bartlett's test, PCA confirmed that all 57 data points for the 41 attributes were valid and suitable for factor analysis.

6 Data Analysis and Result

PCA was used to minimise down the initial set of 41 variables and identify the underlying relationships between the proposed controllable green metro attributes. Three steps were taken: factor extraction, factor rotation, and attribute removal from the anti-image correlation matrix. By loading each variable onto the other variable, factor rotation was used to formulate the attributes in a more interpretable form after factor extraction to determine the attributes through the PCA (Field 2013).

Nine components were extracted and subjected to varimax rotation with Kaiser normalisation based on the extraction criterion for principal components, which was that their eigenvalues were greater than one of these attributes accounting for 74.35% of the total variance. The two attributes are extracted and the major controlling attributes are 39. The interpretation of underlying variables is based on contributing variables. Nine underlying components were produced by PCA using varimax rotation of the 39 controllable green metro station attributes. Figure 2 displays the factor loadings and overall variance of these nine components for the controllable green metro station attribute.

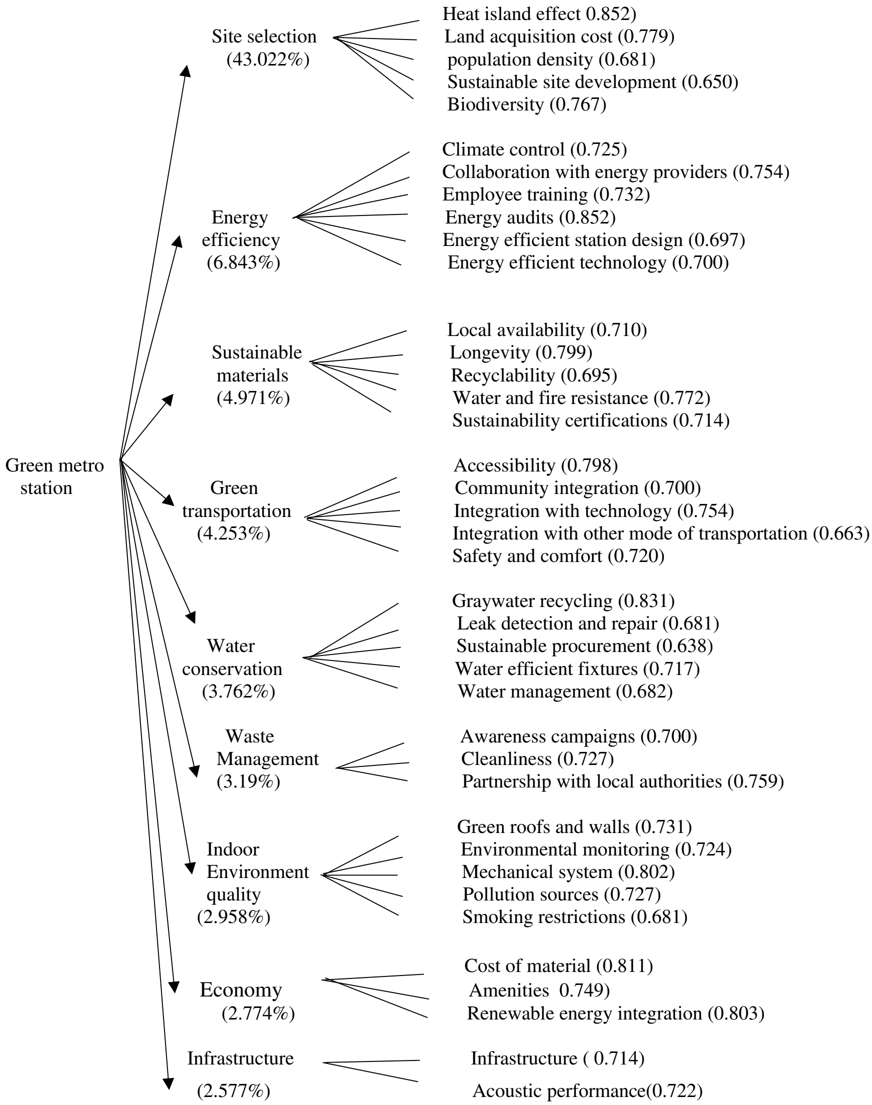

Fig. 2 Framework of green metro rating system. *Source* Author

7 Discussion

By reducing any tendency towards general component in the solution, the attributes extracted by PCA with varimax rotation could achieve a straightforward structure. The number of components extracted was determined using the eigenvalue criterion. The following provides a description of the 9 components that PCA with varimax rotation allowed us to extract from the set of 41 green metro station attributes (Field 2013).

7.1 Site Selection

The primary focus was on developing a green metro station, with site selection identified as a crucial key factor. The first attribute explored was the heat island effect, emphasising the importance of mitigating urban heat islands through thoughtful design and material choices [9]. Next, the consideration of biodiversity was highlighted, stressing the need to preserve and integrate natural ecosystems within and around the metro station to support local flora and fauna [33]. The third attribute examined was land acquisition cost, underscoring the significance of cost-efficient land procurement strategies to optimise the project's economic feasibility. Population density was identified as another crucial factor, illustrating how accommodating high-density areas can enhance the metro station's accessibility and reduce its overall environmental impact [34]. Lastly, sustainable site development practises were explored, underscoring the necessity of implementing environmentally friendly construction and infrastructure methods to minimise ecological footprints and maximise long-term sustainability benefits [3]. By delving into these attributes during the site selection process, the research provides valuable insights and guidelines for creating eco-friendly and socially responsible metro stations.

7.2 Energy Efficiency

The development of a green metro station with energy efficiency is the main priority. The first prominent attribute explored is climate control, which underscores the importance of implementing advanced technologies and designing strategies to maintain optimal indoor climate conditions while minimising energy consumption [10]. The significance of collaboration with energy providers is also highlighted, emphasising the need for partnerships to secure renewable and sustainable energy solutions for the station's operations [13]. Employee training emerges as another vital aspect, emphasising the role of educating staff members on energy-saving practises and sustainability measures to foster a culture of environmental consciousness. Additionally, conducting regular energy audits is identified as essential to identifying areas of energy in efficiency and implementing targeted improvements [14]. The research also delves into the attribute of energy-efficient station design, which focuses on integrating passive design principles and sustainable materials to enhance the station's overall energy performance. Lastly, the adoption of energy-efficient station technology is explored, emphasising the use of advanced systems and equipment to reduce energy consumption and optimise the metro station's sustainability [14]. By addressing these attributes, the research offers comprehensive insights into creating a truly eco-friendly and energy-efficient metro station.

7.3 Sustainable Materials

The primary focus is on developing a green metro station, with a key parameter being the use of sustainable materials. The first prominent attribute explored is the local availability of materials, which highlights the importance of sourcing construction resources from nearby regions to minimise transportation-related carbon emissions and support local economies (Moriconi n.d.; Ram et al. 2020). Longevity is identified as another critical attribute, emphasising the need to choose materials that have a prolonged lifespan, reduce the frequency of replacements, and minimise waste generation. The research also goes into recyclability, underscoring the significance of opting for materials that can be easily recycled at the end of their useful lives and promoting a closed-loop approach to resource management. Water and fire resistance emerge as essential attributes, stressing the need for materials that can withstand environmental challenges and enhance the station's safety and durability [16]. Lastly, the inclusion of sustainability certifications is discussed, emphasising the importance of selecting materials certified by recognised sustainability standards, ensuring compliance with environmental performance criteria, and promoting transparency in the station's construction processes [17]. By considering these attributes, the research offers comprehensive insights into the strategic utilisation of sustainable materials for the creation of an eco-friendly and socially responsible metro station.

7.4 Green Transportation

The development of a green metro station, with green transportation as a major component, is the focus. The first prominent attribute explored is accessibility, which underscores the importance of designing metro stations that are easily accessible to all members of the community, including individuals with disabilities, elderly people, and those using alternative transportation methods [18]. Community integration is identified as another critical attribute, emphasising the need to consider the station's design in a way that enhances its integration into the surrounding community, fosters a sense of belonging, and encourages sustainable transportation choices [20]. The research also delves into the attribute of integration with technology, which focuses on leveraging smart technologies to optimise station operations, improve passenger experiences, and reduce energy consumption. Additionally, the integration with another mode of transportation is explored, emphasising the significance of seamless connections with other sustainable transit options, such as buses, bicycles, or pedestrian pathways, to facilitate multimodal journeys and promote green commuting [21]. Lastly, safety and comfort are discussed, highlighting the importance of prioritising passenger safety, and creating a welcoming environment that encourages the use of public transportation over private vehicles. By addressing these attributes, the research provides comprehensive insights into the development of an eco-friendly and socially responsible green metro station that promotes sustainable transportation choices and integrates harmoniously with the community.

7.5 Water Conservation

A green metro station is being developed, with water conservation playing a major role. The first prominent attribute explored is Graywater recycling, which highlights the importance of capturing and treating wastewater from non-toilet sources for reuse in non-potable applications, reducing overall water consumption [24]. Leak detection and repair emerge as another critical attribute, emphasising the need for regular monitoring and timely fixing of water leaks within the station's infrastructure to prevent wastage and promote efficient water use. Sustainable procurement is also discussed, underscoring the significance of sourcing water-related products and materials from environmentally responsible and water-efficient suppliers, thereby contributing to the station's overall sustainability goals [25]. The research further delves into the attributes of water-efficient fixtures, focusing on the installation of water-saving faucets, toilets, and other fittings to minimise water usage while maintaining user convenience [1]. Lastly, water management is explored, highlighting the importance of implementing comprehensive water management strategies that optimise water use, promote responsible irrigation practises, and ensure a judicious allocation of water resources throughout the station's facilities [23]. By addressing these attributes, the research provides comprehensive insights into creating a water-efficient and environmentally conscious green metro station that contributes to water conservation efforts.

7.6 Waste Management

The primary focus is on developing a green metro station, with waste management as a key parameter. The first prominent attribute explored is the implementation of awareness campaigns, which highlight the significance of educating passengers, staff, and stakeholders about the importance of proper waste disposal and the benefits of recycling, fostering a culture of environmental responsibility [26]. Cleanliness is identified as another critical attribute, emphasising the need for efficient waste collection and disposal systems within the station to maintain a clean and hygienic environment for passengers and staff [27]. The research further delves into the attribute of partnership with local authorities, stressing the importance of collaborating with relevant municipal bodies to develop effective waste management policies and practises, ensuring the metro station's waste management efforts are integrated with the city's overall waste management infrastructure []. By addressing these attributes, the research provides comprehensive insights into creating a waste-conscious and environmentally friendly green metro station that contributes positively to waste reduction and environmental sustainability.

7.7 Indoor Environment Quality

The development of a green metro station is the main topic of the discussion section of this research paper, with indoor environmental quality as a crucial component. The first prominent attribute explored is the incorporation of green roofs and walls, which highlights the significance of integrating living vegetation into the station's design to improve air quality, regulate temperature, and enhance overall indoor comfort for passengers and staff. Environmental monitoring is identified as another critical attribute, emphasising the need for continuous monitoring of air quality, temperature, and humidity levels within the station to identify and address potential issues promptly, ensuring a healthy and pleasant indoor environment [28]. The research further delves into the attributes of mechanical systems, focusing on the importance of energy-efficient ventilation, heating, and cooling systems to maintain optimal indoor air quality and minimise energy consumption (Prasanna Gandhi and Vishal Prajapati 2011). Pollution sources are also discussed, stressing the necessity of identifying and mitigating potential sources of indoor air pollution, such as cleaning chemicals or exhaust emissions, to safeguard the well-being of station occupants. Lastly, smoking restrictions are explored, emphasising the significance of implementing smoking bans within the station premises to protect passengers and staff from exposure to harmful smoke and improve overall indoor air quality [22]. By addressing these attributes, the research provides comprehensive insights into creating a green metro station that prioritises indoor environmental quality, promoting the well-being and comfort of all those who utilise the facility.

7.8 Economy

The green metro station concept focuses on key factors that play a crucial role in its success. The first major factor emphasised is the economy, highlighting the significance of cost-effectiveness and financial viability in the development and operation of these stations. The second essential attribute is the integration of renewable energy sources, emphasising the need to harness sustainable power options to reduce the environmental impact and dependency on traditional energy (Hidoussi et al. 2019).

The third aspect of consideration is the cost of materials, suggesting the importance of selecting eco-friendly and durable construction materials to ensure long-term sustainability and resource efficiency []. Lastly, the discussion acknowledges the importance of providing amenities within green metro stations, promoting user comfort and convenience, to enhance the overall commuter experience and encourage greater adoption of public transportation [9]. By understanding and prioritising these key factors and attributes, the successful implementation of green metro stations can be achieved, contributing positively to both the environment and the community.

7.9 Infrastructure

The importance of infrastructure in green metro stations, recognising it as a key factor for their successful implementation. The first critical attribute highlighted is the infrastructure itself, emphasising the need for well-designed and efficient layouts to accommodate smooth passenger flow, accessibility, and safety [29]. Additionally, the paper focuses on the acoustic performance of these stations as another prominent attribute, emphasising the significance of noise reduction measures and soundproofing techniques to create a comfortable and pleasant environment for commuters [30]. By considering and optimising these infrastructure-related factors and attributes, green metro stations can be developed and operated in a manner that enhances their overall effectiveness and encourages greater usage, contributing positively to sustainable urban transportation systems.

The main limitation of this study is that the developed framework is only applicable to metro stations that are constructed or under construction. The factors that contribute to the sustainability of metro lines were outside the scope of this research. Before the framework could be used to assess the sustainability of metro stations, the relative weights of the nine components had to be determined.

8 Conclusion

The most reliable and widely used methodologies (IGBC, LEED-India, and GRIHA) in both international and local (Indian) contexts were taken into consideration for the comparative study of green metro stations. Special attention was paid to how the sustainable development criteria were weighted in each methodology as well as the similarities and differences between methodologies. The IGBC, LEED, and GRIHA rating systems do not consider some of the domains included in LEED, such as Collaboration with energy providers, Employee training, partnerships with local authorities, etc. The inclusion of attributes in the research questionnaire aims to achieve superiority through a consideration of the most trustworthy criteria in an Indian context to reflect and diagnose metro station environmental performance and to promote a seamless transition to sustainable practises. India is a developing nation, so there is a great opportunity to promote sustainable development. As a result, there is an urgent need for a stakeholder-friendly sustainability assessment scheme that can be used to promote the use of sustainable energy and green metro station principles.

The results of the expert questionnaire survey identified the green metro station and sustainability factors that are crucial for new construction in India. 41 variables and 9 components were extracted using PCA, and this data was then used to build a framework for assessing the sustainability of metro stations in India. The nine components are (1) site selection, (2) energy efficiency, (3) sustainable materials, (4) green transportation, (5) water conservation, (6) waste management, (7) indoor environment quality, (8) economy, and (9) infrastructure. The attributes associated with these components are shown in Fig. 2. The framework for evaluating the sustainability of a metro station was developed using the nine components and the attributes connected to them. The components and attributes have been discovered to be the most significant, and the rating system can be developed using the most reliable attributes rather than measuring sustainability with many attributes. Since the framework is simple to use, most stakeholders would be encouraged to implement it in the Indian context. This study can be further continued by taking various case studies and evaluating them with the help of this rating system and certification with an award. This study is limited to only metro station projects, whereas there are various other construction projects being developed whose construction quality can be evaluated. The present study is limited to only Indian construction industry. The conditions may differ from country to country and so the results after a similar analysis may show different results. A systematic and combined procedure should be followed in metro station construction process from start to the end of project. This will not only help in achievement of high quality but will help in on time completion of project within budget.

References

1. Mohammed Shahanas K, Bagavathi Sivakumar P (2016) Framework for a smart water management system in the context of smart city initiatives in India. Procedia Comput Sci 92:142–147. https://doi.org/10.1016/j.procs.2016.07.337
2. Bivina GR, Gupta A, Parida M (2019) Influence of microscale environmental factors on perceived walk accessibility to metro stations. Transp Res Part D: Transp Environ 67:147–155. https://doi.org/10.1016/j.trd.2018.11.007
3. Lee H, Son J, Jomao D, Ha J, Yun S, Lim CH, Lee WK (2020) Sustainable water security based on the SDG framework: a case study of the 2019 Metro Manila Water Crisis. Sustainability (Switzerland) 12(17) (MDPI)
4. Ali HH, Al Nsairat FS (2009) Developing a green building assessment tool for developing countries – Case of Jordan. Build Environ 44:1053–1064. https://doi.org/10.1016/j.buildenv.2008.07.015
5. Bapat H, Sarkar D, Gujar R (2021) Application of integrated fuzzy FCM-BIM-IoT for sustainable material selection and energy management of metro rail station box project in western India. Innov Infrastruct Solut 6(2)
6. Vyas GS, Jha KN (2016) Identification of green building attributes for the development of an assessment tool: a case study in India. Civ Eng Environ Syst 33(4):313–334

7. Fenner AE, Kibert CJ, Li J, Razkenari MA, Hakim H, Lu X, Kouhirostami M, Sam M (2020) Embodied, operation, and commuting emissions: A case study comparing the carbon hotspots of an educational building. J Cleaner Prod 268:122081. https://doi.org/10.1016/j.jclepro.2020.122081
8. Lü X, Lu T, Viljanen M, Kibert CJ (2013) A new method for controlling CO2 in buildings with unscheduled opening hours. Energ Build 59:161–170. https://doi.org/10.1016/j.enbuild.2012.12.024
9. Dahiya D, Gupta H, Dutta MK (2020) A deep learning based real time assistive framework for visually impaired. In: 2020 international conference on contemporary computing and applications, IC3A 2020, pp 106–109
10. Mateus R, Neiva S, Bragança L, Mendonça P, Macieira M (2013) Sustainability assessment of an innovative lightweight building technology for partition walls – Comparison with conventional technologies. Build Environ 67:147–159. https://doi.org/10.1016/j.buildenv.2013.05.012
11. Ganesh B, Rajakumar T, Malathi M, Manikandan N, Nagaraj J, Santhakumar A, Elangovan A, Singh Malik Y (2021) Epidemiology and pathobiology of SARS-CoV-2 (COVID-19) in comparison with SARS, MERS: an updated overview of current knowledge and future perspectives. Clin Epidemiol Glob Health 10:100694
12. Ma L, Li M, Ma X, Cheng L, Du P, Liu Y (2017) A review of supervised object-based land-cover image classification. ISPRS J Photogrammetry Remote Sens 130:277–293. https://doi.org/10.1016/j.isprsjprs.2017.06.001
13. Zhou H, Wan Y, Ye H, Jiang M, Wang J (2021) Real-time energy-efficient optimal control of high-speed electric train. Control Eng Pract 112
14. Hanaysha J, Tahir PR (2016) Examining the effects of employee empowerment, teamwork, and employee training on job satisfaction. Procedia—Soc Behav Sci Int Conf Innov Appl Energy 219:272–282 (Hidoussi, Faouzi, Oxford)
15. Liu Z, Hao H, Cheng X, Zhao F (2018) Critical issues of energy efficient and new energy vehicles development in China. Energy Policy 115:92–97
16. Luhar S, Nicolaides D, Luhar I (2021) Fire resistance behaviour of geopolymer concrete: an overview. Buildings 11(3):1–30 (MDPI AG)
17. Ji S, Lin PS (2022) Aesthetics of sustainability: research on the design strategies for emotionally durable visual communication design
18. Wang C (January 24, 2020) A novel coronavirus outbreak of global health concern. Lancet. 15;395(10223):470–473. https://doi.org/10.1016/S0140-6736(20)30185-9
19. Dorotić H, Doracic B, Dobravec V, Puksec T, Krajacic G, Duic N (2019) Integration of transport and energy sectors in island communities with 100% intermittent renewable energy sources. Renew Sustain Energy Rev 99:109–124
20. Kazanskiy NL, Popov SB (2015) Integrated design technology for computer vision systems in railway transportation. Softw Hardw Pattern Recogn Image Anal. https://doi.org/10.1134/S1054661815020133
21. Tuzkaya G, Gülsün B, Kahraman C, Özgen D (2010) An integrated fuzzy multi-criteria decision making methodology for material handling equipment selection problem and an application. Expert Syst Appl 37(4):2853–2863. https://doi.org/10.1016/j.eswa.2009.09.004
22. Hill RC, Bowen PA (1997) Sustainable construction: principles and a framework for attainment. Const Manage Econo 15(3)223–239. https://doi.org/10.1080/014461997372971
23. Lee M, Tansel B, Balbin M (2013) Urban sustainability incentives for residential water conservation: adoption of multiple high efficiency appliances. Water Resour Manage 27:2531–2540. https://doi.org/10.1007/s11269-013-0301-8
24. Chaabane S, Riahi K, Hamrouni H, Thayer BB (2017) Suitability assessment of grey water quality treated with an upflow-downflow siliceous sand/marble waste filtration system for agricultural and industrial purposes. Environ Sci Pollut Res 24:9870–9885. https://doi.org/10.1007/s11356-016-7471-x
25. Patel DJ, Patel DA (2023) Identification of potential demolition hazard attributes: an exploratory factor analysis approach. J Legal Affairs Dispute Resolut Eng Construct 15(2)

26. Saladié O, Santos-Lacuev R (2016) The role of awareness campaigns in the improvement of separate collection rates of municipal waste among university students: A Causal Chain Approach. Waste Manag 48:48–55
27. Malika NKA, Abdullaha SH, Manafb LA (2015) Community participation on solid waste segregation through recycling programmes in Putrajaya. In: International Conference on Environmental Forensics 2015 (iENFORCE2015), Procedia environmental sciences, vol 30. 10–14
28. Barriuso F, Urbano B (2021) Green roofs and walls design intended to mitigate climate change in urban areas across all continents. Sustainability 13(4):2245. https://doi.org/10.3390/su13042245
29. Ding GKC (2008) Sustainable construction-the role of environmental assessment tools. J Environ Manag 86(3):451–464
30. Sharholy M, Ahmad K, Mahmood G, Trivedi RC (2008) Municipal solid waste management in Indian cities—A review. Waste Manag 28:459–467
31. Benhammou M, Draoui B (2015) Parametric study on thermal performance of earth-to-air heat exchanger used for cooling of buildings. Renew Sustain Energy Rev 44:348–355
32. Field AP (2009) Discovering statistics using SPSS and sex and drugs and rock "n" roll. SAGE Publications
33. Berardi U (2013) Sustainability assessment of urban communities through rating systems. Environ Dev Sustain 15:1573–1591. https://doi.org/10.1007/s10668-013-9462-0
34. Golldack D, king IL, Yang O (2011) Plant tolerance to drought and salinity: stress regulating transcription factors and their functional significance in the cellular transcriptional network. Plant Cell Rep 30:1383–1391. https://doi.org/10.1007/s00299-011-1068-0
35. Mills B, Schleich J (2012) Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. Energy Policy 49
36. Mwasilu F, Justo JJ, Kim EK, Do TD, Jung JW (2014) Electric vehicles and smart grid interaction: a review on vehicle to grid and renewable energy sources integration. Renew Sustain Energy Rev 34
37. Ramasubramani R, Gunasekaran K (2021) Sustainable alternate materials for concrete production from renewable source and waste
38. Vyas GS, Patel DA, Vallabhbhai S (2016) Development of a ranking algorithm for the green building attributes-a case of Indian cities
39. Wasim M, Vaz Serra P, Ngo TD (2022) Design for manufacturing and assembly for sustainable, quick and cost-effective prefabricated construction–a review. Int J Constr Manag 22(15):3014–3022
40. Zlatev M, Pahl S, White M (2010) Perceived risk and benefit for self and others as predictors of smokers' attitudes towards smoking restrictions. Psychol Health 25(2):167–182
41. Chaabane S, Riahi K, Hamrouni H et al (2017) Suitability assessment of grey water quality treated with an upflow-downflow siliceous sand/marble waste filtration system for agricultural and industrial purposes. Environ Sci Pollut Res 24, 9870–9885. https://doi.org/10.1007/s11356-016-7471-x
42. Kardellass S, Servant C, Drouelle I, Chrifi-Alaoui FZ, Idbenali M, Abahazem A, Hidoussi A, Bendarma A, Selhaoui N (2019) Calphad-type assessment of the Pd-Yb binary system supported by first-principles calculations – Part II: Results. Mater Today: Proceed
43. Kumar, M, Ramb B, Sewwandic H, Sulfikard, Hondae, R Chamindac T (2020) Treatment enhances the prevalence of antibiotic-resistant bacteria and antibiotic resistance genes in the wastewater of Sri Lanka, and India. Environ Res 183:109179
44. Gupta S, Jha KN, Vyas G (2022) Construction and demolition waste causative factors in building projects: survey of the Indian construction industry experiences. Int J Const Manage. https://doi.org/10.1080/15623599.2022.2111962

Impact Assessment of Built Environment on Urban Flooding Using SCS-CN Method

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1 Introduction

The majority of rainfall that falls and comes in contact with the ground either penetrates into the soil or evaporates and returns to the atmosphere. Roofs, pavements, and other impermeable surfaces have sealed natural soils throughout urbanization, limiting natural seepage and evapotranspiration and turning rainwater into runoff [1]. Since development operations have compacted soils to the point where they operate as impermeable surfaces, seepage from open lands in urban areas is also decreasing [2].

Traditionally, engineered structures like gutters, channels, and pipelines have been used to transfer rainwater from sealed surfaces as quickly as possible to retention facilities, centralized detention ponds, and nearby streams. When it rains heavily, these facilities often cannot keep up with the peak flows that discharge from various sealed surfaces, which causes overflow and flooding [3].

The demand for urban area expansion is rising as a result of growing population and the migration of people to urban areas from rural areas. Rapid urbanization causes a number of environmental issues, including the loss of species, the urban heat island effect, changes in hydrological processes, and the use of water resources [4].

Due to an increase in impervious surface area, urbanization alters hydrological processes by changing the properties of surface infiltration. The amount of built-up land increases runoff volumes, peak discharge, and flooding frequency while decreasing water infiltration, base-flow, and lag duration [5, 6].

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One significant factor influencing worldwide change is the monitoring of land use and land cover (LULC) change, which is crucial for the management and planning of sustainable urban growth. Analyzing how land use, land cover (LULC), and climate change impact a region's hydrology is essential to completely understanding the hydrological-related issues the area faces. The warning scenario for towns and cities throughout the world is unplanned urban expansion and changes in land use and cover.

In case of Kolhapur, Maharashtra, India, a study is required that analyzes the LULC and rainfall changes over the years, and quantifies its impacts on the hydrological water-related processes that result in urban flooding.

In India, most solutions for combating urban flooding are prescribed on built infrastructure level (gutters, ponds, etc.) with respect to current or past rainfall patterns without considering the rainfall that can be expected in the coming future and the amount of rainfall which can be accommodated by these prescribed methods. These methods are not designed considering the changes that may happen in LULC properties. These solutions contribute to increased flooding by making ground surface impermeable with the use of concrete, etc.

This study will prove more beneficial in terms of preventing hydrology-based urban problems which occur/may occur as a result of change in land use and land cover. This will have environmental as well as economic benefits as it will lead to savings in the space, material, and energy required to build the above said structural solutions and will lead to rejuvenating the water table of the urban areas which is on a decline with time.

This paper studies the changes in land use, land cover, and rainfall patterns of the study site for the past 35 years, and analyzes its impacts on two hydrological processes namely, surface runoff and maximum potential water holding/storage capacity of soil that affect urban flooding.

2 Literature Review

Numerous scholars have looked into how urbanization affects watersheds' hydrological response.

To examine the impacts of land cover change (urbanization) on the hydrology of a basin in central Indiana, Choi, Engel, Muthukrishnan, and Harbor [7] used the Cell-Based Long Term Hydrological model (CELTHYM). Franczyk and Chang [8] looked into how urbanization and climate change affected runoff in the Portland Metropolitan Area's Rock Creek Basin. Chu et al. [9] used the distributed hydrological model to study the connection between land cover change and [10] hydrology of the Wu-Tu watershed in Northern Taiwan. In Oman, Al-Rawas et al. [11] looked into how urban structure affected the usage of curve numbers in rainfall-runoff modeling. To accomplish more accurate rainfall-runoff modeling in their study, typical CN values in the residential land use zone were adjusted. In Shanghai et al. [12] investigated how urbanization affected urban pluvial floods.

In India, studies on assessment and effects of LULC changes have been done to some extent.

Zope et al. [13] found small increment in the runoff peak flows and volumes throughout the watershed as a result of land use land cover change in Mumbai, India's Mithi River basin. Ahmad et al. [14] created a number of LULC maps of Ranchi, India's urban regions, which were examined between 1989 and 2015. Using geographic techniques like remote sensing and GIS, they forecasted LULC changes. Narendra Hengade & T I Eldho, using the VIC model, have assessed the effects of LULC variations and rainfall trends on the hydrological variables in Godavari River basin in India [15]. Using multi-spectral satellite data, Sandipta Das and Dasharatha P. Angadi have identified changes in land use/land cover and their relationship to rises in Land Surface Temperature (LST) in the Barrackpore Sub Divisional area of West Bengal [16]. Shailesh KumarKharol, D. G. Kaskaoutis investigated the long-term impacts of LULC (land use & land cover) changes on land-atmosphere fluxes and on precipitation and aerosol loading in Rajasthan state, India [17].

3 Research Objectives

As seen in the above section, a study specifically done with respect to Kolhapur, Maharashtra, India has not been done before. The methods used in the literature can be difficult to grasp. The frequency of floods in Kolhapur is rising by every year which states the importance and necessity of this study. Also, the method used for the research i.e. CSC-CN method is chosen as this is an easy to use and understand method which requires minimal resources and time.

From the available literature following objectives are drawn for the study: (1) To analyze the transmogrification of urban morphology. (2) To evaluate the impact of urbanization in terms of land use and land cover properties on urban flooding.

4 Methodology

Firstly, a representative location—Kolhapur City, Maharashtra, India has been selected for the study. Precipitation data of the study location has been taken from the government website. The changes in land use and land cover of the site have been extracted from USGS Earth Explorer with the help of Q-GIS software. Along with this, data regarding floods have been taken from the local government body (Kolhapur Municipal Corporation). Next, flooding risk in terms of runoff coefficient and potential maximum water storage capacity of the soil has been measured. Then, relation between LULC changes, surface runoff, and maximum water storage capacity of soil has been drawn. After this, the rate of these changes has been calculated. Lastly, area to accommodate the rainfall to manage flooding has been derived and the rate

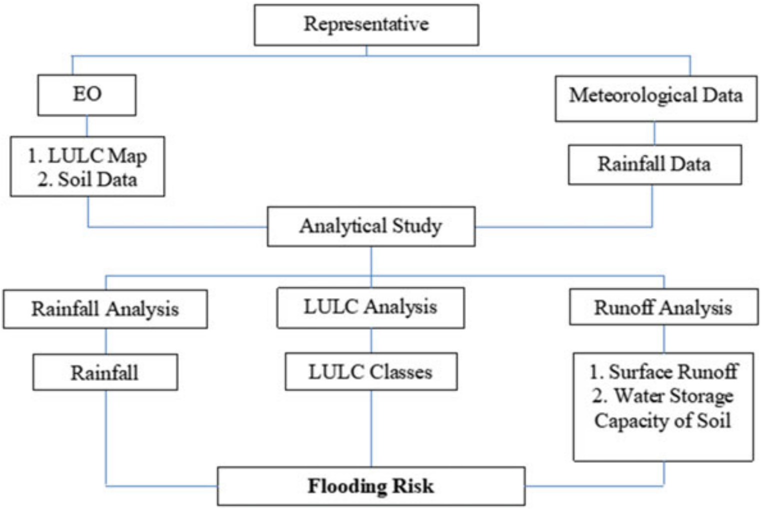


Fig. 1 Methodology chart

at which the changes in LULC must happen has been calculated. Figure 1 describes the methodology adopted for the study.

5 Tools and Techniques

In any research endeavor, the tools and techniques used play a vital role in establishing the validity and reliability of the results obtained. These methods and tools are used to gather, analyze, and interpret data, and they must be properly chosen and used in order to guarantee the accuracy and applicability of the findings.

In this research, Q-GIS is used to determine changes in LULC pattern whereas CSC-CN method is used to carry out runoff analysis.

5.1 Site

Kolhapur is a tier-2 city located in the western zone of Maharashtra state in India, surrounded by the Sahyadri mountain range and the Konkan coastal plain. The city is popular for its rich cultural and heritage, varied topography, and scenic beauty, and is primarily dependent on the Panchaganga River for its water supply. The climate of Kolhapur is tropical, characterized by hot and dry summers and moderate to cool winters, with moderate to heavy rainfall during monsoon.

Fig. 2 Kolhapur city map

As depicted in Fig. 2, in Kolhapur, the LULC is a mix of urban, rural, and semi-urban areas. The urban areas are characterized by high-density residential and commercial development, with buildings, roads, and other infrastructure dominating the landscape. The rural areas, on the flip side, are characterized by agricultural land, forests, and other forms of natural vegetation. The semi-urban areas are those that lie between the urban and rural areas, with a mix of residential, commercial, and agricultural land uses.

Urban flooding is a common problem in Kolhapur city, as in many other urban areas in India. There are several factors that contribute to urban flooding in Kolhapur, including: Poor drainage systems, Unplanned urbanization, Waste disposal, Climate change, and Unscientific construction.

5.2 Land Use and Land Cover Change

In this study, LULC changes were explored with two data sets, namely—ORNL DAAC (Oak Ridge National Laboratory Distributed Active Archive Center) and MODIS Land Cover—Product MCD12Q1.

The MODIS Terra + Aqua Combined Land Cover package contains 5 unique land cover categorization schemes that were developed using a supervised decision-tree classification algorithm. The principal land cover scheme defines 17 IGBP classes, which are divided into 11 classes of naturally occurring vegetation, 3 classes of vegetation that has had human influence, and 3 classes of uninhabited land. Seasonal

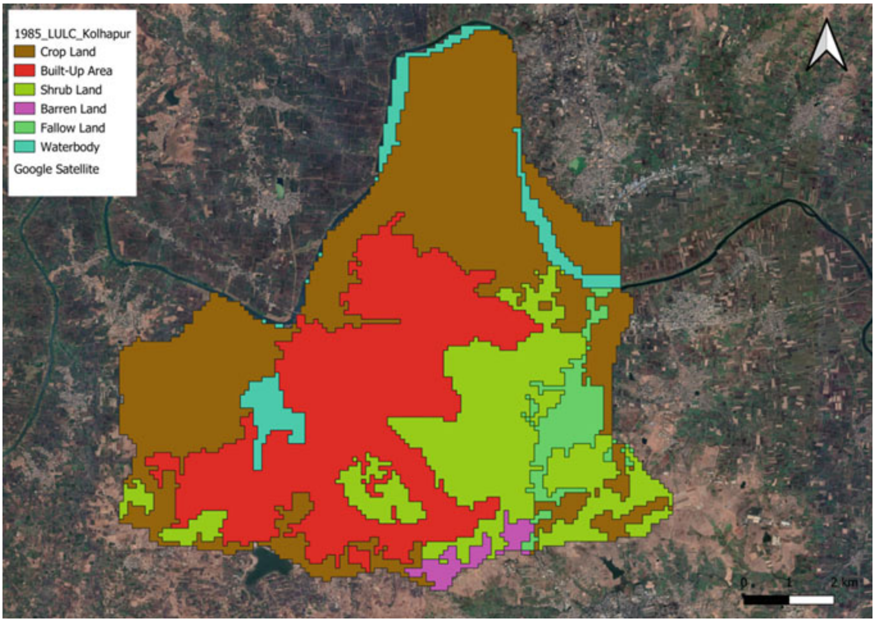


Fig. 3 Kolhapur LULC 1985

cycles are shown in the Land Cover Dynamics product by layers that describe when plants develop, reach maturity, and senescence. By giving estimates of vegetation phenology twice a year from the two 12-month focus periods, July-June and January-December, the product may, if required, record two growth cycles. This accounts for the variations in growth seasons between hemispheres.

LULC data for the years 1985, 1995, 2005, 2017, 2048, 2019, and 2020 was generated from the above said datasets using Q-GIS software (Table 1) (Figs. 3 and 4).

5.3 Precipitation Changes

Rainfall data from 1991 to 2020 has been taken from official website of "India Meteorological Department, Ministry Of Earth Sciences, Government Of India". We can see an uptrend in the rainfall over the years (Table 2).

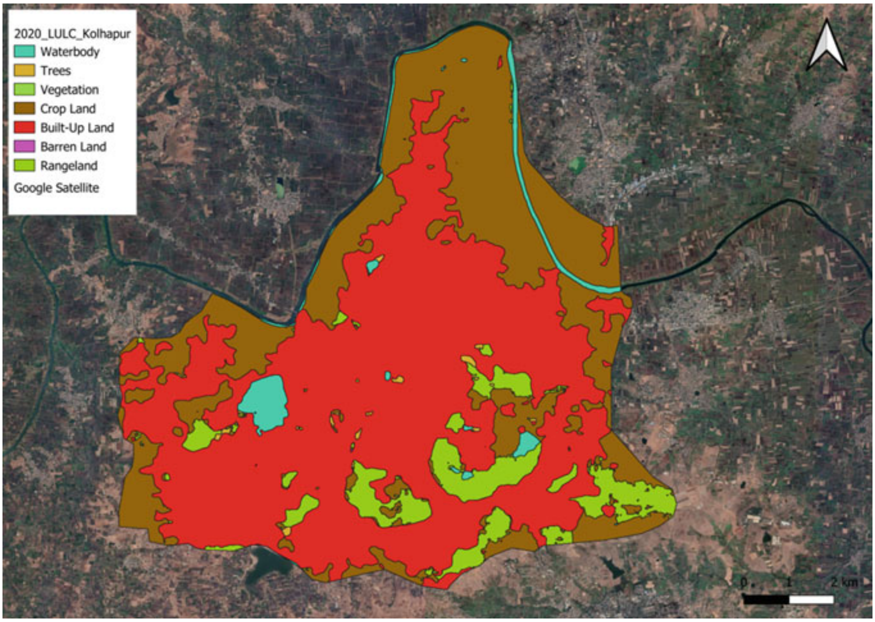


Fig. 4 Kolhapur LULC 2020

Table 1 Area change in LULC classes, Kolhapur

LULC	Area over the years (km^2)						
	1985	1995	2005	2017	2018	2019	2020
Built-up land	27.96	38.9	38.69	50.46	50.94	52.02	52.24
Agricultural land	37.11	32.74	33.02	31.85	32.96	31.63	28.92
Shrub land	17.77	12.37	12.27	6.4	4.91	5.31	7.38
Barren land	1.30	1.30	1.25	1.23	1.20	1.10	1.10
Fallow land	3.32	3.54	3.49	2.50	2.10	2.10	2.00
Waterbody	3.75	2.34	2.28	2.25	2.26	2.2	2.43

5.4 *Runoff Analysis*

Surface Runoff. The NRCS SCS-CN method is used that is contingent upon the water balance equation of the rainfall in a known interval of time Δt, which can be expressed as:

$$P = I_a + F_a + P_e \tag{1}$$

where

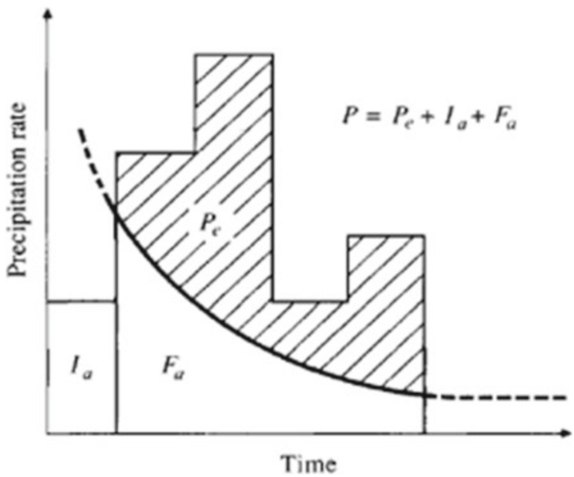
Table 2 Rainfall trend, Kolhapur

Year	Annual rainfall (mm)	Year	Annual rainfall (mm)
1991	1610.69	2006	1892.07
1992	1418.31	2007	1546.68
1993	1658.85	2008	1403.59
1994	1741.96	2009	1592.56
1995	1118.38	2010	1463.43
1996	1299.1	2011	1549.28
1997	1945.64	2012	1227.04
1998	1346.9	2013	1335.57
1999	1539.87	2014	1313.92
2000	1165.53	2015	794.55
2001	1144.68	2016	1293.5
2002	1077.55	2017	1320.69
2003	1104.58	2018	1449.59
2004	1401.74	2019	2410.9
2005	2000.54	2020	1737.4

P total Precipitation,
I_a initial abstraction,
F_a Cumulative infiltration excluding Ia and,
P_e direct surface runoff (all in units of volume occurring in time Δt) (Fig. 5).

The ratio of actual amount of direct runoff, Pe to maximum potential runoff ($= P - I_a$), is equal to the ratio of actual infiltration (F_a) to the potential maximum retention (or infiltration), S.

Fig. 5 Law of water balance



$$\frac{P_e}{P - I_a} = \frac{F_a}{S} \tag{2}$$

The amount of initial abstraction (Ia) is some fraction of the potential maximum retention (S):

$$Ia = \lambda S \tag{3}$$

Therefore on the basis of above equations, surface runoff (P_e) has been derived:

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{4}$$

Potential Maximum Retention. Soil Conservation Services (SCS) expresses S (mm) in terms of a dimensionless parameter CN (Curve number) as:

$$S = \frac{25400}{\text{CN}} - 254 = 254\left(\frac{100}{\text{CN}} - 1\right) \tag{5}$$

The Curve Number is now related as:

$$\text{CN} = \frac{25400}{S + 254} \tag{6}$$

CN has a range of $0 < \text{CN} < 100$
CN 100 represents zero potential retention (i.e. impervious catchment)
CN 0 represents an infinitely abstracting catchment with $S = \infty$.

Runoff Coefficient. The percentage of precipitation that results in runoff is known as the runoff coefficient. The coefficient's value, which is stated as a constant between zero and one, is based on the physiographic features of the drainage region as well as climatic circumstances.

Then, using runoff, Q, per precipitation event, P, each land cover feature's corresponding runoff coefficient, C, was calculated, as in following equation:

$$C = \frac{Q}{P} \tag{7}$$

Runoff coefficients are calculated for each of the studied land cover class (i.e., Built, Agriculture, Shrub Land, Fallow Land, Barren Land and Waterbody) from 1985 to 2020, using the below equation for range of precipitation (rainfall) events.

Then, using equation where A_i is the land area for each land cover feature and C_i is the runoff coefficient for each land cover class, the weighted mean runoff coefficient (Cmean) is derived for the whole research region from 1985 to 2020, and A_T is the total site area.

$$C_{\text{mean}} = \frac{\sum A_i \times C_i}{A_T} \tag{8}$$

Curve Number. SCS-CN method, as described in previous chapter, has been chosen for runoff analysis.

This method considers a dimensionless CN parameter that determines the antecedent possible retention number.

Curve number—CN depends upon:

(a) Soil type, (b) Antecedent moisture condition, (c) Land use/cover

(a) Soil Type: In the determination of CN, the hydrological soil classification is adopted. Based on the infiltration and other factors, soils are divided into the four classes A, B, C, and D here. Effective depth of soil, average clay content, infiltration properties, and permeability are significant soil traits that affect the hydrological categorization of soils.

The site—Kolhapur, falls under soil group "D" (Fig. 6) i.e. Clay soils (soils with high water table).

(b) Antecedent Moisture Condition (AMC): AMC stands for the soil's initial moisture content during the rainfall-runoff event under study. It is generally established that AMC controls early abstraction and penetration.

For practical application SCS has recognized three levels of AMC as follows:

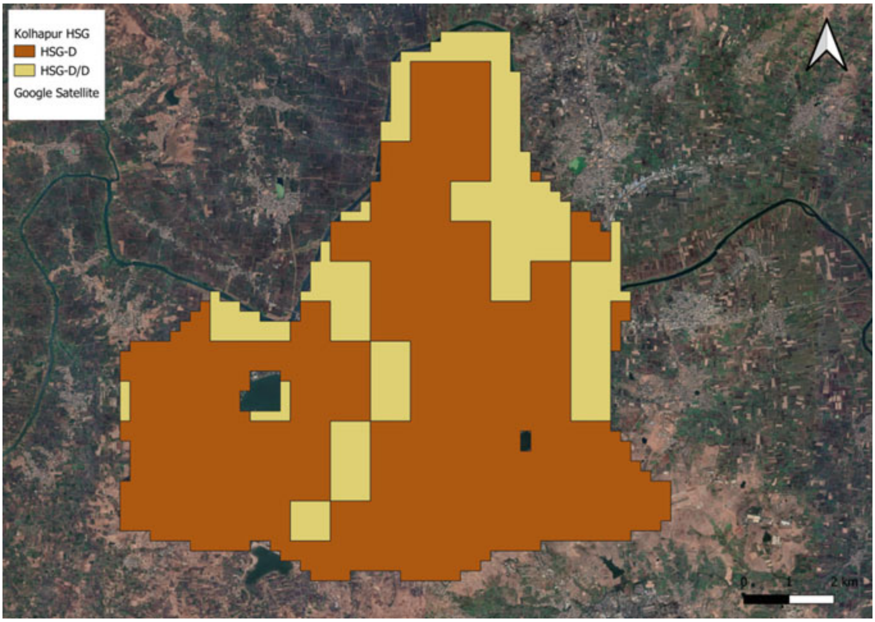


Fig. 6 Hydrologic Soil groups, Kolhapur

AMC-I: The soil is dry but not to the point of withering. Successful cultivation has occurred.
AMC-II: Conditions are average.
AMC-III: Within the last five days, there has been enough rain, and the earth is currently wet.

Kolhapur falls under "AMC-I" as Kolhapur has a dry summer prior to the rainy season.

(c) Land Use Land Cover: The earth's surface's physical substance is known as the land cover. The term "land use" refers to how people use the land for socioeconomic activity.

The kind of cover may be determined using a variety of techniques. Field reconnaissance, aerial photography, and maps of land usage are the most popular types.

The curve number (CN) is estimated in the study "Urban hydrology for small watersheds", also known as "TR-55", as a function of the catchment's impervious area, hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC).

Seven LULC classes have been identified for the study, namely: Built, Agriculture, Shrub Land, Fallow Land, Barren Land, and Waterbody (Table 3).

Based on the above three factors to determine curve numbers, report TR-55 provides CN numbers for AMC-II which then needs to be converted to required antecedent moisture condition (Tables 4 and 5).

The following correlation equations can be used to transform CNII into the other two AMC conditions:

For AMC-I,

Table 3 LULC class's definitions

Land cover class	Definition
Built-up	Land occupied by constructions constructed by humans, including buildings
Crop land	Region that has been temporarily planted, harvested, and then left naked for a while (such as in single- and/or multiple-cropping systems)
Shrub land	land covered with woody vegetation that is less than 2 m tall and has a shrub canopy cover of at least 10% There are two types of shrub foliage: evergreen and deciduous
Fallow land	Agricultural land that has been temporarily put aside for one or more seasons without being planted
Barren land	At no time of year can there be more than 10% of plant cover; instead, there should only be sand, bare soil, rocks, or snow
Waterbody	Areas where there is surface water, either flowing as rivers, streams, etc. or being impounded in the form of ponds, lakes, or reservoirs. Might be fresh or salt waterbodies

Table 4 Curve numbers for built area LULC components

Built area split-up	CN
Paved parking lots, driveways, etc.	98
Storm sewers and paved curbs	98
Paved open ditches	93
Commercial and business built	95
Industrial built	93
Residential built	86.8
Newly graded areas	94
Mean	93.97

Table 5 Curve numbers for in-site LULC classes (AMC-II)

Surface character	Impervious surface fraction	Pervious surface fraction				Waterbody
Land cover class	Built area	Barren land	Shrub land	Fallow land	Crop land	
Curve number (AMC-II)	93.97	94	78	90	83	98

$$CN_{I} = \frac{CN_{II}}{12.281 - 0.01281 CN_{II}} \quad (9)$$

For AMC-II,

$$CN_{III} = \frac{CN_{II}}{0.427 - 0.00573 CN_{II}} \quad (10)$$

6 Results and Discussions

6.1 LULC Analysis

Figure 7 and Table 7 show the notable changes that have taken place in LULC classes between 1985 and 2020, and are seen as follows (Table 6).

It is seen that the built class has increased by 24.28 km^2 whereas, agricultural land, shrub land, barren land, fallow land, and waterbodies have reduced by 8.19 km^2, 10.39 km^2, 0.20 km^2, 1.32 km^2 and 1.32 km^2 respectively. However it is seen that after the year 2017, the pace of increase in built area and pace of decrease in un-built area has reduced (Fig. 8).

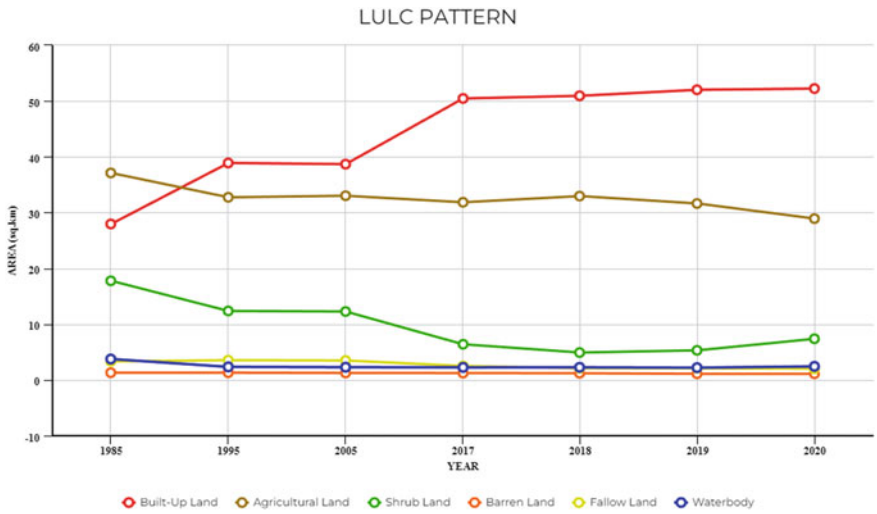


Fig. 7 Changes in LULC classes

Table 6 Changes in LULC classes, Kolhapur

LULC Class	Change between 1985 and 2020 (km^2)	Change between 1985 and 2020 (%)
Built-up land	24.28	186.84
Agricultural land	−8.19	22.08
Shrub land	−10.39	58.48
Barren land	−0.20	15.33
Fallow land	−1.32	39.69
Waterbody	−1.32	35.18

Table 7 Change in built and un-built land cover, Kolhapur

Surface cover	Change between 1985 and 2020 (%)
Built	+186.84
Un-built	−33.86

6.2 Precipitation

The annual average rainfall of Kolhapur city from the year 1991 till 2020 is 1513.9 mm based on the data obtained from "India Meteorological Department, Ministry Of Earth Sciences, Government Of India". The data shows a significant increasing trend (Fig. 9) that can be given by the equation:

$$\text{Rainfall} = (2.66 \times \text{Year}) - 3859 \quad (11)$$

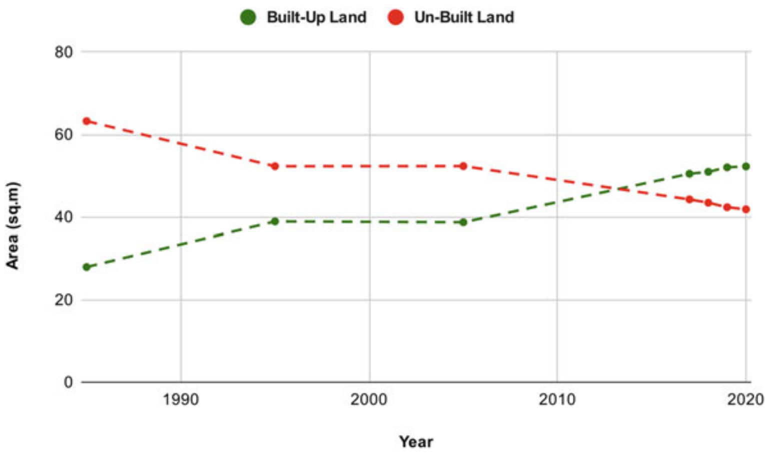


Fig. 8 Change in built and un-built land cover

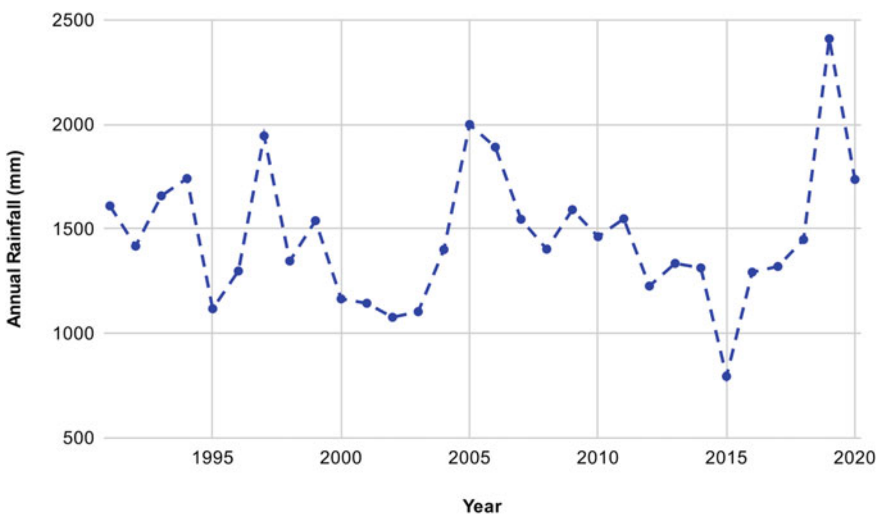


Fig. 9 Rainfall pattern

Increase in the rainfall is increasing the surface runoff of the study site.

6.3 Surface Runoff and Runoff Coefficient

Also, it was discovered that the surface runoff for every LULC class has increased significantly over the period of study and is in an overall uptrend (Fig. 10).

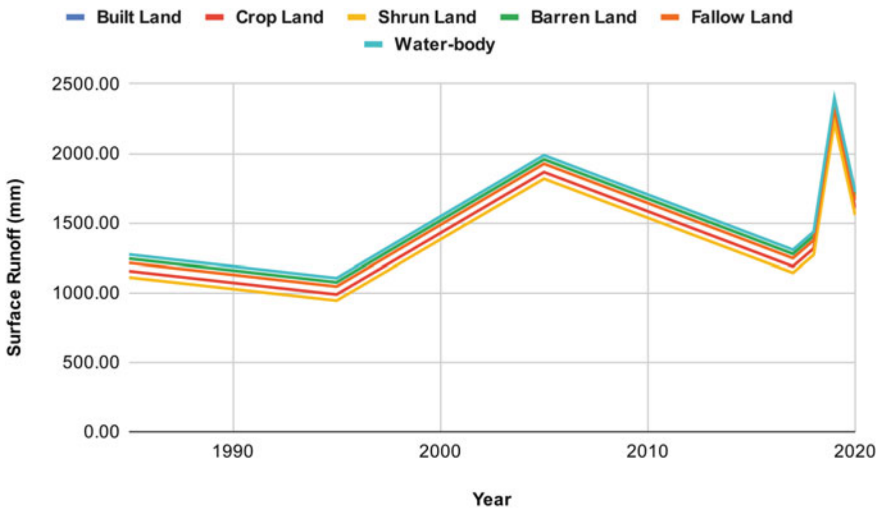


Fig. 10 Change in surface runoff

When considering all LULC classes together, the average surface runoff of the site has increased by 448.82 mm. The reason behind this is that the LULC classes that hold most of the water have declined over the years.

The weighted mean runoff coefficient which measures the site's total impact of LULC rose from 0.92 in 1985 to 0.98 in 2020 as a result (Fig. 11).

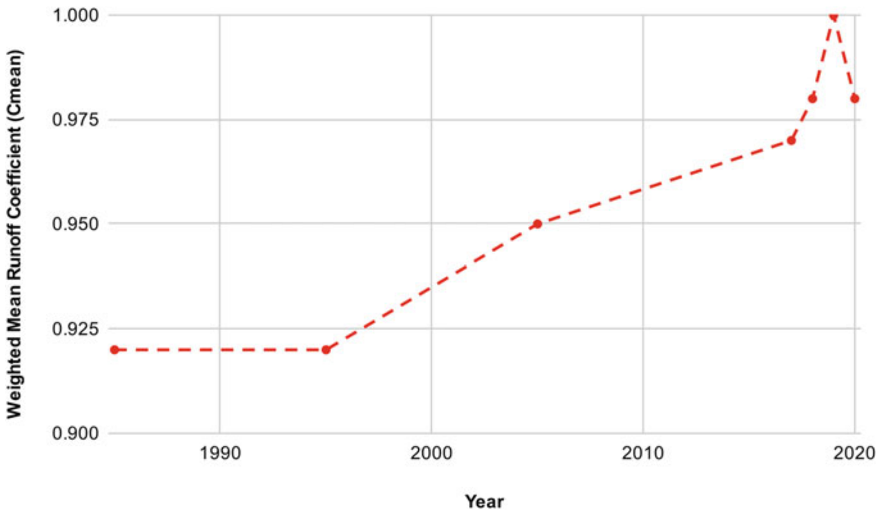


Fig. 11 Change in runoff coefficient

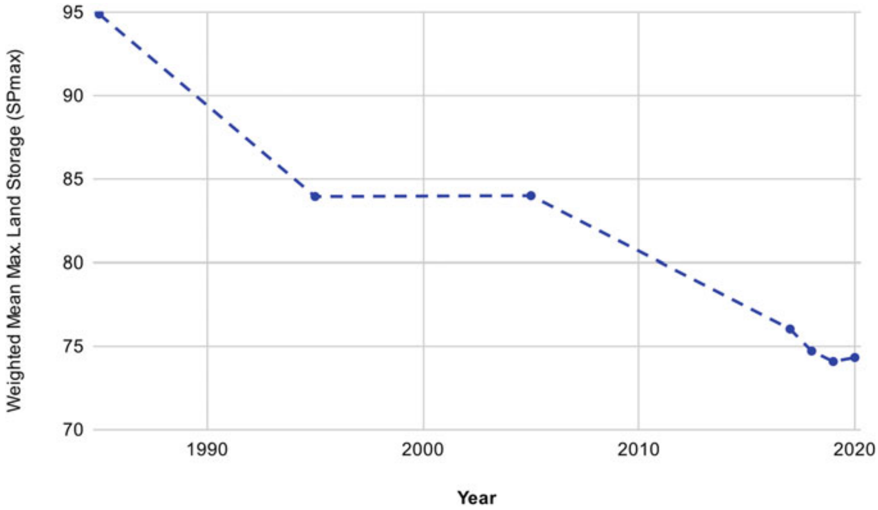


Fig. 12 Change in weighted mean potential maximum water storage capacity of the soil

6.4 Potential Maximum Soil Water Storage Capacity

As the un-built LULC classes that are responsible for absorbing and holding the surface water have decreased over the years, it has resulted in the water storage capacity of the soil to decrease.

Weighted mean maximum water storage capacity of soil has been calculated to measure the impact of LULC change on water storage capacity of the study site.

Weighted mean maximum water storage capacity of the study site is given by the formula:

$$\frac{A_1 S_1 + A_2 S_2 + A_3 S_3 \ldots\ldots\ldots A_n S_n}{\text{Precipitation of the particular year}} \tag{12}$$

where, A = Area of LULC, S = Water Storage capacity of the LULC.

Between 1985 and 2020, the weighted mean maximum water storage capacity of the study site as a whole has decreased from 94.89 to 74.33 (Fig. 12).

6.5 Flooding Risk and LULC

Impact of LULC change on flooding for the study area is studied based on two parameters which play a major role on urban flooding, namely: Surface runoff/Runoff coefficient and potential maximum soil water storage capacity.

As inferred from Sects. 4.1, 4.3, and 4.4, with reduction in un-built area and increase in built area, there is significant increase in surface runoff and reduction in maximum water storage capacity of soil. It says that the area of land needed to absorb the rainwater is reduced which results in increased flooding in study area.

After precipitation events, the water remaining on the surface after abstraction in the soil is increasing, due to which, the flooding risk of Kolhapur can be said to have increased.

7 Conclusion

It is seen that changes in land use and land cover impact the hydrological processes immensely. These LULC changes affect the hydrological processes of the catchment area which in turn lead to disasters such as urban flooding and cause loss of life and property. In case of Kolhapur, Maharashtra, India, no prior study related to LULC or impact of LULC on flooding has been done before. This states the importance of the study. During the study, it was found that the decrease in un-built areas which are majorly responsible for the absorption of rainwater are on a decline and the built area which is responsible for preventing the seepage of rainwater into the ground is on rise. Also, the rain is in an uptrend which indicates more rainwater needs to be managed. All these factors increase the flooding risk of Kolhapur city. By analyzing the relation between land use and land cover, runoff, factors affecting runoff, and flooding potential in Kolhapur City, Maharashtra, this study illustrates the effect of urbanization on urban flooding and gives the city and other comparable cities a foundation for developing sustainable urban flood management practices.

References

1. Recanatesi F, Petroselli A, Ripa MN, Leone A (2017) Assessment of stormwater runoff management practices and BMPs under soil sealing: a study case in a peri-urban watershed of the metropolitan area of Rome (Italy). J Environ Manag 201:6–18
2. Gregory JH, Dukes MD, Jones PH, Miller GL (2006) Effect of urban soil compaction on infiltration rate. J Soil Water Conserv 61(3):117–124
3. Ferguson BK (1995) Storm-water infiltration for peak-flow control. J Irrig Drain Eng 121(6):463–466. https://doi.org/10.1061/(asce)0733-9437(1995)121:6(463)
4. Du S, Shi P, Van Rompaey A, Wen J (2015) Quantifying the impact of impervious surface location on flood peak discharge in urban areas. Nat Hazards 76(3):1457–1471
5. Ogden FL, Raj Pradhan N, Downer CW, Zahner JA (2011) Relative importance of impervious area, drainage density, width function, and subsurface storm drainage on flood runoff from an urbanized catchment. Water Resour Res 47(12)
6. Du J, Qian L, Rui H, Zuo T, Zheng D, Xu Y, Xu CY (2012) Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. J Hydrol 464:127–139
7. Choi JY, Engel BA, Muthukrishnan S, Harbor J (2003) GIS based long term hydrologic impact evaluation for watershed urbanization 1. JAWRA J Am Water Resour Assoc 39(3):623–635

8. Franczyk J, Chang H (2009) The effects of climate change and urbanization on the runoff of the Rock Creek basin in the Portland metropolitan area, Oregon, USA. Hydrol Process: Int J 23(6):805–815
9. Chu HJ, Lin YP, Huang CW, Hsu CY, Chen HY (2010) Modelling the hydrologic effects of dynamic land-use change using a distributed hydrologic model and a spatial land-use allocation model. Hydrol Process 24(18):2538–2554
10. Sharif HO, Al-Juaidi FH, Al-Othman A, Al-Dousary I, Fadda E, Jamal-Uddeen S, Elhassan A (2016) Flood hazards in an urbanizing watershed in Riyadh, Saudi Arabia. Geomat Nat Haz Risk 7(2):702–720
11. Al-Rawas GA, Valeo C, Khan UT, Al-Hafeedh OH (2015) Effects of urban form on wadi flow frequency analysis in the Wadi Aday watershed in Muscat, Oman. Urban Water J 12(4):263–274
12. Huang Q, Wang J, Li M, Fei M, Dong J (2017) Modeling the influence of urbanization on urban pluvial flooding: a scenario-based case study in Shanghai, China. Nat Haz 87(2):1035–1055
13. Zope PE, Eldho TI, Jothiprakash V (2015) Impacts of urbanization on flooding of a coastal urban catchment: a case study of Mumbai City, India. Nat Haz 75(1):887–908
14. Ahmad F, Goparaju L, Qayum A (2017) LULC analysis of urban spaces using Markov chain predictive model at Ranchi in India. Spat Inf Res 25(3):351–359
15. Hengade N, Eldho TI (2016) Assessment of LULC and climate change on the hydrology of Ashti Catchment, India using VIC model. J Earth Syst Sci 125(8):1623–1634
16. Das S, Angadi DP (2020) Land use-land cover (LULC) transformation and its relation with land surface temperature changes: a case study of barrackpore subdivision, West Bengal, India. Remote Sens Appl: Soc Environ 19:100322. https://doi.org/10.1016/j.rsase.2020.100322
17. Kharol SK, Kaskaoutis DG, Badarinath KVS, Sharma AR, Singh RP (2013) Influence of land use/land cover (LULC) changes on atmospheric dynamics over the arid region of Rajasthan State, India. J Arid Environ 88:90–101. https://doi.org/10.1016/j.jaridenv.2012.09.006

Overview of Urban Vulnerability and Resilience Frameworks

Shekhar Vishnu Nagargoje and Sanjay Govind Patil

1 Introduction to Urbanization and Its Challenges

In the twenty-first century, our planet is undergoing an unprecedented transformation into an urbanized world. Rapid urbanization is a global phenomenon. Its accelerated pace began in the 1950s [1] and has surged, particularly in recent decades. According to UNDESA report on World Urbanization Prospects, since 1950, there has been a nearly six-fold increase in the global urban population, soaring from 751 million to 4.2 billion in 2018. Projections indicate that this trend will continue, with the world's cities and towns expected to accommodate a significant portion of the global population growth by the year 2050. It is estimated that the current figure of approximately 4.4 billion individuals residing in cities will rise to 6.7 billion by 2050. While the growth of populations in large metropolitan areas remains significant, there will also be a substantial increase in the number of regional and mid-sized cities, ranging from 500,000 to 5 million people, by 2030 [2]. Urbanization holds the capacity to significantly influence all facets of sustainable development, intricately interlacing with its three core elements: economic, social, and environmental dimensions. Proper planning and adept management can leverage urbanization to reduce poverty and inequality, augmenting job opportunities, life quality, and accessibility to high-grade education and healthcare. However, unmanaged urbanization risks harmful consequences, including congestion, crime escalation, pollution, amplified inequality, and surging social exclusion [3]. Urban areas take the form of intricate systems that are characterized by complicated socio-economic activities that have the capacity to change the built environment. These changes involve converting rural areas into urban settings, which causes a substantial population shift from rural to urban areas and, as a result, changes the geographic distribution of inhabitants. Additionally, urbanization sparks significant changes in the prevalent professions, lives,

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traditions, and habits, leading to profound demographic and social structural changes in both urban and rural areas [4]. It is anticipated that a substantial portion of the predicted urban expansion from now until 2050 will be concentrated in three key countries: India, China, and Nigeria. Projections indicate that India may witness the addition of approximately 416 million urban residents, China around 255 million, and Nigeria about 189 million by the year 2050. These staggering figures underscore the significant role these countries will play in shaping the global urban landscape in the coming decades [5].

2 Critical Aspects of Urban Vulnerability and Need for Resilience Planning

The increased rate of population in urban areas will add additional pressure and stress on existing infrastructure and overall quality of living in the cities. Further rapid urbanization can lead to additional issues and challenges such as inequality, urban sprawl, unemployment, higher living costs within the urban areas, weaker urban local bodies with poor financial capacity leading to further environmental degradation and stress on urban utilities [6]. These challenges and gaps are making the cities more vulnerable to live.

Since most of the global population now resides in urban areas, addressing calamities and their connection to urbanization has emerged as a crucial and top priority for world leaders. The unprecedented impact of the novel coronavirus disease (COVID-19) has unleashed havoc upon the economic and social fabric of societies worldwide. While larger and denser cities have traditionally been hailed as engines of growth and productivity, attracting migrants from less developed regions, the rapid spread of COVID-19 infections within urban centers has raised profound concerns regarding development, city density, economic prosperity, and vulnerability. The exponential transmission of COVID-19 within densely populated cities has posed significant questions about the sustainability of high-density urban environments. It is evident that higher population densities in cities contribute to increased vulnerabilities during pandemics like COVID-19. This understanding requires a critical reassessment of the conventional view of urban densities as “engines of progress”. It’s now apparent that they can be not only detrimental but also pose serious risks during major biological crises like COVID-19 [7].

Any natural disaster causes major losses of lives and property as well as damage to infrastructure leading to substantial economic costs. The degree of these impacts depends on many factors such as the scale of the event, the level of preparedness of Governing systems, the resilience of residing population, the available support, etc. [8]. The dynamics and patterns of urbanization exert various influences on the risk and vulnerability associated with natural disasters. These effects appear in various forms, such as increasing environmental impacts, amplifying the severity of climate change-related phenomena, and extending the susceptibility and density of the population

[9]. They are further increased by complex interactions of physical, economic, socio-cultural, and institutional circumstances [10]. Notably, in developing countries, urban populations are found to be more vulnerable to natural disasters, primarily due to the unregulated expansion of cities.

According to the report released by the Department of International Development, it is imperative to prioritize raising awareness, enhancing resilience, facilitating preparedness, and implementing effective response strategies to address the escalating vulnerability. Achieving this goal necessitates the active involvement of various stakeholders, including urban local bodies, state and national governments, civil society, and the private sector. Increasing awareness plays a crucial role in fostering understanding of risks and enhancing the potential for behavioral and policy-level changes. Furthermore, community participation and effective communication of data are essential in improving planning and preparedness efforts. To cultivate resilience, it is essential to adopt an integrated planning approach that ensures the resilience of systems to existing and future vulnerabilities [11].

Promoting the resilience of urban and rural communities worldwide has become increasingly paramount as they strive to address challenges such as poverty, climate change, inequality, fragility, social exclusion, violence, and disaster risks [12]. The establishment of sustainable communities, whether in villages, cities, or entire countries and societies, will be instrumental in eradicating poverty and fostering shared prosperity. The concept of “Sustainable Cities and Communities” is recognized and emphasized by the Urban, Disaster Risk Management, Resilience, and Land Global Practice (GPURL) of the World Bank. This concept encompasses four key dimensions:

- First and foremost, sustainable communities prioritize environmental sustainability by promoting cleanliness and efficiency.
- Secondly, these communities exhibit resilience in the face of social, economic, and natural shocks, effectively preparing for the escalating intensity and frequency of climate change-induced disasters.
- Thirdly, inclusivity is a core focus of sustainable communities, ensuring active participation and engagement of all segments of society, including marginalized and vulnerable groups, in their markets, services, and overall development.
- Lastly, sustainable communities strive for competitiveness, maintaining productivity levels and generating employment opportunities for their residents.

As per World Bank, it’s important to create cities and communities that include everyone, are resilient from challenges, are economically strong, and are environmentally friendly. This is a key step to reach the Sustainable Development Goals by 2030. This way, we can eliminate serious poverty and promote wealth that everyone can enjoy at the local, regional, and national levels [12].

3 Urban Resilience—Conceptual Framework

The concept of urban resilience encompasses a diverse range of practices aimed at adaptation and risk reduction. The increasing interest in building resilient cities has also sparked a series of important questions. As discussed by Chelleri Lorenzo in 2014 [13], the notion of resilience, much like the holistic principles of sustainability, has faced criticisms due to clashes with prevailing business-as-usual practices, a lack of comprehensive system-wide indicators, and the scalability challenges of proposed innovations.

From a representative perspective, resilience generally pertains to the ability to "deal with change" by adapting to shocks and stresses [14]. The concept of resilience originated in the scientific realm during the mid-nineteenth century, as described by Alexander in 2013 [15], referring to the capacity of a material to withstand forces without incurring permanent deformation. Over time, it found application in psychology during the 1950s (relating to the ability to recover after stress), ecology in the 1970s (pertaining to the amount of disturbance a system can absorb before undergoing change), and social studies in the 1990s (highlighting the necessity and capacity to manage change through adaptation rather than passive reaction).

In the context of cities, resilience pertains to the capacity of urban areas to function effectively, ensuring that all residents, particularly those who are poor and vulnerable, not only survive but also thrive in the face of various stresses and shocks [16]. Integrated urban planning processes play a pivotal role in shaping the well-being of city inhabitants and directly influencing urban growth. Specifically, the adoption of strategic resilient planning serves as a crucial tool for sustainable development and urban resilience. This approach encompasses the following key aspects:

- Optimizing land use and ensuring the integrity of transportation systems: Integrated urban planning considers the efficient use of land and promotes a well-connected transportation network. This approach enhances the functionality and resilience of cities.
- Reducing population vulnerability to climate change: By facilitating improved access to essential resources, services, and amenities, integrated urban planning helps mitigate the vulnerability of urban populations to the impacts of climate change. This includes addressing challenges related to extreme weather events, water scarcity, and other climate-related risks.
- Fostering sensitivity toward the environment and incorporating social and economic goals: Integrated urban planning recognizes the importance of harmonizing environmental considerations with social and economic objectives. It seeks to create sustainable and resilient urban environments that balance the needs of the community, the economy, and the natural surroundings.

By integrating these principles into urban planning decisions, cities can effectively promote resilience, low carbon development, and the overall well-being of their inhabitants [17].

According to the TERI Report on Climate Resilient and Sustainable Urban Development, urban systems exhibit dynamic characteristics, experiencing periods of balance or normalcy as well as periods of stress caused by various factors such as climate, socio-economic conditions, and demographics. Sustainability is defined as the capacity of a system to sustain its optimal structure and function over time. On the other hand, resilience goes beyond maintaining optimal conditions; it encompasses the ability to adapt to new changes and withstand periods of stress, transitioning to new states while preserving critical functions that were previously provided. In this sense, resilience and sustainability share common ground, as resilience overlaps with the principles of sustainability [18] Refer to Table 1.

According to Folke [19], to address the relationship between change, persistence, and sustainability a socio-ecological system vision shall be adopted by further conceptualizing resilience and transforming across scales. Table 2 provides a clear depiction of the convergence of various resilience approaches, including recovery, adaptation, and transformation, in terms of their impacts and services over a specific time. The visual representation of a ball in a basin serves as a metaphorical explanation for each approach, illustrating the concepts of returning to equilibrium (bounce back), expanding the system's tolerance range, and undergoing regime change [20].

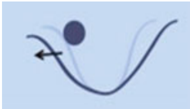
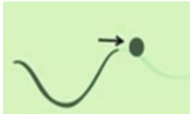
The interconnection between ecosystems and urban areas represents a bidirectional relationship characterized by intricate dynamics. Ecosystems play a pivotal

Table 1 Conceptual understanding of sustainability and resilience

	Sustainability	Resilience
		
Definition	A system's ability to maintain its optimal form and function throughout time	Ability to accommodate new alterations and stress situations while preserving the set of important services previously given
	Integrated urban planning	Adaptation
	Disaster risk reduction	Mitigation
	Urban services	
	Green buildings	
	Sustainable transport	
State of urban system = Services + Planning + Governance		
Stress due to impact of Climate, Socio-economic, Demographic		

Source TERI report on Climate Resilient and Sustainable Urban Development [18]
Analysis Climate-resilient and sustainable urban development entails the strategic planning and design of cities with the dual objective of reducing their negative environmental impact and strengthening their ability to cope with and endure the consequences of climate change. This approach to urban development strives to create cities that are environmentally sustainable and equipped to withstand the challenges posed by climate change

Table 2 Three (partially overlapping) stages of resilience related to short-, medium- and

Action	Recovery	Adaptation	Transformation
			
Explanation	Recovery relates to either ensuring the supply of essential infrastructure services or disaster recovery	A reactive modification technique that reduces a system's vulnerability to disturbances and hazards, including climate change	Transformation refers to physical or qualitative changes in form, structure, function, or meaning
Social-ecological system	Resilience/robustness	Resilience	Resilience
Socio-technical system	Resilience	Robustness	Transition

Source Adapted [20] "Findings and final remarks", in L Chelleri and M Olazabal (editors) 0.2012
Analysis In general, the table indicates that different sorts of systems necessitate different types of behaviors to achieve resilience. Resilience and robustness are crucial for social-ecological system recovery and adaptation, while transformation is important for total resilience building. Resilience is crucial for action in socio-technical systems, but robustness and transition are important for recovery and adaptation. Finally, creating resilience necessitates a comprehensive and integrated approach that considers the distinct characteristics of various systems as well as the many sorts of stresses that they are expected to undergo

role in bestowing numerous physical and environmental advantages upon cities and their inhabitants, thereby bolstering the resilience of urban environments. However, the rapid urbanization and haphazard development witnessed in many cities have resulted in a worrisome decline of ecosystems. This detrimental trend disrupts the delicate equilibrium and resilience of not only the affected cities but also of other interconnected urban centers. The prevailing "extractive" nature of urbanization tends to undervalue the preservation of ecosystems, thereby impacting the livelihoods of those reliant on them and compromising the overall well-being of the city itself [21]. Broadly most of the literature emphasizes that City resilience generally refers to a city's ability to absorb shocks, adapt to change, and respond to any future shocks. However, urban resilience also echoes similar terms such as governance, sustainability, and economic development [22]. The issues discussed above indicate the necessity of understanding resilience and its application making future cities a better place to live. A detailed literature review is conducted to further explore various dimensions of resilient cities.

4 Literature Study and Overview of Urban Resilience Frameworks

In the scholarly article titled "Designing, Planning, and Managing Resilient Cities: A Conceptual Framework" authored by Desouza [23], two fundamental inquiries regarding resilient cities are raised:

1. What are the key aspects to which cities need to exhibit resilience?
2. How can cities, being complex systems, cultivate resilience?

The paper thoroughly explores the concept of resilience within urban contexts and presents a conceptual framework. This framework encompasses a comprehensive examination and analysis, with a focus on essential dimensions such as planning, designing, and managing for resilience. The aim is to provide a deeper understanding of resilience and its practical implementation in urban settings (Refer to Table 3).

Planning is the initial phase in the process, where the identification of new components to be integrated within a region takes place. These components may include new structures, systems, infrastructure development, or the integration of newcomers into cities. This planning phase presents an opportunity to enhance resilience by adopting flexible strategies that can adapt to evolving environmental conditions and employing planning processes that are responsive to emerging knowledge and events. Current efforts are focused on increasing public engagement in resilience planning, recognizing that planning cannot be solely for citizens but must involve citizens, enabling information and political feedback to flow in multiple directions. A crucial aspect of effective preparation lies in establishing and communicating common goals consistently. The success of "Project Production as Preparation" is contingent on the level of consensus, flexibility, and transparency among participants, as well as the coherence and clarity of inter-community communication during these processes (Fig. 1).

The subsequent phase is design. Once the plans are formulated, the design processes commence, recognizing that there may be iterations between planning and design. The reason for delineating them here is to emphasize that while flexibility is emphasized in the planning phase, the goal at the design stage is to create adaptable structures. Planning processes can encounter obstacles such as stakeholder inflexibility or financial constraints that limit available responses. Whether creating tangible objects like buildings or conceptual constructs like policies, a focus on adaptability ensures the production of items that can be repurposed, expanded, or modified in times of stress. Adaptable objects are more likely to absorb the impact of stressors, recover from their effects, and readily reconfigure themselves to continue functioning and generating value.

The third component is management. Management encompasses a series of decisions and actions undertaken during normal and crisis situations that influence the current and future state of various community components. For a city to be competitive, agile management is essential, requiring the city to exhibit dynamism and consistency in capitalizing on opportunities and addressing challenges. Agility entails the system's capacity to identify climate changes, assess their impacts on the city

Table 3 Components of resilience assessment: system exposure and response capability

Types of stress	Ways to boost resilience	Examples
Resource stress	Exposure to and robustness against chronic stress from resources such as energy, water, and food	Implementation of resource-efficient technologies and sustainable resource management practices can enhance resilience
Societal stress	Social factors exacerbating the vulnerability of the system to chronic and acute stress	Ensuring equitable access to essential resources and diversifying risk distribution strategies can enhance resilience
Acute events stress	Susceptibility to and resilience against sudden shocks from catastrophes or other acute incidents	Implementing adaptation strategies and employing risk mitigation measures can enhance resilience
Learning foresight & self-organization	Capacity of the system to anticipate stresses, acquire knowledge from them, adjust and evolve in response, and exhibit self-organization when confronted with new challenges	
Interdependency	Interconnections and vital interdependencies at the system level among resources and other stress factors	Energy-intensive water sources
Structural resilience	Redundancy Modularity Requisite diversity	
Integrative resilience	Multiscale interactions thresholds social capital	
Transformative resilience	Distributed governance foresight capacity innovation & experimentation	

Source Albani et al. [26]. A pragmatic frame to explore resilience, 2014
Analysis Overall, the table emphasizes the significance of using a complete and integrated approach to increasing system resilience, considering many types of stresses, and employing multiple ways to boost resilience against each stress

and its goals, and proactively implement constructive measures to counter imminent stressors (when altering the trajectory of the stressor is not feasible). This includes considering cultural and process dynamics within the city and its physical features. Resilience, akin to sustainability, is an abstract concept, making it challenging to determine specific approaches for resilience planning [23].

Resilience planning necessitates the identification, refinement, protection, and management of resource and information flows within urban spatial and cognitive networks. To accommodate these complexities, a shift from focusing solely on planning urban products toward a more process-oriented approach is advocated, merging design with evolutionary, selective, generative, and adaptive functionality. Given the

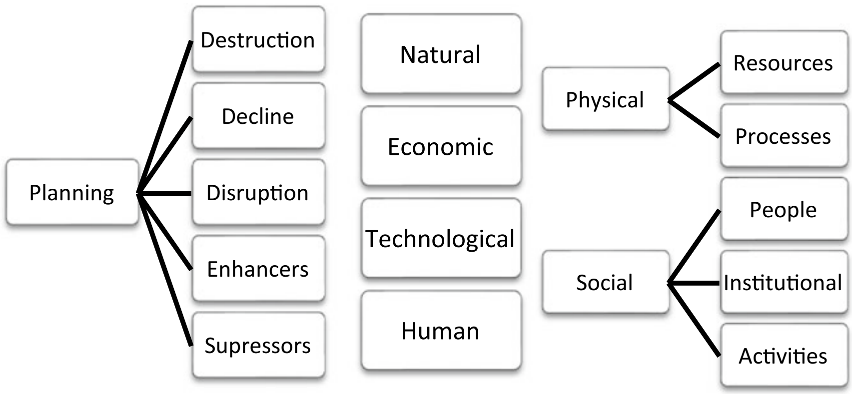


Fig. 1 "Designing, planning, and managing resilient cities: A conceptual framework" [23]

dynamic nature of relationships and interactions, particularly within the social realm, it becomes impossible to predict the optimal future when designing and constructing current built infrastructure, social institutions, or systems. The challenges of planning a complex system like a city extend beyond spatial considerations to encompass temporal dynamics as well. The notion of unknowability arises as a significant challenge, particularly concerning the current state of a system, as cities are open and therefore not bound by finite boundaries. Moreover, due to the intricate interplay of variables and interactions, planners face uncertainties in determining the effects of interventions. Finally, for resilience planning, it is crucial to recognize that there is no definitive and knowable future state that can be deemed optimal [24].

As per the research report "Advancing urban resilience in the face of environmental change" by S. Rajaratnam School of International Studies authored by [25], conceptualizing resilience is an essential but far from straightforward activity, and various sectors and actors have different assumptions about the concept, its characteristics and its requirements. However, it is critical that urban resilience contributes to development goals and enhances human protection by helping individuals, populations, cities, and states to adapt to environmental changes in urban areas. Identifying people and societies as beneficiaries of resilience building and human and community security as primary goals and rationales will help shape how resilience is described and sought. In other words, resilience could not be decoupled from development goals, but instead tried to strengthen them in complementary ways. Similarly, it is important to challenge the assumptions about resilience—and what it means to various stakeholders.

Urbanization brings with it shifts in natural environments, capital flows, populations, trends, individuals, livelihoods, and vital infrastructure. Such changes mean that resilience goals and approaches will inevitably be versatile, multidimensional, and dynamic, and guided by disciplines in the hard and social sciences. Given the complex nature of the situation, all stakeholders—from academics to policymakers to industry—must continue to foster resilience dialogue, both to understand future developments and to pool their experience in urban resilience building to create a stronger knowledge base for policymakers in the area. Engaging with the above segments in the resilience planning process is crucial to mitigating these situations, which can only be accomplished by far-sighted governance and resource mobilization. Cities often function at scales beyond their ecological and political capability, making it especially difficult to promote resilience. Handling the day-to-day management and governance needs of cities is becoming more complicated, often leaving no spare capacity to tackle longer-term resilience-building efforts. Responding to these challenges requires good leadership and participatory governance. Although these structures themselves pose difficulties by bringing many conflicting interests to the fore, they remain important for the creation of resilience mechanisms that will be embraced and accepted by relevant stakeholders. Spatial planning is a key field in which good governance is required to balance, on the one hand, the needs, and interests of a multitude of stakeholders with, on the other, the need to develop urban resilience to current and imminent environmental stresses. To be successful, the proposals must consider regional awareness and interests, the geographical limits and economic factors of the city and the evolving state of the environmental systems on which the city depends. In the first place, lack of good urban planning is the key cause of many environmental hazards and daily stressors in cities around the world. When designing responses to stressors and disasters, emphasis must be put on broad-based strategies that focus not only on costly engineering and infrastructure-oriented solutions, but also on the social contexts and root causes of stressors themselves.

To develop knowledgeable, scalable, and responsive governance structures, a carefully balanced combination of top-down and bottom-up processes, including checks and balances, will need to be developed. We need to expand through urban areas and beyond to the peri-urban and rural areas in which Asia's growing cities rely. This will help to promote medium-and long-term resilience while addressing the immediate and systemic needs of the most vulnerable regions [25].

In an increasingly uncertain and unstable world, business leaders are drawn to the idea of improving the stability of their economic structures. However, implementing this concept, particularly in a way that captures the complexity emphasized by resilience and complexity studies, proves challenging. Resilience, as an emergent property of complex systems in the face of uncertainty, is difficult to measure and forecast accurately. Adaptive capacity is crucial for resilience as it allows for quick adaptation to new opportunities, effective management of interconnected systems, and improved response to changing circumstances. While resilience is a very appealing concept in theory, converting it into practical applications sets a significant challenge. Simply resorting to traditional risk management approaches is not sufficient, as they may not fully incorporate the dynamic knowledge that a resilience assessment provides. Realizing this need, the Resilience Action Initiative (RAI) has developed a simplified framework that facilitates the practical implementation of resilience. This comprehensive framework, comprising five dimensions, has been successfully tested in various settings, including industrial clusters, cities, and large regions, offering valuable insights into the complex challenges of fostering resilience.

The framework considers the external stresses on the system, its interrelationships, and the system's capacity for learning and predicting. It helps in understanding the interaction of multiple actions and has proven valuable in exploring resilience challenges. Through a series of workshops, the framework's system elements have been tested and refined, resulting in a powerful yet straightforward approach to creating a resilient system. The framework includes the following "system elements" (Refer to Table 3):

1. Exposure to stresses: The horizontal axis focuses on the system's exposure to stresses, which are categorized as resource, societal, and acute events stresses.
2. Impact amplification: One element represented on the vertical axis examines how the tight coupling of the system's exposure to different stresses can increase the impact of individual stresses.
3. Resilience enhancement: The other element on the vertical axis looks at how the system can increase its resilience through foresight, learning, and overall adaptive capacity.

This framework enables a simple yet powerful way to analyze and develop resilient systems, providing a comprehensive understanding of the system's resilience issues. By considering external stresses, their interrelationships, and the system's capacity for learning and adaptation, the framework offers valuable insights into building resilience in various contexts [26].

The table below appears to enumerate several elements that contribute to system resilience, with specific examples relating to various types of pressures.

Recent literature stresses the need for a philosophy of resilience that helps policymakers to cope with equity problems. Resilience cannot be presumed to be the correct policy objective in the same manner as sustainable development [27] with a better quest for sustainable development being formulated, particularly as regards governance problems and possible solutions. The role of inclusive resilience is to explain the need for these questions at the moment when they are called upon to be realistic so that resilient structures can be built which lead to changes and are socially just and then important for global challenges in the field of sustainability [28].

The four aspects—subjectivity, integration, size, and change—have near interrelationships as a foundational perspective from the study. Subjectivities demonstrate how the way people perceive themselves, how environments, personalities, and social experiences are formed. The process by which subjectivities are discussed will be substantive inclusion. Equitable resilience must also cross scales to make radical improvements to the structure feasible, particularly in circumstances where adjustment by the populations involved is considered desirable. Every challenge is important, but the awareness of all four and their relationships is necessary to foster equality in the practice of resilience. To achieve equal resilience, it is important to define social structures covering these four aspects. Systematic problems need structural remedies, and change. In addition, achieving change involves strong, equitable government, spanning diverse forms of societies and taking various levels of authority into account. The observations analyzed by the authors confirm the concept of egalitarian resilience as considering control, subjection, or resistance issues; recognize and unite socially created vulnerabilities facing populations and individuals at all levels to prevent ineffective measures, whether based on disastrous reaction or growth.

Equitable resilience in action requires all four factors to be addressed by the approaches used to prove that individuals and institutions endorse or motivate others that are intended to benefit from ideologies, practices, or modes of legislation. Resilience and recognition of the potential to support and strengthen existing power-and-resource relationships [29]. The study indicates that a systemic study of subjectivities, the impact on the equity of inclusion, scale and the capacity for change is needed in coping with essential resilience. When resilience in policy and action becomes more widespread, exposure becomes more relevant to the needs for fair resilience. By extending resilience beyond the emphasis on utilities, defense and facilities, resilience would risk increasing instability and introducing new threats for timescale and spatial-distributed communities. Clearly placed, this means creating a durability that is beyond modification and addresses structural change. To foster fair resilience, government and professionals engaged with social, economic, and political transition policies will have to participate [30]. While this is a new and significant challenge, it's necessary and urgent. Equitable sustainability must be built into a program strategy, and it goes beyond merely taking parity into account while operating and distributing growth results, which brings them into the complexities of social systems even more thoroughly. In these middle-level social systems precisely defined concepts of scientifically measurable empirical resilience are flatter and priority needs to be directed to achieving equal resilience [31].

As global interest in resilience continues to grow, particularly in relation to climate change adaptation and other activities, it is imperative that concrete actions are taken to translate our knowledge of resilience into tangible improvements. The language used in disaster relief and humanitarian intervention must incorporate resilience, and infrastructure funding plans may also need to consider resilience requirements. Professionals in the field have a crucial role in ensuring that "resilience" goes beyond being a mere buzzword in mission statements and action plans and becomes a systematic perspective on how societies adapt to adversity.

Enhancing the capacity of populations to cope with severe weather conditions involves not only easily observable changes but also psychological and socio-ecological considerations. It is essential to engage local stakeholders from the outset through inclusive meetings and obtaining their buy-in, to ensure their full participation in the strategy, implementation, and evaluation processes. Practitioners can learn objective and creative approaches to achieve this through the insights provided by group resilience perspectives and accessible tools offered by organizations like the Resilience Alliance.

While these efforts may require additional time, energy, and complexity in development aid contracts, they are crucial for ensuring that initiatives aimed at promoting stability truly benefit the people they are intended to support and have lasting impacts beyond their duration [32]. Several key concepts are integral to the process of transforming cities into sustainable entities. Firstly, it is essential to emphasize the integration of knowledge in decision-making to effectively address the new social challenges of the twenty-first century. This integration represents a true reinvention of science, and the most effective way to achieve it is through practical application, learning, and testing. Secondly, public policy and successful decision-making play a crucial role in the sustainability agenda by mitigating the accumulation of systemic risks and avoiding potential "perfect storms". Risk and disaster managers have long been at the forefront of local sustainable development efforts, making it rational and realistic to frame city sustainability within the context of risk management. Thirdly, the comprehensive urbanization process holds the potential to determine the success or failure of the global pursuit of sustainable development. However, the current lack of a global critical mass of eco-city innovations poses a challenge. To address this, there is a pressing need to accelerate research and facilitate knowledge sharing through the study of existing case studies. The urgency of the sustainability transition necessitates finding ways to expedite these processes and learn from ongoing initiatives [33]. The paper published by Liu and others [34] mainly provides an operational framework to advance the quantitative evaluation of urban resilience and to further inform the urban social-ecological system's planning practice. This study investigates the relationship between land-based indicators and the capacity for resilience in urban environments, focusing on the spatial characteristics of urban resilience and its growth. It explores the interconnection between the structure, configuration, and dynamics of the urban landscape and the resilience of cities. The study establishes a close correlation between these factors, providing valuable insights into the understanding and assessment of urban resilience [35]. The urban landscape can be viewed as a complex system that encompasses the interactions between humans and the natural environment, providing valuable insights into the nature of urban systems. A well-planned distribution of ecosystems within this landscape plays a crucial role in mitigating risks and facilitating the swift recovery of the urban economy. Moreover, optimizing the sharing of the social-ecological environment, which includes land and encompasses social factors such as social institutions and social capital, along with the ecological landscape represented by natural or semi-artificial land, allows for the optimization of both social and ecological environments [36]. Furthermore, the adoption of urban landscapes facilitates the assessment, comprehension, and simulation of urban resilience by leveraging landscape ecology tools and methodologies. These tools, such as landscape metrics, enable the intuitive articulation of landscape characteristics. As a result, urban environments serve as effective platforms for shaping resilience capacity through human interventions. In essence, urban environments, which embody and are shaped by social-ecological interactions, offer a means of quantifying and operationalizing urban resilience that is both accessible and efficient [34]. As observed by Olazabal and Chelleri [20]. While cities have often been associated with negative environmental and social impacts such as pollution, segregation, and poverty, it is important to acknowledge that they also possess the potential and opportunities to become catalysts for positive change and transformation. Numerous researchers have emphasized that cities can serve as hubs for innovation, offering prospects for finding novel solutions and driving resilience. By harnessing their inherent capabilities, cities can pave the way for sustainable development and contribute to a more resilient future [20] found in a recent urban resilience workshop, that it is important to transform them gradually for the purpose of enhancing cities' resilience in lifestyles, services, infrastructure, workplace accessibility and institutional and business models. The transformation is spatial and social so that urban planners, politicians, and citizens must cooperate and engage [37]; in his paper Jabreen has established a new conceptual framework for resilient cities (Resilient City Planning Framework) that discusses the most important question of what cities and their urban populations can do to ensure that they become more resilient in the future (Refer to Table 4).

The Resilient City Planning Framework (RCPF) is characterized as a theoretical network encompassing interconnected concepts that offer a comprehensive comprehension of urban resilience. Within the Resilient City Planning System, there exist four guiding principles. Each principle comprises specific components that determine and evaluate their contribution to the overall system, as outlined in this paper. The cumulative contribution of observable components shapes the Urban Resilience system. While several measurement methods may already exist for certain components, future research should prioritize a comprehensive approach to measure all components. The resilient city framework, serving as a complex and non-deterministic phenomenon, represents a framework for urban resilience and community resilience, acknowledging the existence of structural complexities and uncertainties. The planning process involves a wide range of stakeholders due to its impact on multiple economic, social, spatial, and physical factors. It is important to note that the proposed RCPF is not a dynamic and versatile structure but can be modified in accordance with the fundamental concepts of the framework. According

Table 4 Resilient city planning framework

Resilience city transaction				
Component	Vulnerability analysis matrix	Uncertainty oriented planning	Urban governance	Prevention
1	Uncertainty	Adaptation	Equity	Mitigation
2	Informality	Planning	Integrative	Restructuring
3	Demography	Sustainable form	Economics	Alternative energy
4	Spatiality			

Source Jabreen [37]
Analysis Overall, the table demonstrates that developing urban resilience necessitates a multidimensional and integrated approach that includes risk assessments, uncertainty-oriented design, effective urban governance, and proactive prevention measures. Each component is related with various types of transactions that are required for resilience building. Cities may become more resilient and better suited to handle future shocks and pressures by employing an integrated approach that addresses each of these components and its accompanying transactions

5 Conclusions and Observations

From the above review of literature, various dimensions of Urban—Sustainability, Vulnerability, and Resilience were studied and can be summarized as follows:

- The world's urban population has experienced a significant increase, growing six-fold since 1950. Urbanization is intricately linked to sustainable development in economic, societal, and environmental dimensions. Carefully planned and managed urbanization can enhance employment opportunities and quality of life, reducing poverty and inequality. However, inadequate planning can result in congestion, higher crime rates, pollution, and inequality.
- The growing urban population poses additional pressure and stress on existing infrastructure and overall quality of life in cities. The emergence of the COVID-19 pandemic has caused unforeseen disruptions worldwide, highlighting the significance of calamities and their relationship with urbanization. With most of the global population residing in cities, addressing vulnerabilities during pandemics like COVID-19 becomes crucial. Revaluating the sustainability aspect of urban densities becomes imperative, as high densities can become counterproductive and even life-threatening during biological disasters.
- Natural disasters have the potential to cause significant loss of lives, property, and infrastructure damage. Developing nations with unplanned urban growth are particularly vulnerable to these disasters. Various stakeholders, including urban local bodies, state and national governments, civil society, and the private sector, play crucial roles in mitigating these risks. Raising awareness, enhancing resilience, facilitating preparedness, and effective response planning are essential in addressing the current challenges and ensuring a more resilient future.
- The concept of "Sustainable Cities and Communities" includes key dimensions such as environmental sustainability, cleanliness, and efficiency, as highlighted by the World Bank's Urban, Disaster Risk Management, Resilience and Land Global Practice (GPURL).
- Urban and rural communities worldwide are increasingly recognizing the need to address challenges and enhance resilience to poverty, inequality, social exclusion, violence, fragility, climate change, and disaster risks.
- City resilience refers to the capacity of cities, including the well-being of the poor and vulnerable, to function and thrive despite encountering various stresses and shocks. The relationship between ecosystems and cities is interconnected and influences the resilience of cities. Unplanned urban development poses threats to ecosystems, impacting the overall balance and resilience of cities [38].
- A conceptual framework proposed by [23] emphasizes planning, designing, and managing for resilience, providing a comprehensive discussion and analysis of important dimensions related to urban resilience.
- Resilience planning involves identifying, refining, protecting, and managing internal and external resource and information flows. Marshall [24] suggests a shift from planning the products of urbanism to focusing on processes, merging design

with evolutionary, selective, generative, and adaptive functionality. Unknowability, particularly the current state of a city as an open and evolving entity, poses the greatest challenge.

- Urbanization brings about shifts in natural environments, capital flows, populations, livelihoods, and infrastructure. Cities often face governance and management complexities beyond their ecological and political capacity, making resilience goals and approaches versatile, multidimensional, and dynamic.
- Business leaders find improving the stability of economic structures appealing, as resilience emerges in complex systems in the face of uncertain events. Adaptive capacity, enabling rapid leveraging of opportunities, managing interrelated systems, and responding to signals of change, is a key aspect of resilience.
- Resilience should not be automatically assumed as the correct policy objective, like sustainable development. A better understanding of governance problems and solutions is crucial for sustainable development and the pursuit of socially just changes. Subjectivity, integration, size, and change are interconnected aspects that form the foundational perspective of the study.
- The Resilient City Framework, a framework for urban and community resilience, involves multiple stakeholders and encompasses economic, social, spatial, and physical factors. It is important to note that the proposed Resilient City Planning System is not a static structure but can be modified based on the fundamental concepts of the framework.
- Building inclusive, resilient, competitive, and sustainable cities and communities is vital for achieving the Sustainable Development Goals by 2030, eliminating extreme poverty, and promoting shared prosperity at the local, regional, and national levels.

In conclusion, research on urban resilience framework highlights the critical importance of sustainable and resilient cities and communities. The rapid urbanization experienced since 1950 brings both opportunities and challenges. Properly planned and managed urbanization can enhance employment opportunities and quality of life, reducing poverty and inequality. However, inadequate planning can lead to congestion, crime, pollution, and inequality. The increase in urban population adds pressure on existing infrastructure, particularly evident in the wake of unforeseen events like the COVID-19 pandemic. Natural disasters pose significant risks, particularly in developing nations with unplanned urban growth. Awareness, resilience building, preparedness, and effective responses are vital for managing these risks. The interplay between ecosystems and cities influences urban resilience, with ecosystem preservation often undervalued.

6 Recommendations

Various conceptual frameworks provide insights into planning, designing, and managing for resilience, emphasizing adaptive capacity and the need for process-oriented approaches. Achieving inclusive resilience requires addressing governance issues and ensuring socially just transformations. The Resilient City Framework highlights the interconnectedness of governance, physical, economic, and social systems in defining resilient cities. Ultimately, building inclusive, competitive, and sustainable cities and communities is essential for achieving the Sustainable Development Goals, eliminating poverty, and fostering shared prosperity at all levels. Through comprehensive research and collaborative efforts, we can develop strategies and policies to create resilient urban environments that can thrive in the face of uncertainties and challenges, ensuring a sustainable and prosperous future for generations to come. Following are the suggestions and recommendations for developing more robust urban resilience frameworks for our future cities:

- Holistic Assessment: Develop assessment frameworks that evaluate not only physical infrastructure but also social, economic, and institutional dimensions of resilience. Consider both acute shocks and chronic stresses.
- Localized Strategies: Tailor resilience strategies to the unique characteristics of each city, accounting for its geographical, cultural, and socio-economic context. Avoid a one-size-fits-all approach.
- Education and Awareness: Invest in public education and awareness campaigns to foster a culture of resilience. Informed citizens are more likely to engage in preparedness and mitigation efforts.
- Inclusive Planning: Ensure marginalized and vulnerable populations are included in resilience planning. Addressing inequality is integral to enhancing overall urban resilience.
- Long-Term Vision: Resilience frameworks should extend beyond short-term goals and consider long-term sustainability. Incorporate scenarios for future challenges like climate change impacts.
- Collaborative Research: Encourage interdisciplinary research that combines expertise from urban planning, engineering, social sciences, ecology, and other relevant fields to develop comprehensive solutions.
- Monitoring and Evaluation: Establish robust monitoring and evaluation mechanisms to track the progress and effectiveness of resilience strategies. Flexibility in adapting strategies based on real-time data is crucial.
- Capacity Building: Invest in training programs to enhance the skills and knowledge of urban planners, policymakers, and stakeholders involved in resilience initiatives.

References

1. Gilbert A (1993) Third world cities: the changing national settlement system. Urban Stud 30(4/5):721–740. www.jstor.org/stable/43195971
2. United Nations, Department of Economic and Social Affairs, Population Division (UNDESA) (2019) World Urbanization Prospects: the 2018 Revision (ST/ESA/SER.A/420). UNDESA, UN
3. UNDESA (2020) Urbanization: expanding opportunities, but deeper divides. https://www.un.org/devUNDESA; Urbanization: expanding opportunities, but deeper divides. https://www.un.org/development/desa/en/news/social/urbanization-expanding-opportunities-but-deeper-divides.htmlelopment/desa/en/news/social/urbanization-expanding-opportunities-but-deeper-divides.html. Accessed 15 May 2020
4. Montgomery RM et al (2004) Cities transformed: demographic change and its implications in the developing world. Earthscan, London
5. Ghosh I (2019) 70 years of urban growth in 1 infographic. weforum. https://www.weforum.org/agenda/2019/09/mapped-the-dramatic-global-rise-of-urbanization-1950-2020
6. Zhang QX (2016) The trends, promises and challenges of urbanisation in the world. Habitat Int 54(3):241–252
7. Desai D (2020) Urban densities and the covid-19 pandemic: upending the sustainability myth of global megacities. Observer Research Foundation, ORF Occasional Paper No. 244
8. Bankoff GFHD (2004) Mapping vulnerability: disasters, development, and people. Routledge
9. Lankao PR, Qin H (2011) Conceptualizing urban vulnerability to global climate and environmental change. Curr Opin Environ Sustain 3(3):142–149
10. Gencer E (2013) The interplay between urban development, vulnerability, and risk management. Springer Briefs in Environment, Security, Development and Peace
11. Department for International Development (DFID) (2016) Revised protocol-Urbanisation and natural disaster. https://eppi.ioe.ac.uk/CMS/Portals/0/PDF%20reviews%20and%20summaries/Revised%20protocol-Urbanisation%20and%20Natural%20Disaster.pdf
12. World Bank (2020) Sustainable cities and communities. https://www.worldbank.org/en/topic/sustainable-communities
13. Chelleri L (2014) The urban resilience fallacy: gaps between theory and practice. https://ugecviewpoints.wordpress.com/2016/10/11/the-urban-resilience-fallacy-gaps-between-theory-and-practice/
14. Walker B, Salt D (2006) Resilience thinking: sustaining ecosystems and people in a changing world. Island Press
15. Alexander D (2013) Resilience and disaster risk reduction: an etymological journey. Nat Hazards Syst Sci 13:2007–2716
16. Rockefeller Foundation (2014) Akshay Urja climate proofing Indian cities: a policy perspective. http://www.indiaenvironmentportal.org.in
17. Nagargoje S, C. S (2019) Resilient cities: strategies & concepts from global best practices. In: EVF'19, 6th international conference on energy & city of the future—EVF'19, MIT Pune
18. Report TERI (2020) Climate resilient and sustainable Urban Development. Indiaenvironmentportal. http://www.indiaenvironmentportal.org.in/files/sustainable-urban-development-background-paper.pdf
19. Folke C (2006) Resilience: the emergence of a perspective for social–ecological systems analyses. Glob Environ Chang 16(3):253–267
20. Chelleri L, Olazabal M (2012) Multidisciplinary perspectives on Urban Resilience: a workshop report, Basque Centre for Climate Change (BC3), 78 pages, 67–75
21. Gupta AK, Singh S, Wajih SA, Mani N, Singh AK (2017) Urban resilience and sustainability through Peri-Urban ecosystems: integrating climate change adaptation and disaster risk reduction. Gorakhpur Environmental Action Group, Gorakhpur, UP
22. Tompkins E, Hurlston-McKenzie LA (2012) Public-private partnerships in the provision of environmental governance. In: Boyd E, Folke C (eds) Features of adaptive governance: networks, hybrids and multilevel transformations in coupled SES. Cambridge, p 2

23. Turner KFT, Desouza DM (2013) Designing, planning, and managing resilient cities: a conceptual framework. Cities 35:89–99
24. Marshall S (2012) Planning, design and the complexity of cities. In: Portugali J et al (eds) Complexity theories of cities have come of age. Springer, Berlin, Heidelberg, pp 191–205
25. Ewing JAG, Ewing AG (2013) Sustaining resilience. S. Rajaratnam School of International Studies. www.jstor.org/stable/resrep17172
26. Albani MR et al (2014) A pragmatic frame to explore resilience. In: Kupers R (ed) Turbulence: a corporate perspective for resilience. Amsterdam University Press, pp 37–47
27. Elmqvist T (2017) Development: sustainability and resilience differ. Nature 546(7658):352
28. Chelleri L, Waters JJ, Olazabal M, Minucci G (2015) Resilience trade-offs: addressing multiple scales and temporal aspects of urban resilience. Environ Urbaniz 27:181–198
29. Ensor JE, Park SE, Attwood SJ, Kaminski AM, Johnson JE (2016) Can community-based adaptation increase resilience? Climate Dev 10(2):134–151
30. Ensor JFJ, Ensor DM (2018) Bringing rights into resilience: revealing complexities of climate risks and social conflict. Disasters 42(4):S287–S305
31. Ensor JM, N. F. J, M. N (2019) Four key elements for putting resilience into practice. Stockholm Environment Institute. www.jstor.org/stable/resrep22984
32. Glandon DM (2015) Measuring resilience is not enough; we must apply the research. Researchers and practitioners need a common language to make this happen. Ecol Soc 20(2):27
33. Ciumasu I (2013) Dynamic decision trees for building resilience into future eco-cities. Technol Forecast Soc Chang 80(9):1804–1814
34. Xie Z, Liu C, Wang S (2019) Landscape-based assessment of Urban resilience and its evolution: a case study of the Central City of Shenyang. Sustainability 11. https://doi.org/10.3390/su11102964
35. Ahern J (2013) Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. Landsc Ecol 28:1203–1212
36. Cote M, Nightingale A (2012) Resilience thinking meets social theory: situating social change in socio-ecological systems (SES) research. Prog Hum Geogr 36:475–489
37. Jabareen Y (2012) Planning the resilient city: Concepts and strategies for coping with climate change and environmental risk. Cities. https://isiarticles.com/bundles/Article/pre/pdf/255.pdf
38. Foundation CRI (2014) Akshay Urja climate proofing Indian cities: a policy perspective. http://www.indiaenvironmentportal.org.in

Technology and Innovation in Process and Products

Framework for Module Identification in Construction Projects

Anikesh Paul, Abhishek Kumar, and J. Uma Maheswari

1 Introduction

1.1 General

The construction industry is the most customer-driven industry and the work is very chaotic in nature [1]. With the growth in the industry, new projects are coming up demanding increased complexity with reduced delivery time and cost. It has been observed that almost all construction projects, either simple or complex suffer from the delay during their project life cycle [2]. These delays may arise due to variation in scope, involvement of stakeholders who are not directly related to the project, delay in approvals, iterations in design process, wrong interpretation of scope, etc. [3, 4]. They create negative impacts on the project performance both in schedule as well as financial terms.

In construction projects, there are multiple interactions among different activities involved in the design phase of the project. These activities are sequentially executed in the conventional concept of project execution. Also, it is often found out that the constructability of the design is not considered thoroughly while carrying out the design process. For instance, the designer often lacks the knowledge regarding issues arising while erection or construction of structure. In situations where any change arises due to reasons which may or may not be in control of the design team, the entire design phase suffers, and a large amount of rework is carried out as a result of these changes. This heavily impacts the cost and schedule during the design phase, having a cascading effect on the entire project.

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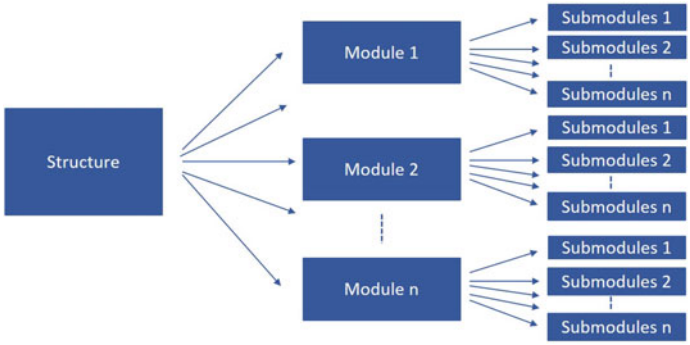

Fig. 1 Concept of module generation

1.2 Concept of Modularity

As defined by Erixon (1998), modularization is the decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific reasons. Modules are basically standardized units or exchangeable product parts with similar interface. The modules represent group of elements that should have a relatively high level of interactivity [5]. Modularity is an approach to manage the design of complex systems by partitioning and assigning elements of a complex to simpler subsystem according to a planned architecture as shown in Fig. 1.

There is a distinction between the developed modules and sub-assembly or parts of the system. A sub-assembly is often the result of the assembly planning activity and is restricted by the project structure i.e., it is not possible to perform the entire assembly in one flow because the product design does not permit to do so. This leads to the need of sub-assemblies which are assembled together to form the part of a system.

However, the modules are developed and chosen as a result of the careful analysis of the systems. Consequently, a sub-assembly is not always a module, but a module is often a sub-assembly [6]. The concept of modularization is to produce modules which can be worked on independently and which have minimum or no interactions with the surroundings. Using this approach, the concept of concurrent engineering can be utilized for project execution.

1.3 Research Gaps

Past literature has shown that tools like automation [7], standardization, and modularization [6] can help in managing the changes and assist the designers in executing the

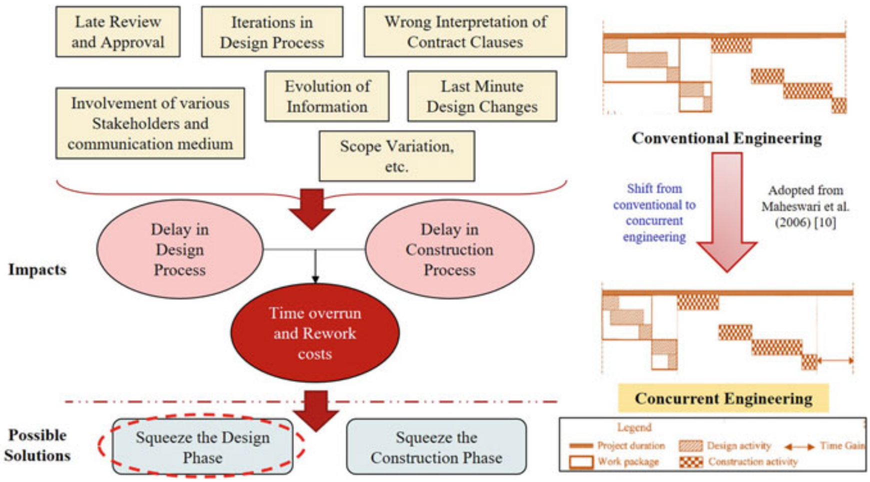

Fig. 2 Problems in conventional design-construction process and possible solutions

design process efficiently through squeezing either the design phase or the construction phase [8, 9] as shown in Fig. 2. Majority of these literature utilized automation for conceptual design and decision-making. So, there is ample scope for using automation to squeeze the design phase with the concept of modules, which acts as a prerequisite for the application of automation.

The concept of modularity (refer to sub-Sect. 1.2) is very popular in the manufacturing and part design sector [5], but there is very limited research in the application of modularity concept in the construction sector. Developed in early 1980s, DSM has proved to be a valuable instrument for capturing the interactions between multiple design domains and visualizing coupled or interdependent elements [10]. DSM is also a very powerful tool for decomposition and integration problems [11]. It has been mostly utilized for time-based studies for effective planning of construction projects [12]. Therefore, in this study, an attempt has been made to combine the concept of modularity and DSM to develop a framework to identify various design modules for simplifying the design phase (i.e., time and effort reduction).

Further, the paper has been divided into five sections—Sect. 2 deals with the motivation behind and objectives of this study, Sect. 3 introduces the case studies, its methodology, the data collection required, Sect. 4 consists of data analysis using DSM and development of module identification framework, Sect. 5 deals with testing of the proposed framework on separate projects, while Sect. 6 undertakes the discussions and conclusions related to this study.

2 Motivation and Objectives

2.1 *Motivation for the Study*

In order to bring out the problem more substantially, a preliminary analysis was conducted using data from three completed bridge projects (namely Mandovi River Bridge Project, DFCC bridge project package 15B and 15C). The bridges represent the top level of the intellectual capacity of the construction sector and the structural engineering field [13, 14]. Hence, a delay analysis study was performed on these projects. And, as shown in Fig. 3, all the projects were delayed due to reasons like delay in design approval, variation, and scope change, wrong interpretation of contractual clauses, delay in personnel appointment, etc., leading to a rework in the design process. This rework has some cost and time associated with it as seen in Fig. 3. Also, majority of these situations are directly related to design phase of a project. Therefore, it becomes evident to modify the conventional way of project execution to reduce the impact of these situations (refer to Fig. 2) especially in the design phase of a project.

2.2 *Objectives of the Study*

Based on the preliminary analysis and the research gap observed in this study, a framework shall be developed for identification of modules by thoroughly studying the design-construction process to manage multiple interactions occurring among the design activities. With the creation of these modules, the number of design iterations and rework shall be reduced, thereby reducing the time and effort consumption. The major objectives of this study are delineated below:

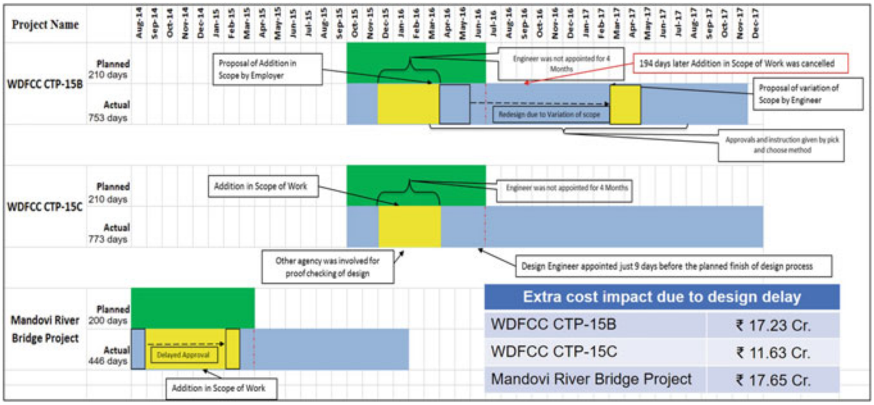

Fig. 3 Motivation for the study—preliminary analysis

- To study the design-construction process and capture the multiple interactions and interdependencies between various design activities.
- To develop a generic framework of module identification using DSM, and test the proposed framework to ensure efficacy.

To achieve these objectives, case study data from multiple bridge projects have been utilized. The proposed framework can be used to develop a sustainable design package architecture for all kinds of construction projects.

3 Case Study Information

Before delving into the case study methodology, it is necessary to have a brief outlook on the bridge construction projects and the scope of work considered in this study.

3.1 Bridge Construction Projects

For the case studies, only bridges with "Through type Steel Truss Superstructure with Circular Well Foundation" have been considered. Figure 4 represents a typical bridge schematic of this sort. The bridge components have been broadly categorized into three main areas namely, foundation, substructure, and superstructure for this study.

The design of bridges is generally carried out in two phases: conceptual design phase and detailed design phase. In the conceptual phase of the design the types of foundation, substructure, and superstructure systems are selected based on the various project requirements like economics, ground condition, number and length of span, discharge level, usage of bridges, etc. After this, the detailed structural

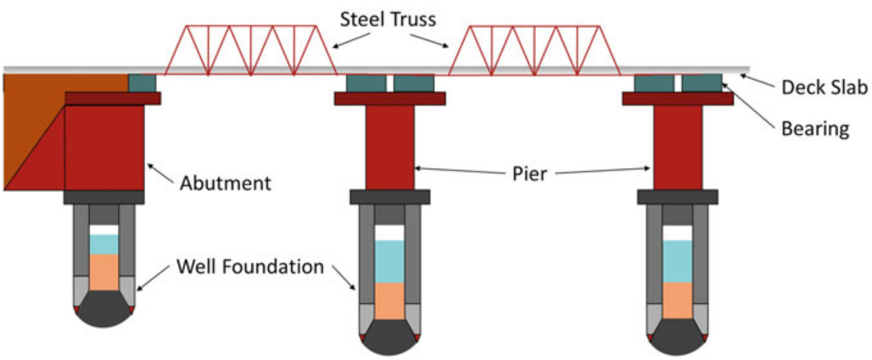

Fig. 4 Typical bridge project—steel truss type

design is carried out as the second phase of bridge design, to finalize the dimensions, materials, arrangement, and connection details of the bridge.

The construction methodology of the bridges is primarily dependent on the type of superstructure system, as the superstructure construction costs nearly 65% of the entire bridge cost. The availability of clear span, ground condition, traffic condition, availability of raw materials, and movement of construction equipment plays a crucial role in deciding the type of bridge superstructure construction methodology. Apart from this, expertise of contractor, schedule requirements, budget requirements, and owner's preference also play critical role in deciding the construction and erection methodology of the superstructure. Based on this importance, the scope of this study is limited to the design of superstructure portion of the bridge and the framework has been prepared accordingly (although it can be extended for all portions).

3.2 *Case Study Methodology*

The major objective of the study is to capture the interaction of the design-construction process and to develop and test a generic framework for module identification. Hence, a case study methodology was formulated for data collection and further analysis for achieving the objective of the study is depicted in Fig. 5.

The first step in the case study methodology is data collection from pilot case study. The three bridge projects (same as mentioned in the preliminary study in sub-Sect. 2.1) are utilized for this purpose. Upon required data collection, data analysis (sub-Sect. 4.2) shall be performed under four steps as shown in Fig. 5. They are identification of major design activities (Step I), decomposition of Design-Construction

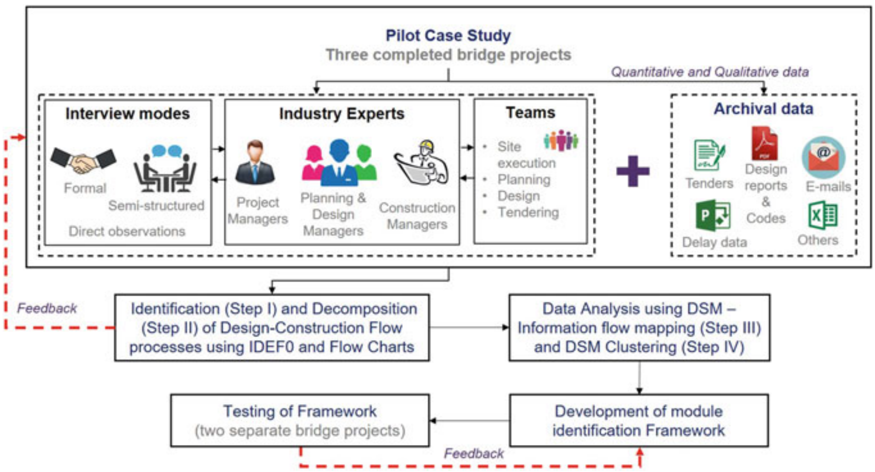

Fig. 5 Detailed case study methodology

flow processes using IDEF0 (Step II), information flow mapping in DSM (Step III), and DSM clustering cum module identification (Step IV). The pilot case study data have been used for the development of framework (refer to sub-Sect. 4.3) and further, two separate projects (involving different superstructure erection methodologies) have been used for testing and applicability of the proposed framework in Sect. 5.

3.3 Data Collection–Pilot Case Study

The data collection was done through three completed bridge projects of similar nature. Both qualitative as well as quantitative data were collected for this study, continuously for a duration of three months. Firstly, the documented data in the form of tender documents, design manuals, drawings, e-mail correspondence, change reports, design codes, delay data, and other archival reports were collected and analyzed (refer to Fig. 5).

Secondly, formal interactions and semi-structured interviews were conducted with various personnel (project managers, construction managers, project site supervisors, design managers, and planning managers) for decomposition and identification of the design-construction flow processes using IDEF0 and flow charts. Further, data analysis using DSM has been done for module identification and framework development in the following section.

4 Pilot Case Study Analysis and Framework Development

In this section, the data analysis of the collected data through DSM has been explained to develop the module identification framework.

4.1 Utilizing DSM for Module Identification

Before going into detailed analysis, it is imperative to understand how DSM can help in module development. Matrix-based methods have proved their prowess in handling multiple interactions and integration/grouping problems. Here, DSM-based approach is proposed for mapping the interactions among design activities and thus, identification of design modules. The design phase of the project can be first decomposed [15] into lower levels of activities. Tools such as flow charts and IDEF0 [16] can assist in proper decomposition of design phase.

Thus, it is possible to completely capture the design procedure and activity relationships with due consideration to every aspect related to the bridge design project,

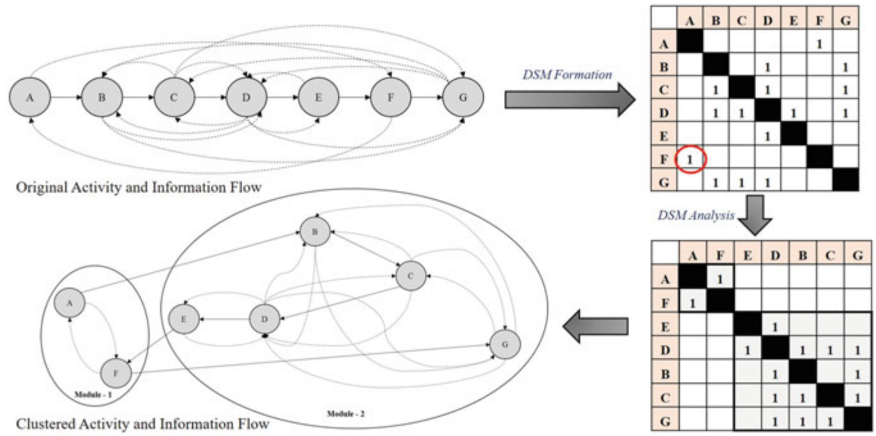

Fig. 6 Clustering of information flows for module identification using DSM

such as structural dependencies, constructability issues, interfaces between structural components, etc. These interactions and dependencies between activities can be mapped to develop the design matrix. The 1 s represent the dependency between any two given activities. For example, the arrow from A to F represents information transfer from activity A to activity F. This dependency has been represented in the DSM in the first column (highlighted in Fig. 6). The final design matrix obtained can then be partitioned to identify the clusters which are having activities with maximum interactions (shown in Fig. 6). These clusters can be used as modules and sub-modules for design activities. This module identification approach has been used to develop a detailed generic framework for the construction projects in the following sub-sections.

4.2 Data Analysis–Pilot Case Study

Based on the idea in sub-Sect. 4.1, the detailed analysis of the acquired data has been broken down into four major steps (mentioned in sub-Sect. 3.2) and each step is explained thoroughly in this sub-section. These steps lay the foundation for development of proposed framework shown in sub-Sect. 4.3.

Step I: Identification of Major Design Activities. After the appropriate data from pilot projects are collected, the first step is to identify the major components of the project and the design activities required for execution of those components. The entire design methodologies were studied to identify the role and influence of different design activities in the bridge design project. The viewpoint of the entire stakeholders involved in the design process was taken into consideration for capturing the data. During the conceptual design of the bridge, not all details are taken into consideration, once the project proceeds toward the detailed design phase all the three major components of bridge i.e., superstructure, substructure, and foundation are designed separately and exclusively. For example, in this study, the major design activities for bridge superstructure are survey, analysis, and finalization of superstructure type, selection of codal provisions, design assumptions, calculation of loads, determination of properties of all members, design of connection joints, etc.

Step II: Decomposition of Design-Construction Flow Processes Using IDEF0. During this step, an early involvement of the execution engineers for proper capturing of construction process may be fruitful in proper designing. This improves the constructability of the design developed and reduces rework eventually. The major design activities involved are linked to their corresponding construction processes and the entire flow is captured in this process using flow charts. All these processes provide input to one another and thus, feedback loops are also present among them.

The entire design of the bridge is thus decomposed into more detailed levels for better mapping of the interactions among various entities using IDEF0 in Microsoft Visio. The IDEF0 breakdown of complete bridge design is displayed in Fig. 7. A detailed analysis using flow charts and IDEF0 was done to identify the constraints, inputs, resources, and outputs for the different activities. These final obtained relationships and interactions were verified by the industry experts.

Step III: Information Flow Mapping in DSM. Upon complete verification of all the information flows, all the activities and relationships are mapped into Design Structure Matrix. For example, the design assumptions undertaken for dimensions of top chord of a bridge will influence the dimensions of bottom chord, lateral bracings, girders, connection joints and their respective design (the 1 s in column ‘f’ of Fig. 8 are highlighted in red). Also, the finalized design load will give information regarding the respective dimensions of the members of the superstructure (refer to the 1 s in column ‘e’ of Fig. 8). Similarly, the complete DSM obtained for the design of superstructure

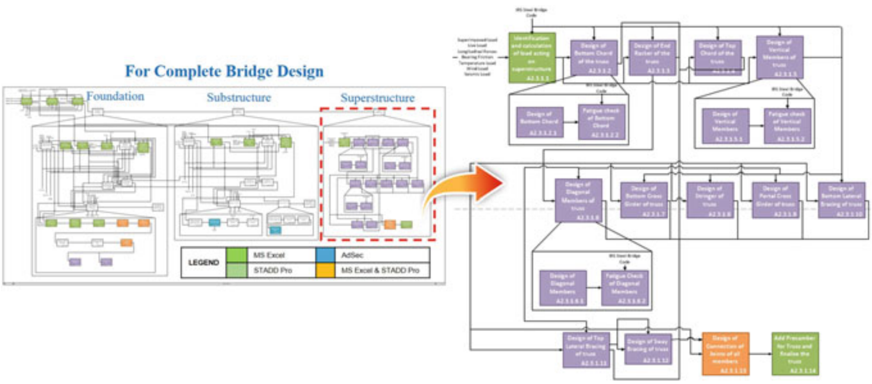

Fig. 7 Design-construction flow process decomposition using IDEF0

		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	aa	ab	ac	ad	ae
Topographic Survey Activities	a			1	1																											
Bathymetric and Hydrologic Survey Activities	b			1	1																											
Geotechnical Soil Investigation Activities	c				1																											
Making of Design Assumptions & Use of Codal Provisions	d					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Calculation of Loads on Superstructure	e						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
Determination of Dimension of Top Chord	f					1		1	1		1	1		1	1					1											1	1
Determination of Dimension of Bottom Chord	g					1	1		1	1	1	1	1				1		1												1	1
Determination of Dimension of Vertical Member	h					1						1									1										1	1
Determination of Dimension of Stringer	i					1		1					1				1						1								1	
Determination of Dimension of End Raker	j					1		1								1		1									1				1	
Determination of Dimension of Diagonal Member	k					1			1																	1					1	
Determination of Dimension of Bottom Cross Girder	l					1		1		1							1					1									1	
Determination of Dimension of Top Lateral Bracings	m					1	1								1														1		1	
Determination of Dimension of Portal Cross Girder	n					1	1																	1							1	
Determination of Dimension of Sway Girder	o					1	1				1							1							1						1	
Determination of Dimension of Bottom Lateral Bracings	p					1		1		1			1															1			1	
Determination of Dimension of Sway Bracings	q					1					1					1														1	1	
Design of Bottom Chord	r							1																								
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Design of Portal Cross Girder	w														1																	
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Design of Connection Joints	ad						1	1	1	1	1	1	1	1	1	1	1	1														
Determination of Precamber for truss	ae						1	1	1																							

Fig. 8 DSM for design of bridge superstructure

has been illustrated in Fig. 8 after considering all the interdependencies. Once the DSM is ready, the matrix is then partitioned using partitioning algorithm [17]. The first step of the algorithm is Topological Sorting, in which the DSM matrix is checked for empty rows and columns in order to arrive at the active matrix for further analysis.

Step IV: DSM Clustering and Module Identification. After the Topological Sorting is done, the next step is to identify the cycles or loops. For identification of loops, repeated process of power of adjacency matrix and condensation of the strongly related components is done as explained by Maheswari et al. [17]. At each step, the matrix is analyzed for identification of system activities which are activities that have interactions with almost all other activities in the system. In many cases, the system elements cannot be decomposed further and therefore they have a significant influence on the entire system activities. Since their influence is high, it is desirable to have these activities managed by the system organization that maintains interactions with all the design groups and have no stake in any single module. The system activities require special attention and thus are usually managed separately from the clusters as shown in Fig. 9. Finally, the condensed activities are represented in the block or cluster.

Once all the activities are condensed into clusters and the obtained active matrix has no upper diagonal marks then the resultant matrix is the partitioned matrix. These clusters identified are the modules generated through DSM. The partitioned DSM with identified modules is illustrated in Fig. 9. Further these obtained modules have also been broken down into smaller sub-modules for better analysis.

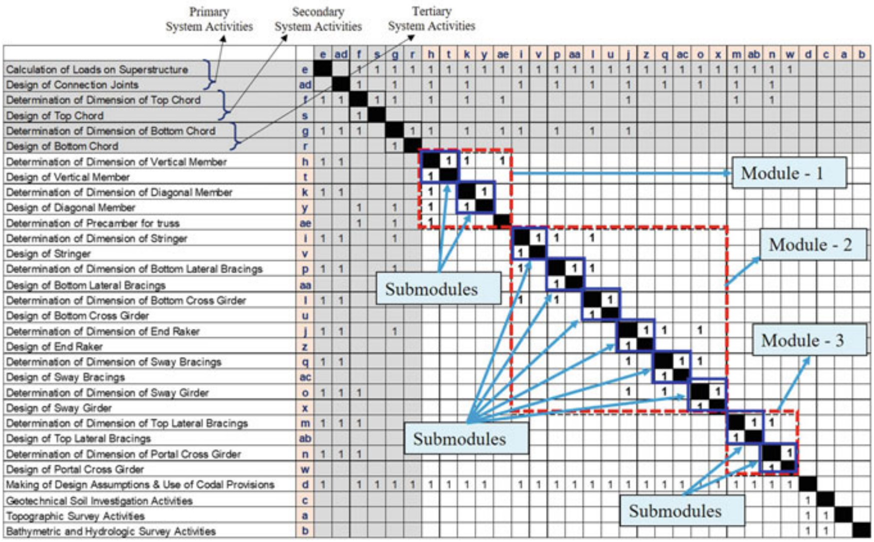

Fig. 9 Modules generated for design of bridge superstructure

4.3 Framework Development

The detailed steps discussed in sub-Sect. 4.2 have been combined along with the necessary checks and inputs from various sources to develop the proposed generalized framework for design module identification in construction projects. Figure 10 depicts the aforementioned framework.

The framework starts with the data collection from similar projects, then identifies the major design activities and the design-construction flow processes in the design

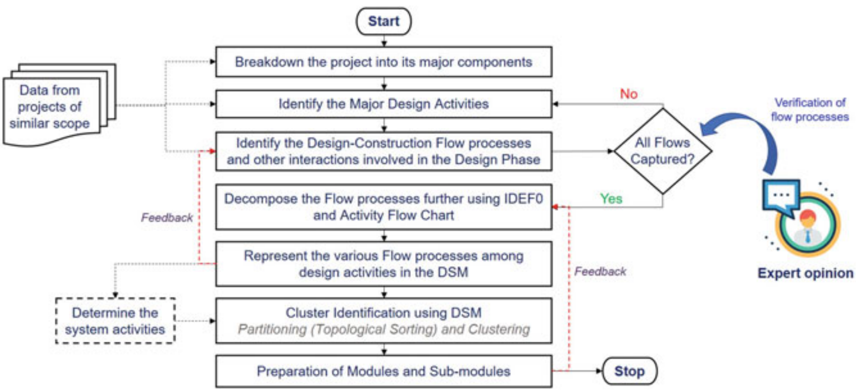

Fig. 10 Proposed generic framework for module identification

phase. This is followed by detailed decomposition of the flow processes using IDEF0, which shall be verified by the industry experts for further processing. These captured interdependencies shall then be represented in DSM for the partitioning process. The system activities shall be identified parallelly with the partitioning until final iteration. Finally, after cluster identification, the modules and sub-modules, if any, shall be identified. This framework has been further tested on two separate bridge construction projects, which are discussed in the next section.

5 Testing of Proposed Framework

Following the framework development, the testing of the framework has been done on two separate types of bridge projects in the state of Maharashtra, India and the results obtained are shown in this section.

Project 1: Streel Truss Bridge with Tandem Lifting Erection. The proposed framework was first tested for design of design-construction activities of bridges with construction methodology of tandem lifting erection for superstructure. In this methodology, the steel truss is lifted part-by-part and placed over the abutments by means of co-ordinated working of cranes. The design matrix developed along with the modules and sub-modules formed are displayed in Fig. 11.

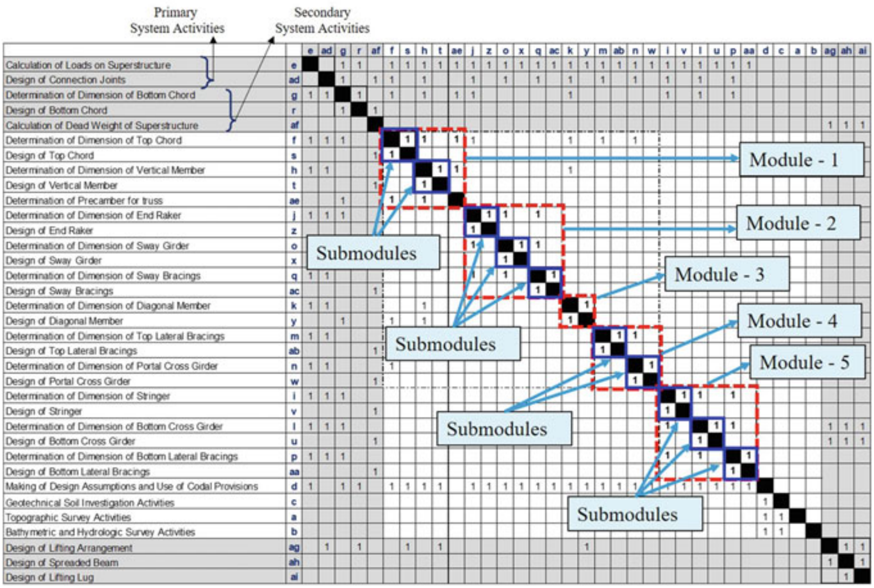

Fig. 11 Identified modules for design of superstructure activities—tandem lifting

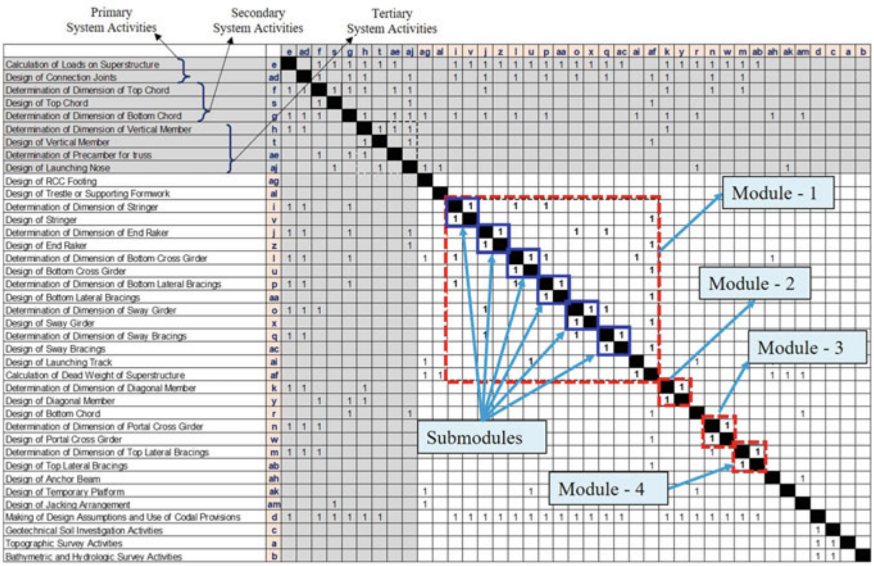

Fig. 12 Identified modules for design of superstructure activities—push launching

As evident from Fig. 11, upon application of the framework, three modules and several sub-modules are identified. Module 1 has been further broken down into two sub-modules and one allied design activity. Similarly, Module 2 has six sub-modules of two activities each. Further, Module 3 has two sub-modules of two activities each. Also, it is observed that some of the activities are neither a part of any cluster nor they are system activities. Those activities must be dealt with individually while carrying out the design of superstructure.

Project 2: Streel Truss Bridge with Push Launching Erection. Similarly, the framework was then tested for design of bridges with methodology of push launching erection. In push launching erection, the entire steel truss is pushed from one end of the abutment toward other abutment using launching nose, trestle, or supporting formwork and jacks. The testing of framework for identification of modules for this design package is illustrated here. The final DSM containing the modules and sub-modules formed in this case are displayed in Fig. 12.

6 Discussions and Conclusion

The basic objective of the study was to develop a framework for identification of modules by thoroughly understanding the interdependencies in the design-construction process. To get consistent and meaningful clusters, system activities in the DSM had to be excluded from the active matrix while partitioning. On careful examination, these activities can be identified by the large number of entries appearing along their rows and columns in the DSM. They can be generally treated as prerequisite to the design process. It was also observed that some of the interactions were outside the cluster which signifies that there were certain interactions present among different clusters.

This process of module generation requires a signification knowledge about the system, their activities and interactions. It is difficult to decompose and map the activities into the framework unless the user has a clear understanding of the activity and the system. Therefore, using this framework is highly advantageous if the process is carried out by a team of experts or users that have complete knowledge about the system. The results of the framework are majorly dependent on the decomposition of the design package and accurate capture of the interdependencies.

Flow charts and IDEF0 provide a rational approach for decomposing the work packages into design activities. They are capable of suitably capturing all the interactions between activities, their logics and sequence of execution. Better modules can be developed if fine granularity level data is utilized in the framework. The modules identified are primarily based on the relationships mapped by the user and the results may vary from one project to another.

The clusters (modules) in this study were identified taking into consideration the interactions among various design activities only, but it will be interesting to observe the behavior of clusters when the influence of different stakeholders and other interfacing design packages are also taken into consideration. The modules which are identified from the framework can be further developed into standardized design modules, which can be modified and used according to the project requirements. With the development of an integrated system of independent design modules, they can be used to manage of design phase smoothly (lesser time & effort consumption), cut down the time and cost spent on redesign/rework, and manage changes efficiently through concurrent engineering, thus promoting design sustainability.

References

1. Luo L, He Q, Jaselskis EJ, Xie J (2017) Construction project complexity: research trends and implications. J Constr Eng 143(7):04017019. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001306
2. Shah KJ, Apte MR (2015) Causes of delay in construction of bridge girders. IOSR J Mech Civ 12(1):08–12. https://doi.org/10.9790/1684-12140812
3. Chan DWM, Kumaraswamy MM (1997) A comparative study of causes of time overruns in Hong Kong construction projects. Int J Proj Manage 15(1):55–63. https://doi.org/10.1016/S0263-7863(96)00039-7
4. Lindhard S, Wandahl S (2014) Exploration of the reasons for delays in construction. Int J Constr Manage 14(1):36–44. https://doi.org/10.1080/15623599.2013.875267
5. Erixon G, von Yxkull A, Arnstroem A (1996) Modularity—the basis for product and factory reengineering. CIRP Ann Manuf Technol 45(1):1–6. https://doi.org/10.1016/S0007-8506(07)63005-4

6. Erixon G (1998) Modular function deployment—a method for product modularization. Royal Inst. of Technology, Department of Manufacturing Systems, Assembly Systems Division. ISBN 9925736056, 9789925736058
7. Moos S (1957) The scope of automation. Econ J 67(265):26–39. https://doi.org/10.2307/2227629
8. Eppinger SD (1999) Model-based approaches to managing concurrent engineering. J Eng Des 2(4):283–290. https://doi.org/10.1080/09544829108901686
9. Loch CH, Terwiesch C (1998) Communication and uncertainty in concurrent engineering. Manage Sci 44(8):1032–1048. https://doi.org/10.1287/mnsc.44.8.1032
10. Maheswari JU, Varghese K, Sridharan T (2006) Application of dependency structure matrix for activity sequencing in concurrent engineering projects. J Constr Eng 132(5):482–490. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:5(482)
11. Yassine A, Braha D (2003) Complex concurrent engineering and the design structure matrix method. Concurr Eng 11(3):165–176. https://doi.org/10.1177/106329303034503
12. Padala SS (2022) Application of axiomatic design and design structure matrix for early identification of changes in construction projects. J Inst Eng (India): A 103(2):647–661. https://doi.org/10.1007/s40030-021-00612-2
13. Biswas M, Welch JG (1987) BDES: A bridge design expert system. Eng Comput 2(3):125–136. https://doi.org/10.1007/BF01201260
14. Miles JC, Moore CJ (1991) An expert system for the conceptual design of bridges. Comput Struct 40(1):101–105. https://doi.org/10.1016/0045-7949(91)90462-U
15. Maier JF, Eckert CM, Clarkson PJ (2017) Model granularity in engineering design–concepts and framework. Des Sci 3. https://doi.org/10.1017/dsj.2016.16
16. Presley A, Liles DH (1995) The use of IDEF0 for the design and specification of methodologies. In: Proceedings of fourth industrial engineering research conference, Nashville
17. Mujumdar P, Bhattacharya S, Maheswari JU (2015) A study on DSM partitioning through case study approach. In: Proceedings of ICoRD'15–research into design across boundaries, vol 2. Creativity, Sustainability, DfX, Enabling Technologies, Management and Applications, pp. 653–662. https://doi.org/10.1007/978-81-322-2229-3_56

Impact of Implementation of Robots and Automation in Indian Construction Industry

Sumit Raj and Taqdees Anjum

1 Introduction

India is the seventh-largest country in the world, yet it has a poor track record of finishing major projects [1]. Due to the development and expansion of infrastructure in a developing country like India, the building industry may find it necessary to transition from traditional to innovative construction processes to improve performance and efficiency [2]. Although the way building projects are managed has not changed significantly throughout the years, the stakeholders, resources, competition, and customer demands are all continually changing. As a result, there is a gap in management philosophy between how construction projects are now handled and how they can be managed to increase efficiency [3].

Productivity has been one of the most researched topics in the Indian construction industry over the past few decades. The project may be impacted by elements that have an immediate or long-term influence on productivity; certain factors could only have an immediate effect but lead to further effects. Numerous elements contribute to productivity, including labor, money, facilities, infrastructure, machinery, and more. Several studies in different countries have been carried out to identify the factor impacting worker productivity [4].

One of the most promising approaches to boost productivity is to automate some portions of the building process. Naturally, there are a variety of ways to do this, such as an increase in the use of cross-functional teams in construction projects where the

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emphasis is on absorbing and utilizing the most latest Technology [5]. The construction industry is a well-known industrial sector worldwide because of its significant economic productivity and significant social value. But the industry has long been known for its inefficiency and low output. The industry also still demonstrates a low level of automation and digitalization when compared to other sectors [6]. The main obstacles to the deployment of robots in the building construction industry are both the flexibility of construction operations and the complex conditions of the construction environment [7].

According to information from government and industry sources, projects frequently experience cost and time overruns of 20–25%. Resource waste has been identified as one of the key reasons of inefficiency. Aside from a major increase in recent years, the demand for specialists and contractors continues to surpass supply by a wide margin. It is possible that the outdated methods utilized in the Indian construction industry won't be sufficient to fulfill the needs of this dynamic environment because they have produced considerable inefficiencies. The use of innovative project management and procurement techniques can help achieve the required goals as well as provide value [8].

Building now demands quicker, more precise, and economical methods to create progressively more complex designs. It incorporates planning to fit the diverse demands and requirements of the structures, flexible automation, and computer-assisted engineering. At this moment, robots appear on the scene. Robots are able to complete complex tasks on their own under severe conditions without using a lot of human resources. Some of the several types of robots employed to carry out particular building activities include: [9]

- Demolition robots
- Brick laying robots.
- Welding robots
- Exoskeletons
- Surveying and inspection robot (Boston Dynamics' Spot mini)
- Humanoid robot (HRP-5P)
- Laser leveling, Screwing, milling, plasma cutting, material handling, site monitoring, painting, and marking robot (Baubot)
- Robots for indoor works like painting, plastering etc. (OKIBO)
- Ceiling installation (JAIBOT HILTI)

1.1 List of Type of Robots Available in the Construction Industry

Tables 1 and 2 The objective of this paper is to discuss about how implementation of robotics and automation will impact Indian construction industry in terms of cost, quality, time, and productivity as well as impact on the environment, employment, and economy of India.

Table 1 Robots available and their descriptions

Sr. no	Type of robot	Description
1	Demolition robots	Robotic demolition is a type of huge equipment. When it is time for fresh construction, their primary purpose is to demolish structures. However, these robots also do a variety of other tasks. Robotic demolition is a common practice in the construction industry, both for evacuation and demolition. They are necessary for moving heavy objects from the ground floor to the upper stories. Robots used for demolition currently account for 90% of the robotic construction market. There is constantly more demand for such devices. As their implementations increase in quantity, they could even capture more of the market [10]. The advantages include that they are resistant to heat, incredible power, and a system with three arms. They possess a few disadvantages which include that the robots can be operated with training and the right professionals. Two types are available in this kind of robots in the industry namely DXR 310 and DXR 140 [11]
2	Bricklaying robots	Robots that lay bricks, blocks, or other building materials are called "bricklaying robots," and they are employed in the construction sector. These machines may operate constantly without stops or relaxation, being programmed to build bricks in a specified sequence. The majority of these machines come with a range of sensors and cameras that enable them to precisely measure and place bricks, assuring a high degree of precision and accuracy in the final structure. They can also operate considerably more quickly than human bricklayers, which can drastically cut down on the time and expense involved in constructing brick-based constructions. The advantages include increased productivity, accuracy, improved safety, and labor costs are saved. The cons include lack of human touch, high investment, and limited flexibility [12]. The types of brick laying robots available include SAM 100, Hadrian X [12]
3	Welding robots	Manual welding is only appropriate for shorter durations due to the time-consuming preparation process, discomfort suffered by the operator, safety issues, and cost. Construction must consequently use robotic welding to create better-quality welds faster. The majority of human mistakes are eliminated by robots, increasing output, quality, and cost effectiveness. It is easily maneuverable in confined places and welds precisely. The pros of using this robot include waste reduction, quality work and increased productivity. The cons of the robot include proper training for use and high investment [13]
4	Plastering and painting robots	Construction robots that perform plastering and painting tasks have the potential to boost production and efficiency in the building sector. The plastering and painting of walls, ceilings, and other surfaces can be automated by these robots, which will save time and labor. These robots can optimize the quantity of plaster or paint needed for each surface by using innovative technology such as sensors and algorithms, leading to a more exact and uniform finish. Furthermore, the employment of robots for plastering and painting might reduce the possibility of physical stress and harm to employees, enhancing overall health and safety in the construction industry. [14]

(continued)

Table 1 (continued)

Sr. no	Type of robot	Description
5	Exoskeleton	The exoskeleton is yet another cutting-edge robotics breakthrough used in construction. This mechanical gear can boost the strength, speed, and agility of the average worker. Because of it, each employee can lift and carry heavier objects than the average individual

Table 2 Comparison table of construction robots

Name of robot	MULE (Material unit lift enhancer)	Autonomous finishing work robot	PICTOBOT—PBA 300 (Painting robot)	SAM 100 (Bricklaying robot)
Name of company	Construction robotics	OKIBO	Transform robotics	Construction robotics
Productivity	2 × faster	3 × faster	4 × faster	6 × faster
Price	$ 75,000	NA	NA	$ 5,00,000
Cost impact	NA	50% reduction	NA	NA
ROI	90 days	NA	NA	NA
Operator required for execution	NA	1 person	1 person	5 people (mortar mixing—2, brick fed—2, operating machine—1)
Benefits	Reduces fatigue Reduces injuries	Enhanced quality safer work environment	Even & consistent thickness Low paint dust Long hour of operation even in dark	Lower health & safety concerns Can work side by side with the mason

(*Source* Respective official websites)

Some theoretical and practical implications of this research are:

- It will solve the shortage of skilled manpower in the industry.
- It will reduce the accidents, and physical injuries while working on the building projects.
- It will help the construction industry to cut down the wastage, rework and operation costs.

2 Literature Review

The building sector has a substantial influence on India's overall economic growth. The construction industry is the second-largest employer in India. Over the past 50 years, building has accounted for more than 40% of the nation's development expenditures. About 16% of India's working population is supported by the construction sector. It contributes a little over 78% of the total capital production. The importance of the Indian construction industry is emphasized by the impact it has on employment, links to other sectors, and GDP, as well as the possibility that any more inefficiencies could speed the nation's eventual demise [15]. The trends in India's employment development do not provide a promising picture. The yearly rates of employment growth from 1999–2000 to 2004–05, from 2004–05 to 2009–10, and from 2009–10 to 2011–12 have been, respectively, 2, 0.7, and 0.4%. The manufacturing, information technology, and construction industries all saw significant declines between 2013–14 and 2015–16, according to a study using a range of data sources.

This period has seen a major substitution of capital for labor, but there has not been a corresponding reduction in GDP growth. It is clear that this phenomenon of negative employment growth might continue; as robotization spreads throughout the Indian economy, the severity of the country's already-negative employment growth rate could worsen [16]. Even with all of these statistics, it is clear that many industries, particularly the construction industry, have been working to use technology to produce better end results that would save time, improve quality and safety, and work to lower the carbon emissions produced by the building industry. According to recent research, the construction industry is attempting to automate, mechanize, and/or robotize building processes in order to accomplish them more rapidly and for less money overall. Automation may result in improved working conditions, a reduction in risky employment, and the ability to do activities that people are unable to complete. Because of this, the approach of mechanization and automation has been demonstrated to be more dependable in terms of cost, time, and quality in many aspects. Robotics describes the use of a single piece of flexible multi-axis equipment that can perform a range of tasks on its own. As a result, the idea of mass customization may be applied to the production process [17].

Robots can make a construction project go more quickly, they reduce the number of accidents, they are never bored, and they can essentially perform various tasks round-the-clock. Comparatively speaking, robot-produced goods are more precise and of a higher quality than those manufactured by trained humans. Automation may save costs, increase production and efficiency, and free up employees to engage in riskier activities elsewhere. Robotics enhance working conditions by preventing workers from taking on unfavorable roles. The construction industry is slow and boring, but by incorporating robotics into the process, they may prevent project delays and reduce the overall cost of building [18].

The construction industry is known to have a significant impact on the environment due to the large amounts of materials and energy used during construction, as well as the pollution generated by construction sites. The construction industry is thought to be one of the primary global contributors to environmental deterioration. Construction is not an environmentally friendly activity by nature. This is valid for the entire environmental impact chain, starting with the material supply and extending to the resources utilized. Its consequences on the ecosystem are now quite significant. The building sector is responsible for around half of the world's solid waste production, 20–50% of the consumption of natural resources, and half of the carbon emissions. The majority of this occurs when the system is in operation, which has a significant detrimental impact on the environment. The construction sector has a considerable influence on the environment and the resources that are available. By contaminating the air, land, and water, it also endangers the ecosystem. As a result, it is imperative that this injury be minimized [19]. However, the use of robotics in construction can help mitigate these impacts by promoting sustainability and reducing waste. For example, robotics can be used to optimize energy consumption during construction, reducing the carbon footprint of the building process. Additionally, robotic equipment can be electrically powered or run on alternative fuels, reducing the amount of pollution generated on construction sites. This can help to reduce the overall environmental impact of construction projects.

When talking about construction automation, it's important to take robotics applications and the potential for deploying robots to ease jobs that people have traditionally performed into consideration. Investors are putting millions of dollars into developing construction robots. Due to these robots, the construction sector will become more productive. The "SAM 100" robotic device from the firm "Construction Automation" was recently released. A "Semi-Automated Mason" robot is believed to be capable of laying more than 2000 bricks every day, as opposed to a human who may only lay 400 bricks per day. The "SAM 100" brick-laying robot is the first of its kind to be made available for purchase, and it guarantees to speed up labor and enhance revenues wherever it is used [18].

Construction industry challenges, such as falling quality and productivity, labor shortages, a lack of workplace safety, and unfavorable working conditions, have highlighted the need for creative solutions within the industry [17]. However, the use of robotics in the construction sector could also bring about a number of issues and drawbacks, such as the high costs and financial commitments required to acquire and maintain the technology, the fragmented nature of the sector, which prevents the adoption of novel technology, the difficulty of understanding and utilizing the technology, and its incompatibility with current building practices and procedures. Due to contractors' inability to properly integrate automation into their projects due to a lack of expertise and knowledge, the construction sector has found it difficult to adopt robotization [17].

When robots outperform conventional production using humans and machines as close complements, it would be realistic to expect capital shifting from the conventional sector to the robotized sector due to Greater Returns. The workers in the traditional industry will suffer as a result. It would be logical to anticipate that companies cutting off workers will result in a severe recessionary trends. In a version of our story where the increase in aggregate demand brought on by a decline in the relative prices of the items produced by robotizing sectors is surpassed by the recessionary impact of technological unemployment, it is extremely plausible that aggregate demand would decline as workers are laid off. Consequently, there is an increase in unemployment. Because they could meet all of their needs and those of the fewer hired workers by using only robots and some traditional machinery, capital owners might allow the majority of their investment in traditional systems to become obsolete, which could cause the economy to become stuck in a downward spiral.

We can predict with some degree of certainty that human employees will suffer severely when robotization spreads from one industry to another, as this process will take time to complete and be accompanied by search unemployment. Additionally, it's feasible that a decline in personal income will occur concurrently with the real loss of human capital [16].

Some academics have investigated the impacts on cost, productivity, and timeliness as a result of the application of robotization in the construction sector after reading numerous research papers, journals, and publications. But nobody has directly addressed how it would affect the Indian construction sector, and no research has been done on how it will affect quality, productivity, employment, health, safety, the environment or India's economy. Therefore, I am conducting this research to close this gap, and my goals are:

- Impact on Local Level i.e., Cost of project, Time of Project, Quality of Work, and Productivity of Work.
- Impact on Society i.e., Employment, Health, and Safety of labor.
- Impact on Environment.
- Impact on Economy of India.

3 Data Collection and Analysis

After the various papers were studied based on how robotics would impact in the construction industry and its positive and negative effect, we move forward in the research to find out how robotics has impacted the construction industry based on various attributes and the current status, its challenges and drawbacks at present. The research methodology adopted for this has been summarized in the given flowchart (Fig. 1).

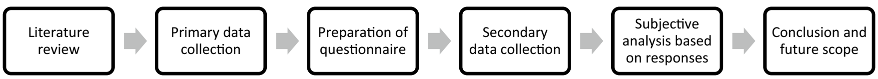

Fig. 1 Flow chart of methodology

3.1 Data Collection

- **Primary Data Collection**—It would be helpful to examine and assess the opinions of skilled experts on the potential effects of construction robots on productivity, cost, time, quality, employment, health and safety, environment, and economy. It also assists in determining the existing level of automation, barriers, and potential uses. A questionnaire was prepared with the questions related to the attributes based on the use of the Likert scale where experts had to rate their answers and the other questions were subjective. The target audience would be the experts and professionals from the construction industry of various kinds of organizations irrespective of their familiarity with robots and automation of all age groups.
- **Secondary Data Collection**—In this, we will calculate productivity, saving in time and saving in cost with the help of data available on the relevant manufacturing company. It will be carried out by contrasting the use of physical labor with currently available construction robots for the same tasks. The following data written in the table was obtained from relevant and trusted websites:

3.2 Data Analysis

Based on the responses obtained from the questionnaire, the following findings were inferred, and analysis of these responses was given:

- **How familiar are you with the use of robots and automation in the construction industry?**

This indicates that even while the usage of robots in the construction business may not be well known, there is increasing knowledge of this technology inside the sector. These results offer crucial perceptions into the knowledge and beliefs that exist now regarding the usage of robots and automation in the construction industry, and they may have implications for how this technology is embraced and incorporated into the sector in the future (Fig. 2).

- **How the use of robots and automation in India will impact on:**
  - **Productivity**

These results imply that while if the use of robots in the construction industry may increase productivity for many workers, there may also be certain difficulties or restrictions to take into account. Overall, the information indicates the possible advantages and disadvantages of using robots in the construction business, which may have an impact on how this technology is embraced and incorporated in the future.

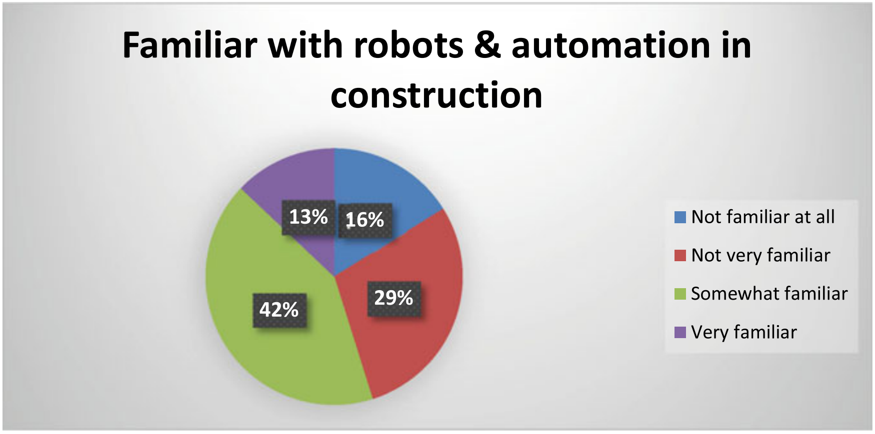

Fig. 2 Familiarity with robots and automation in construction industry (*Source* Author's computation)

– **Cost**

These results imply that the effect of robot implementation on project cost varies and may depend on a variety of factors, including the type of construction project and the particular jobs that robots are utilized for.

– **Speed**

These results indicate that the use of robots in the construction industry may speed up projects, but there may also be certain restrictions or difficulties to take into account. The findings of this study might have an impact on how robots are used and integrated in the construction sector in the future, particularly in terms of enhancing project schedules and construction process efficiency.

– **Quality**

These results show that even while using robots in construction has the potential to increase project quality, there may be certain restrictions or difficulties to take into account. Overall, the data offers insightful information on how robots affect the quality of building projects, which might have a considerable influence on how this technology is applied in the future (Fig. 3).

– **Health & Safety**

These results show that even if using robots in construction has the potential to increase worker health and safety, there may be certain restrictions or difficulties to take into account. The results provide critical light on how robots affect employees' health and safety in the construction sector and might have a major influence on how this technology is applied in the future.

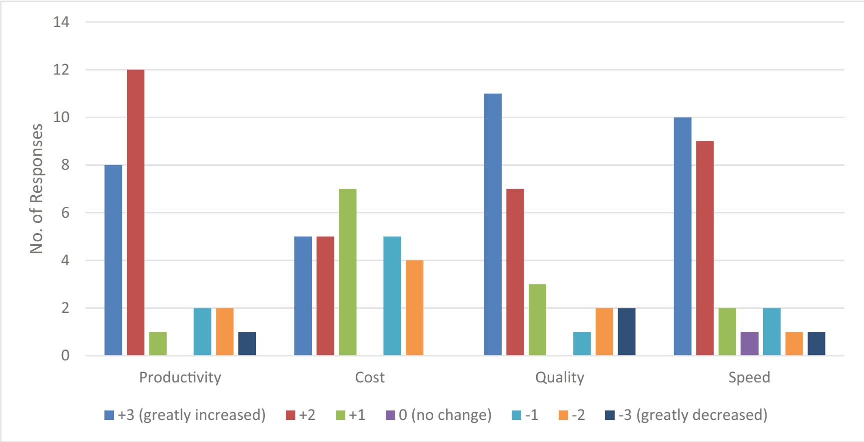

Fig. 3 Responses for attributes include productivity, speed, cost, and quality (*Source* Author's computation)

– **Employment Opportunities**

These results imply that the employment of robots in the construction sector may have an adverse effect on job chances for employees, with fewer positions available as a result of the growing use of automation. The information emphasizes the possible negative effects of robot adoption in the construction sector, particularly with regard to employment possibilities, and might have an impact on how this technology is implemented.

– **Investment in research and development of construction technology**

The general pattern indicates that increased investment in technological development has resulted from the use of robots in the construction industry. This is perhaps because modern technologies, like robotics, are frequently implemented together with a greater focus on technological advancement.

– **Demand for Skilled Labor**

These results imply that although the use of robots in the construction industry may have some positive impacts on the need for skilled labor, it may also have adverse effects. It is significant to highlight that the effect on the need for skilled labor may vary based on the individual jobs and processes that are automated as well as the industry's overall level of technological innovation (Fig. 4).

– **Demand for Unskilled Labor**

These results imply that the use of robots in the construction sector may negatively affect job chances for unskilled employees. There may be fewer chances for unskilled people who lack the technical expertise to operate and maintain this equipment as more operations are automated.

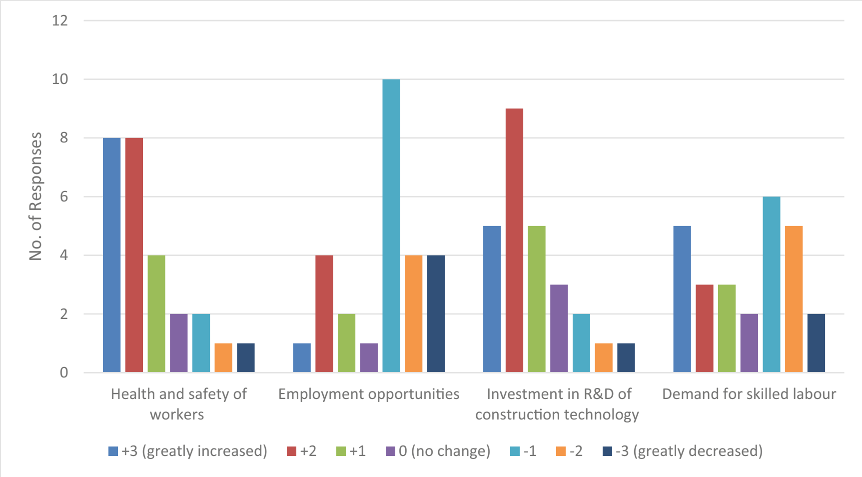

Fig. 4 Responses for attributes such as investment, health and safety, etc. (*Source* Author's computation)

– **Demand for management and supervision roles**

These results imply that the use of robots in the construction industry may have conflicting effects on the need for management and supervisory positions. This could be a result of the industry's evolving character as it adjusts to innovative technology, with certain positions becoming more crucial while others lose significance.

– **Demand for engineering and technical roles**

These results imply that the use of robots in the construction industry has increased demand for technical and engineering positions. There is a growing demand for personnel with technical skills and knowledge to manage and maintain these machines as industry embraces new technologies and procedures.

– **Demand for IT and digital roles**

According to the findings, the use of robots in construction has shifted the sector toward one that is more technologically advanced, opening up new employment chances for those with IT and digital skills. As the construction sector continues to incorporate and integrate new technology, it is projected that this tendency will persist (Fig. 5).

– **Energy consumption in construction project**

These results imply that the use of robots in construction may have conflicting effects on energy use. The increasing use of machinery and equipment needed to run and maintain the robots as well as the energy needed to power the robots themselves may be too responsible for the increased energy consumption that some respondents

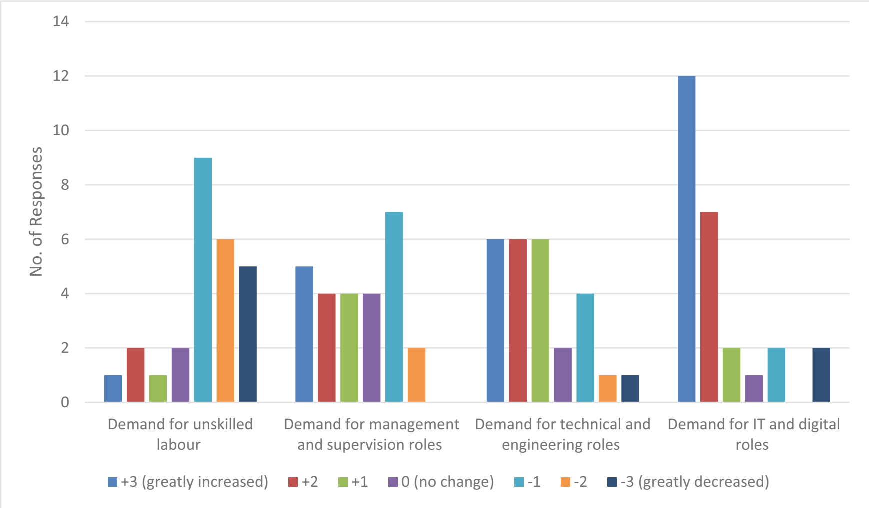

Fig. 5 Demand for different roles (*Source* Author's computation)

noted. The greater efficiency and precision that robots may provide, however, might result in more optimized and streamlined building operations, therefore respondents who claimed a drop in energy use may be experiencing this as a result.

– **Overall Environmental health in India**

The evidence suggests a potential benefit of using robots in the construction sector for India's overall environmental health. It is crucial to remember that the adoption of robots may have an indirect effect on environmental health and depends on a number of variables, including the precise jobs and processes that are automated and the energy sources utilized to power the robots.

– **Adoption of sustainable practices**

These results imply that the adoption of sustainable practices has been positively impacted by the use of robots in construction, with many respondents indicating an increase in sustainable practices as a result of the employment of robots. This may be as a result of the higher efficiency and accuracy that robots can provide, resulting in more streamlined and optimized building operations that minimize waste, lessen their impact on the environment, and encourage sustainability.

– **Wastage of material and resources**

These findings imply that robots are being utilized to maximize material utilization, decrease waste, and promote more environmentally friendly and sustainable construction methods. Reduced material and resource waste may also have economic advantages since it can result in cost savings and improved building project efficiency (Fig. 6).

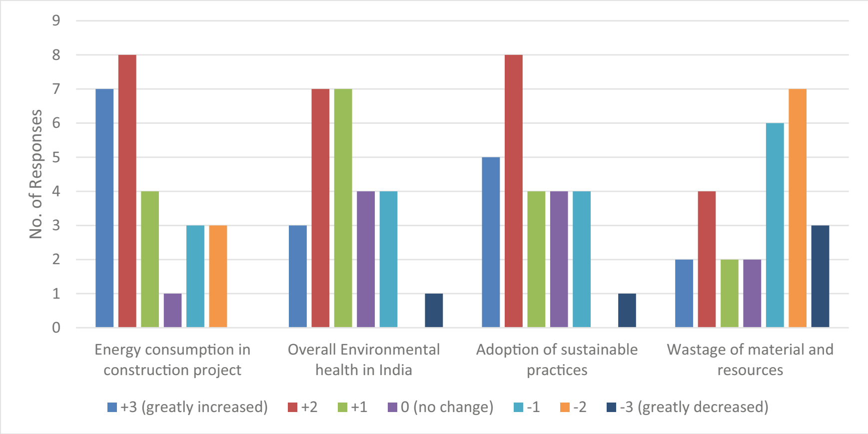

Fig. 6 Responses for attributes related to environment (*Source* Author's computation)

– **Research and development of construction technology**

The future of construction technology and innovation may be significantly impacted by the beneficial effects of robot implementation on research and development of construction technology. It may also affect how robots are integrated and used in the industry moving forward.

– **Level of investment in construction industry**

These results imply that the use of robots in the construction sector may have a favorable effect on the amount of investment in that sector. Construction may become more efficient and productive as a result of the growing use of technology and automation, attracting more investors and fostering growth and development.

– **GDP of India**

These results imply that various respondents' perceptions of the impact of robot deployment on India's GDP may vary, with some claiming positive implications on GDP while others claimed negative ones. The information indicates that the effect of robot deployment on India's GDP is a complicated and multifaceted subject that may require considerable thought and analysis to completely comprehend its implications for the building sector and the larger economy.

– **Overall economic growth in India**

The data indicates that the effect of robot deployment on overall economic growth in India is a crucial factor to take into account for the construction sector and the larger economy and may be a possible area of benefit for fostering growth, progress, and prosperity (Fig. 7).

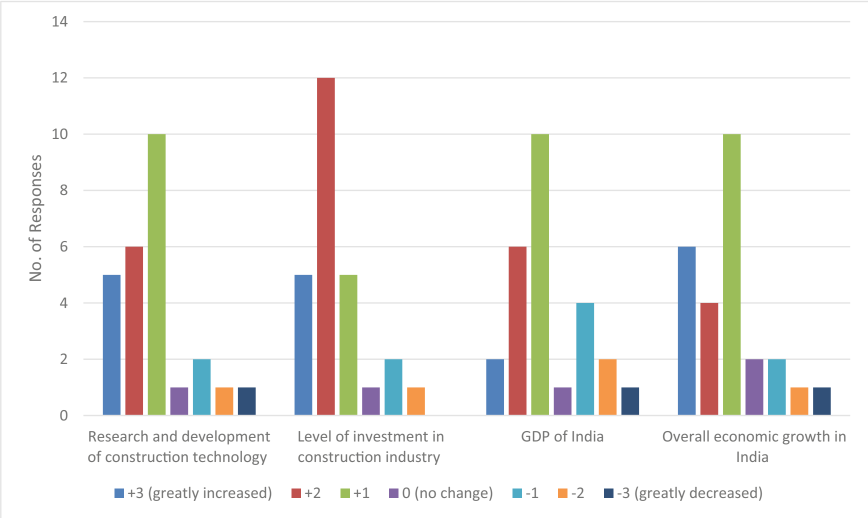

Fig. 7 Responses for attributes related to economy & investment (*Source* Author's computation)

- **Current level of automation in the Indian Construction Industry**

These results imply that respondents generally believe that robotization and automation in India's construction industry are at a relatively low level. This may illustrate the idea that the market has been hesitant to absorb new ideas and technology or that there are high entry barriers for new technologies in the market (Fig. 8).

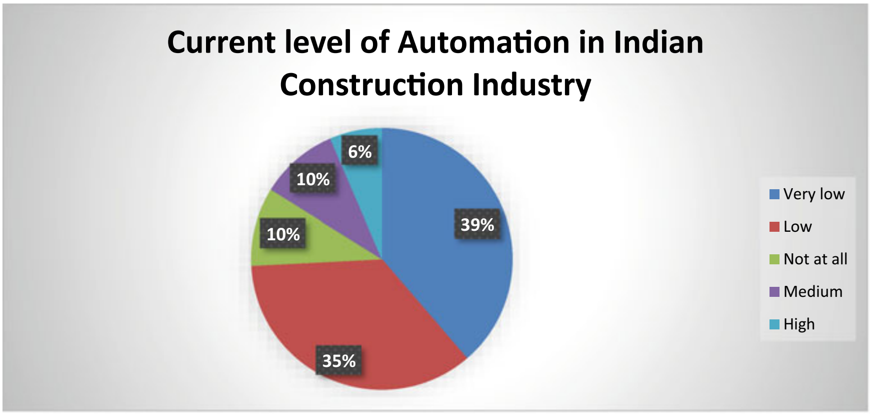

Fig. 8 Current level of automation (*Source* Author's computation)

- **Have you personally witnessed any robots in construction?**

These results imply that there may be a limited level of exposure to and knowledge about robotics and automation in the Indian construction sector. This may be due to a lack of industry adoption or integration of these technologies as well as a need for more education and understanding of the potential advantages and applications of these technologies (Fig. 9).

- **Can Robots replace human workers?**

According to the results below, there is a lot of uncertainty and disagreement among respondents on how automation and robotics can affect employment in India's construction sector. Some respondents could hold the opinion that the industry's adoption of new technologies would increase efficiency and productivity and may also open up new employment possibilities in fields like research and development, maintenance, and use of the new technology. Some people may be worried that the adoption of new technologies might result in considerable job losses, especially for those employed in lower-skilled or manual labor sectors (Fig. 10).

- **Use of robots and automation in Indian Construction Industry in next 5 years**

These results imply that respondents had a generally optimistic attitude on the possibility of robot adoption and integration into the Indian construction sector in the near future. It is possible that the belief that these technologies will be utilized more frequently reflects a growing understanding of the potential advantages of automation and robotization in the workplace as well as a realization of the need for improved productivity, efficiency, and sustainability in that environment (Fig. 11).

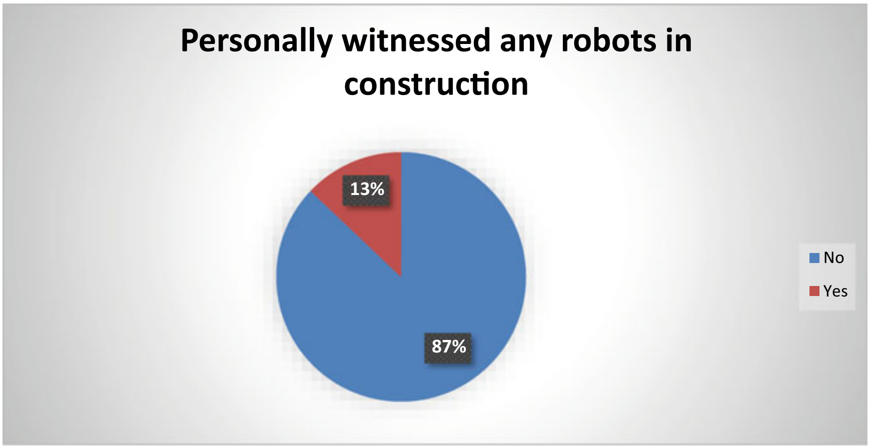

Fig. 9 Personally witnessed any robots in construction (*Source* Author's computation)

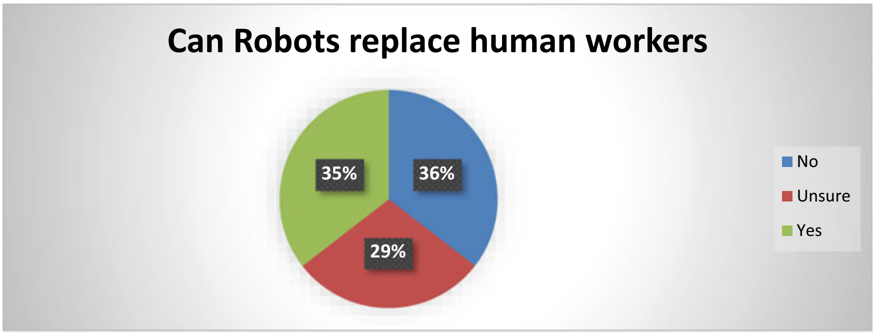

Fig. 10 Can robots replace human workers (*Source* Author's computation)

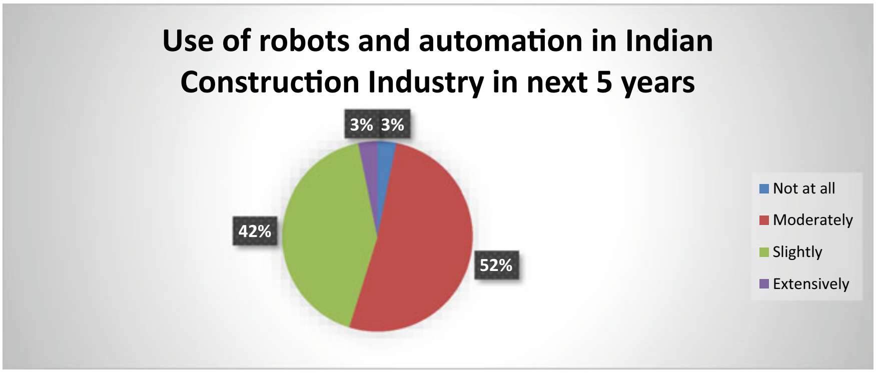

Fig. 11 Use of robots and automation in the next 5 years (*Source* Author's computation)

4 Results and Conclusion

According to the data analysis, the use of robots in the construction sector has positive as well as negative impacts on a number of different factors, including productivity, cost, speed, quality, health and safety, career opportunities, and environment. Increased productivity, quicker project completion, greater project quality, increased worker safety, and a move toward sustainable practices are some of the beneficial effects. On the other side, the negative repercussions range from unpredictable effects on project cost and energy usage to potential job loss, particularly for unskilled labor.

With the deployment of robots in the construction sector, the demand for skilled labor, technical and engineering skills, and IT and digital roles has expanded. This change may be ascribed to the industry's adoption of new technology, which necessitated the need for personnel with technical skills to run and maintain these machines. The use of robots in the construction sector has increased spending on construction technology research and development, industry investment, and the adoption of sustainable practices. Further research is necessary since the effects of robot installation on India's GDP and overall economic growth are still complicated and diverse.

In conclusion, there are possibilities and difficulties associated with the use of robots in the construction industry. It is necessary to balance the advantages of enhanced worker safety, higher productivity, speed, and quality with the possible disadvantages of job loss and variable impacts on cost and energy use. Robotic construction is still at an early stage. It will be difficult for robots to add value for contractors in nations like India where labor costs are extremely low. Robotics must be introduced gradually over time in order to justify their high capital expenditures given the public's understanding of their uses and advantages.

The results of this study also serve as a foundation for further research in several areas:

1. Examine the long-term implications of robot adoption on the construction sector, including any changes to productivity, cost, speed, quality, and environmental sustainability.
2. Investigate how the use of robots will affect the labor force, paying particular attention to mitigation measures for prospective job losses and the shifting nature of labor demand.
3. Assess the connections between the use of robots and several macroeconomic variables, such as the GDP, overall growth of economy, and the investment patterns in the construction sector.
4. Examine the potential for cutting-edge, emerging technologies like artificial intelligence (AI) and machine learning to increase the advantages of robot application in the construction sector and overcome its problems.

The following are some policy recommendations to optimize implementation of robots and automation in Indian Construction Industry:

1. Companies that invest in robots and automation may be rewarded by the government. Tax benefits, subsidies, or grants may be included.
2. The government shall develop a regulatory framework to promote the use of robotics and automation. This might involve establishing criteria for safety and performance, as well as offering guidelines on how to employ robots and automation in the construction business.
3. The government needs to invest in research and development of robots and automation technology. This might contribute to the development of new and innovative technologies for use in the building sector.
4. Workers need to be trained in the use of robots and automation by the government in collaboration with educational institutions. This will help in ensuring that these technologies can be used by a competent workforce.

References

1. Kumar VRP, Balasubramanian M, Raj SJ (2016) Robotics in construction industry. Indian J Sci Technol, Tamil Nadu
2. Oke A, Aigbavboa C, Mabena S (2017) Effect of Automation on construction industry Performance. Atlantis Press, Doornfontein
3. Streule T, Miserini N, Bartlome O, Klippel M, Soto, BGD (2016) Implementation of scrum in the construction industry. Procedia Eng. Zurich
4. Dixit S (2018) Analysing enabling factors affecting the on-site productivity in Indian construction industry. Period Polytech Arch. Noida
5. Chen Q, Soto BGD, Adey BT (2018) Construction automation: Research areas, Industry concerns and suggestions for advancement. Elsevier, Zurich
6. Jakel J, Rahnama S, Albert KK (2022) Construction robotics excellence model: A framework to overcome existing barriers for the implementation of robotics in the construction industry. Aachen
7. Gharbia M, Richards AC, Zhong R (2019) Robotic technologies in concrete building construction: A systematic review. Auckland, Hong Kong
8. Nihas S, Barlish KC, Kashiwagi DT (2015) Construction industry structure in India. ResearchGate, Tempe
9. Editorial (2020) Robotics Biz. [Online]. Available https://roboticsbiz.com/different-types-of-robots-transforming-the-construction-industry/. [Accessed 10 Oct 2022]
10. Rasmussen Equipment co. (2022) Rasmussen Equipment co. [Online]. Available https://www.raseq.com/demolition-robots/#:~:text=Demolition%20robots%20are%20widely%20used,of%20the%20robotics%20construction%20market. [Accessed 18 Feb 2023]
11. Husqvarna, Husqvarna. [Online]. Available https://www.husqvarnaconstruction.com/au/demolition-equipment/dxr140/. [Accessed 18 02 2023]
12. The Constructor, The Constructor. [Online]. Available https://theconstructor.org/building/bricklaying-robots-construction/552063/. [Accessed 18 Feb 2023]
13. Goldiez R (2021) Hirebotics. [Online]. Available https://blog.hirebotics.com/guide-to-welding-robots. [Accessed 19 Feb 2023]
14. Harmon P (2016) Pittsburgh. [Online]. Available https://pittsburghsprayequip.com/blogs/pittsburgh-spray-equipment-company/pros-cons-automated-robotic-painting. [Accessed 7 Mar 2023]
15. Kashiwagi D (2013) Construction industry structure in India. Research Gate, Tempe
16. Mitra S, Das M (2022) Exploring the impact of robotisation on economic development. Online Science Publishing, New Delhi
17. Kamaruddin SS, Mohammad MF, Mahbub R (2016) Barriers and impact of mechanisation and automation in construction to achieve better quality products. Elsevier Ltd., Selangor
18. Sajanpawar K, Pachekar S (2021) Robotics and automation in construction industry. IRJET, Pune
19. Vasilca IS, Nen M, Chivu O, Radu V, Simion CP, Marinescu N (2021) The management of environmental resources in the construction sector: an empirical mode. Energies, Basel

Impact of Optimum Use of Ground Granulated Blast Furnace Slag on Economy and Sustainability of Pune Metro Project

Vishal Dhaygude, Gayatri Vyas, and Chaitali Nikhar

1 Introduction

One of the largest infrastructure initiatives in India, the Pune Metro Project aims to improve the city's transit system. The project uses a significant amount of concrete, which is one of the primary building materials used in construction. However, due to the production process's release of greenhouse gases, the fact that the manufacture of cement, a key ingredient in concrete, negatively affects the environment. As a sustainable substitute for conventional cement, the use of Ground Granulated Blast Furnace Slag (GGBS) in the manufacturing of concrete has grown in favour as a solution to this problem a by-product of the steel and iron production sector is GGBS and has pozzolanic qualities that make it a useful cement alternative in the construction of concrete. Concrete's durability and strength are increased by using GGBS, which also lessens the environmental effect of concrete production. Laboratory testing on concrete samples created with various degrees of GGBS will be used to determine the ideal replacement percent of cement with GGBS in the Pune Metro Project. The goal of the study is to evaluate the efficacy and economic feasibility of GGBS-based concrete in comparison to traditional cement-based concrete. The research will also evaluate how economically feasible it would be to use GGBS in the building of the Pune Metro Project. The goal of the study is to determine if GGBS is appropriate for use in metro construction. Make a mix design suggestion using various GGBS percentages. Interpret the results to determine the best GGBS replacement. In order to calculate the ideal proportion of GGBS, compression and flexural strength tests were carried out. Calculations are made on the cube and beam that are cast for various GGBS percentages and the optimal percentage.

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2 Literature Review

The evaluation covers a wide range of topics, including the impact on fresh concrete qualities, mechanical properties, durability enhancement, microstructure analysis, long-term advantages, and applicable guidelines and standards. Overall, the assessment of literature shows that GGBS can increase the workability, strength, and durability of concrete while also contributing to sustainable construction practises. The great resistance of GGBS mixes to attack in hostile settings like silage pits is presumably related to the flow of moisture, which is caused by the thick and robust microstructure of the interfacial aggregate/binder transition zone. This resistance is presumably due to the mineral makeup of GGBS cement paste, which contains less aluminates and portlandite than Portland cement [1]. Data collection, data processing, testing, and validation of data from metro data are done using neural network. It is essential to note that the success of using neural networks in this context depends on the availability and quality of data, appropriate model selection, and careful interpretation of the results to make informed decisions regarding the implementation of GGBFS in the Pune Metro Project [2]. Use of SEM for various construction to improve strength, workability, and durability characteristics of concrete SEM is an invaluable tool for researchers and engineers in the construction industry to gain deeper insights into the microstructural properties of concrete. Its applications span from understanding the hydration process and optimizing cementitious materials to investigating the impact of additives and addressing durability concerns. By leveraging SEM analysis, concrete formulations can be tailored to achieve better strength, workability, and long-term durability, leading to more sustainable and reliable construction practices [3]. Reduction in carbon footprint, waste utilization, resource conservation and energy saving are the benefits of GGBS. GGBFS offers a range of benefits that align with sustainability objectives. By utilizing this by-product in concrete production, it helps in reducing the carbon footprint, promoting waste utilization, conserving natural resources, and achieving energy savings. Furthermore, the improved durability, compressive strength, and workability of GGBFS-based concrete contribute to the construction of more resilient and environmentally friendly infrastructure [3]. Reduction in carbon emission and cost-effectiveness of concrete will be there, also life cycle assessment studies have been done to examine the total environmental effect of concrete containing GGBS. These studies look at the complete life cycle of concrete, including raw material extraction, manufacture, transportation, usage, and disposal. They demonstrated that GGBS can contribute to a lower environmental effect when compared to standard concrete [4]. The investigation also discovered cost reductions as a result of lower cement consumption and the availability of quarry sand. Overall, the findings show the potential benefits and considerations of employing GGBS and quarry sand as partial replacements in concrete; however, more study is required to establish the best replacement percentages for individual project requirements [5]. Land acquisition and clearance delays, design revisions, utility relocation obstacles, contractor performance concerns, external variables, planning and scheduling errors, and procurement and supply chain challenges were the key contributors. These issues resulted in construction activity disruptions, increased costs for compensation and legal processes, project execution delays, and ineffective project management practises [6]. Rapid population development puts a burden on infrastructure, housing, and basic services. Inadequate housing alternatives and restricted access to basic facilities frequently result in the formation of informal settlements and slums. Inadequate urban planning and governance contribute to inefficient resource allocation, transportation congestion, and environmental deterioration [7]. While GGBFS is known for its potential to reduce carbon emissions in construction, a research gap may exist in understanding the specific environmental impact of its usage in the Pune Metro Project. This could involve conducting a life cycle assessment (LCA) to quantify the environmental benefits, such as greenhouse gas emissions reduction and resource conservation, associated with the use of GGBFS. Due to the degradation of limestone during the clinkerization process, Portland cement contributes the most to ECO_2eq and has the lowest material efficiency of all the component materials. Due to the high temperatures required in the clinker kiln, the manufacturing of Portland cement is also the energy-intensive process. Using recycled aggregates is the strategy that contributes the most to reducing the use of raw materials among the available options for which the potential implications on the life cycle assessment were examined [8]. OPC has been replaced by flyash and ground granulated blast slag (GGBS), which has the workability, strength, and durability that improve the properties of concrete. Alccofine is a specifically processed product made from highly reactive slag acquired through a controlled granulation process. The creation of High Performance Concrete (HPC) has created a critical demand for chemical and mineral additions to enhance the performance of concrete.

3 Methodology

Figure 1 The different strengths of the concrete's M40 mix design are established. In order to reduce CO_2 emissions and achieve standard concrete's strength, GGBS is partially substituted with cement. We raise the proportion from 10, 20, 30, and 40% to discover the ideal alternative for GGBS. The specimen was afterwards cast and cured into cubes, beams, and cylinders. The dimensions of the mounds are 150*150*150 for the cube, 150*150*600 for the beam. Compressive and flexural tensile tests are conducted. For the various percentages of replacement concrete, comparisons are made using a variety of factors.

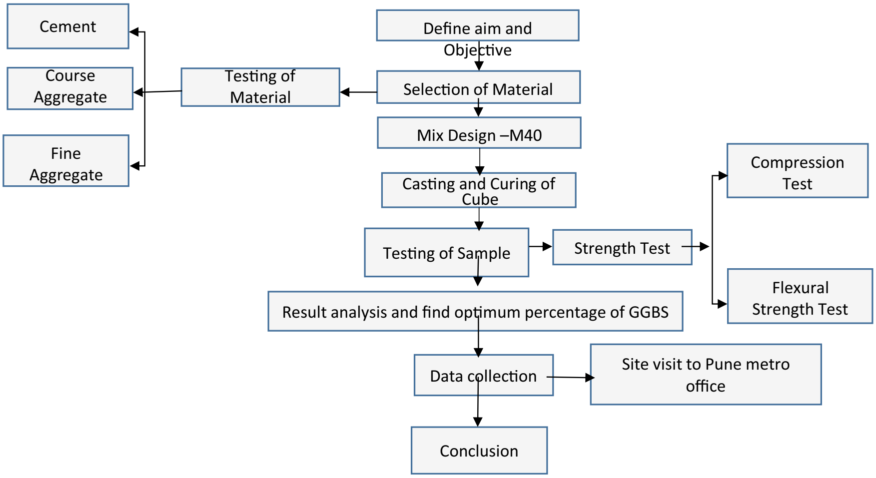

Fig. 1 Methodology

4 Experimental Study

4.1 Cement

The cement used is Ordinary Portland Cement (OPC) grade 53, which meets with IS: 269-1976 and IS: 4031-1988 (Fig. 2).

4.2 Fine Aggregate

According to IS: 383-1970, river sand was retained on 150 microns after passing through a 475mm IS sieve (Fig. 3).

Sr. NO	Tests	Obtained Value	Standard Value
1	Fineness	8 %	<10 %
2	Specific Gravity	3.14	3.1 – 3.2
3	Initial Setting time(Min)	55	>30
4	Final Setting Time (Min)	205	<600

Fig. 2 Cement properties

Sr.No	Tests	Obtained Value	Standard Value
1	Grading Zone	II	I-IV
2	Specific Gravity	2.85	2.5 – 2.8
3	Water Absorption	0.35 %	1-2 %

Fig. 3 Fine aggregate properties

Sr.No	Tests	Obtained Value	Standard Value
1	Grading Zone	I	-
2	Specific Gravity	2.85	2.5 - 3
3	Water Absorption	0.35 %	1 %
4	Impact Value	18.69 %	45 %

Fig. 4 Coarse aggregate properties

Constituents	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3
Amount (%)	32	14.5	1.5	33.2	11.5	0.89	1.40	0.96
Limits (%)	28-38	8-24	1-5	30-50	1-18	1-3	1-4	1-2

Fig. 5 Composition of GGBS

4.3 Coarse Aggregate

The size utilized complies with IS: 383-1970 and is 20 mm (Fig. 4).

4.4 GGBS

Ground granulated blast furnace slag (GGBS), a by-product of the steel industry, can be used in the production of concrete to some extent. The ideal replacement amount of GGBS varies based on the application and particular mix design, but commonly ranges from 20% to 50%. It has advantages such as increased toughness, longevity, and environmental sustainability (Fig. 5).

4.5 Mix Design

The concrete mix composition for M40 grade was completed based on IS: 456-2000 [9]. The concrete mix ratio per 1 m^3 is shown below. The mix design involves the use of 0.6% of admixture (Fig. 6).

Sr.No	GGBS (%)	W/C ratio	Mix Proportion of different Constitutes(kg/m3)				
			Cement	Slag	sand	Agg.	water
1	0	0.4	400	0	660	1167	160
2	10	0.4	360	40	660	1167	160
3	20	0.4	320	80	660	1167	160
4	30	0.4	280	120	660	1167	160
5	40	0.4	240	160	660	1167	160

Fig. 6 Mix design of M40 concrete

4.6 Test Procedure and Test Specimen

This investigation tests 45 cubes and 45 beam specimens. To measure the compressive strength and flexural strength of concrete at the ages of 7 days, 28 days, and 56 days after curing, 150 × 150 × 150 mm cubes and 150 × 150 × 750 mm beams are prepared for each batch of mixes. A compression test (As per IS 516) is carried out to ascertain the concrete's compressive strength, which is a crucial characteristic employed in structural design. Concrete's flexural strength (As per IS 516) can be assessed by this test, which is crucial for determining how the material will respond to bending stresses.

5 Results and Discussion

All test results and graphs of tests are as follows:

5.1 Compressive Test

The compressive strength of cement concrete containing various % of GGBS at the age of 7, 28, and 56 days are given in the table (Figs. 7 and 8).

Sr.No	GGBS (%)	Compressive Strength (N/mm2)		
		7 Days	28 Days	56 Days
1	0	30.86	47.05	51.32
2	10	31.65	49.58	52.00
3	20	32.16	51.21	52.97
4	30	30.86	49.32	51.89
5	40	28.85	46.65	50.36

Fig. 7 Compression test result

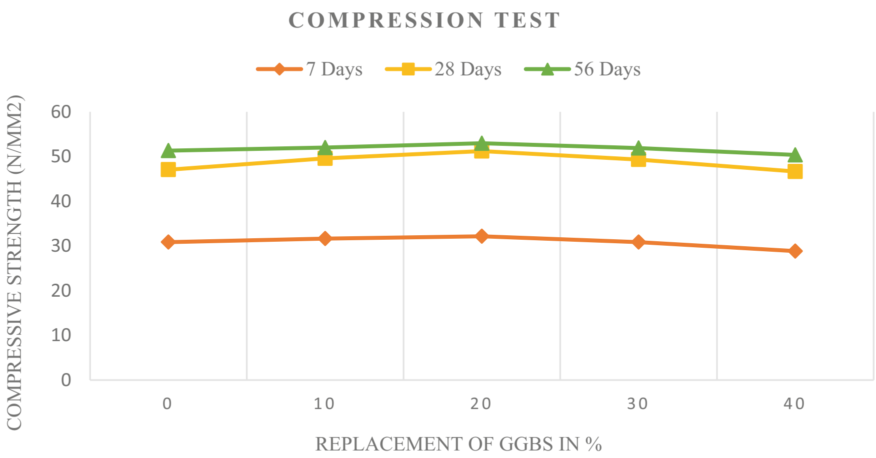

Fig. 8 Strength V/S % replacement Of GGBS

Sr.No	GGBS (%)	Compressive Strength (N/mm2)		
		7 Days	28 Days	56 Days
1	0	4.87	6.85	7.48
2	10	5.13	7.12	8.78
3	20	5.87	7.89	9.13
4	30	5.34	7.34	8.75
5	40	4.89	6.43	7.67

Fig. 9 Flexural strength results

5.2 *Flexural Strength*

The table provides the compressive strength of cement concrete with different percentages of GGBS at ages 7, 28, and 56 days (Figs. 9 and 10).

According to the above test and result, 20% substitution of GGBS results in the highest compressive and flexural strength. Therefore, 20% of OPC should be replaced by GGBS in Pune Metro at the most. Then using this data further life cycle analysis will be performed.

6 Data Collection

Google Forms, questionnaire surveys, and in-person interviews with professionals are used to collect data from the office and sites (Fig. 11).

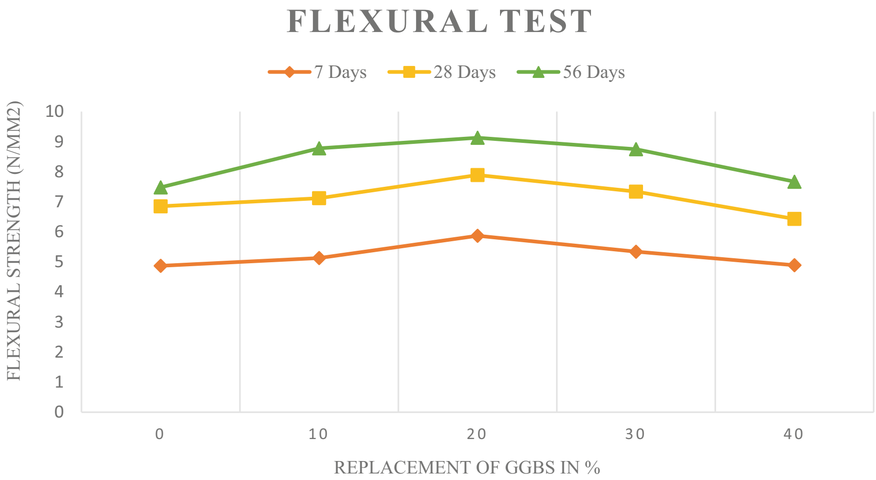

Fig. 10 Strength V/S % replacement Of GGBS

Route of Pune Metro: Phase-1					
Corridor	**Underground (Km)**	**Elevated (Km)**	**Total length (Km)**	**Total Station**	**Quantity of Concrete (M3)**
PCMC-SWARGATE	5.109	11.570	16.589	15	150000

Fig. 11 Concrete quantity

7 Interpretation

The grade of concrete used in metro varies from component to component but commonly used grade is M40 (Fig. 12).

Now the optimum GGBS replacement in the concrete from the results is 20%. So the saving in the cost of cement with GGBS replacement is calculated as follows (Fig. 13).

Ingredient of Concrete	**Cement OPC 53 Grade**	**Crushed Stone** (Kg/m3)	**12.5 mm Aggregate** (Kg/m3)	**20 mm Aggregate** (Kg/m3)	**Admixture** (BASF)	**Water Content**
M40	400	841	380	772	4.14 lit.	154 lit.

Fig. 12 Mix design from metro

Component	Rate per tonne	Quantity in Tonne (for 150000 M3 Concrete)	Total Amount (Rs)
Cement (100%)	6500	60000	39 Cr
Cement (80%)	6500	48000	31.2 Cr
GGBS (20%)	3500	12000	4.2 Cr
Cement + GGBS	-	-	35.4 Cr
Cost Saving	-	-	3.6 Cr

Fig. 13 Interpretation of data

From this data **the percentage saving in Cost is 9.23 %**

8 Conclusion

The Pune Metro Project's usage of GGBS results in lower total project costs, which benefits the economy because it has a smaller environmental impact, using GGBS in the Pune Metro Project helps it achieve its sustainability goals. The research report focuses on how crucial it is to use GGBS as efficiently as possible in order to produce concrete with the necessary strength, workability, and setting time. According to the test findings, the compressive and flexural strengths are at their highest with the 20% replacement cement with GGBS. So we conclude that if 20% GGBS used in the Pune Metro Project, there will be around 9.00 % cost will be saved in material without compromising other parameters. GGBS enhances the durability and long-term performance of concrete. When used in the construction of metro infrastructure, such as bridges, tunnels, and stations, it can lead to a longer service life of these structures. Utilizing GGBS reduces the reliance on conventional cement, which is a major source of greenhouse gas emissions due to its energy-intensive production process. By replacing a portion of cement with GGBS, the carbon footprint of the metro project can be reduced. GGBS has unique engineering properties that improve the performance of concrete, such as reduced heat of hydration, better resistance to sulphate attack, and enhanced workability. These improvements can result in better quality structures and infrastructure for the Pune Metro. The positive outcomes of using GGBS in the Pune Metro can encourage other cities and regions planning their metro systems to adopt similar practices. This could lead to a widespread application of GGBS in metro construction, resulting in significant cost savings and sustainability benefits for future projects. The adoption of GGBS in the Pune Metro can stimulate further research and development in the field of supplementary cementitious materials. This could lead to the exploration of other innovative by-products or waste materials from various industries that could be utilized in construction, promoting circular economy principles.

References

1. Desta E, Jun Z (2018) A review on ground granulated blast slag GGBS in concrete. 12(4):5–10. https://doi.org/10.15224/978-1-63248-145-0-14
2. Paulson AJ, Prabhavathy RA, Rekh S, Brindha E (2019) Application of neural network for prediction of compressive strength of silica fume concrete. Int J Civ Eng Technol 10(2):1859–1867
3. Hanna K, Morcous G, Tadros MK (2014) Effect of Supplementary Cementitious Materials on the Performance of Concrete Pavement. J. Mater. Civ. Eng. 26(4):789–793. https://doi.org/10.1061/(asce)mt.1943-5533.0000862
4. Hawileh RA, Abdalla JA, Fardmanesh F, Shahsana P, Khalili A (2017) Performance of reinforced concrete beams cast with different percentages of GGBS replacement to cement. Arch Civ Mech Eng 17(3):511–519. https://doi.org/10.1016/j.acme.2016.11.006
5. Chaithra HL, Pramod K, Chandrashekara A (2015) An experimental study on partial replacement of cement by ggbs and natural sand by quarry sand in concrete. Int J Eng Res V4(05):1539–1544. https://doi.org/10.17577/ijertv4is051304
6. June J, Student PG (2022) Analysis of causes of time and cost overrun in Pune metro project. 9(6):282–299
7. Rai RK, Nagaraj K (2017) Urbanization challenges in emerging economies. In: Urban Challenges Emerg Econ Energy Water Infrastructure. Transp Infrastructure; Plan Financ—Sel Pap from ASCE India Conf 2017. pp 267–277
8. Cordoba G, In C, Fabi E (2023) Towards an eco-efficient ready mix-concrete industry: Advances and opportunities. A study of the metropolitan region of Buenos Aires. J Build Eng 63(October 2022). https://doi.org/10.1016/j.jobe.2022.105449
9. IS 456 (2000) Plain concrete and reinforced. Bur Indian Stand Dehli:1–114

Lighting Performance Analysis Inside a Building Using Tubular Daylight Guidance System with a Dome Collector Mounted on Tapered Neck Mirror Light Pipe

Devendra Singh Bisht, Vikas Kumar, Kiranjot Kaur, Simranjit Singh, Harry Garg, and R. R. Shravana Kumar

1 Introduction

Solar energy is a sustainable means of energy resources. The use of fossil fuels in order to meet energy demands is no longer an intelligent way for a sustainable energy future. As per the report, ~60% of power requirement is managed using non-renewable energy resources [1], which will be depleted soon in a few decades if utilized continuously at the current pace. The total residential/domestic electricity consumption in India for illumination needs is somewhere in the range of 18–27% [2]. The sun is the prime source of light and energy on Earth. The sun's natural light can be utilized for illumination requirements in interiors. This will lead to lessening the financial burden as this will obviate the need for electricity for lighting requirements, at least during the daytime. Natural light enhances colour rendering, visual comfort, and indoor environment quality for the improved health of inhabitants [3, 4]. Conventional fenestrations like windows, skylights, clerestories, etc., have been the acting daylighting devices from early times. However, these conventional means of daylighting have performance constraints. The drawback of using these devices is that the light intensity falls off rapidly in the spaces away from windows. In the last 30 years, various innovative daylight transporting/guiding technologies have been developed to improve daylighting performance in buildings [5–23]. An appropriate

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amount of daylight for the desired illumination can be harnessed using a suitable daylight guiding device to lighten gloomy spaces at a distance from conventional fenestration. Light transport systems are the means for lighting deep dark spaces in buildings. These primarily consist of three components: collection, transportation, and distribution [24]. The system's collection part, also called the daylight collector, can be either a passive device (no sun tracking involved) or an active device (with sun tracking). Some of the most commonly used light-transporting devices are fibre optics and MLPs. The fibre bundles are generally used in tracking-based active daylighting devices. However, utilizing quartz (glass) optical fibre as a light transport system along with highly precise sun-tracking requirements limits the system to be utilized widely by common households as the cost is very high. The daylighting systems with passive devices are relatively less costly compared to active systems. Though passive systems have compromised efficiency [6, 25] a carefully designed system serves the illumination needs of the occupants and is also well within the reach of common households economically. TDGS, one of the passive daylighting systems, is the focus of study in this paper. Commercially TDGS is the most successful method of daylight guidance, where a light collector collects and delivers sunlight into the transmitting tube [26]. This study evaluates the lighting performance of a designed TDGS having a tapered neck MLP mounted on a cylindrical MLP system with a transparent dome as a daylight collector. The simulation studies have been performed using the lighting simulation software TracePro. Also, the lighting performance of the proposed design was compared with a conventional daylight collector design having a transparent dome as a daylight collector mounted on a cylindrical MLP system. The illuminance levels on the work plane inside the building room were noted for various timings of the day under clear sky conditions.

2 Tubular Daylight Guidance System

One of the kinds of a passive daylighting system called tubular daylight guidance system (TDGS) alternatively called light pipe or tubular skylight (TS) is a means of directing/transporting available daylight into interior spaces as shown in Fig. 1. The illuminance levels fall off rapidly when the distance from traditional skylights, windows, or clerestory increases. In contrast, TDGS is capable of bringing daylight into interior spaces. It has three components, viz. collector, transmitting tube, and diffuser. The light collector collects both beam sunlight and diffuse skylight and delivers it into the transmitting tube. A transmitting tube called MLP is a hollow structure with a reflective internal surface. These hollowed structures with reflective sidewalls help to transmit the light efficiently and deeper into spaces needed to be lit. The cross-section of the transmitting tube can be circular, rectangular, or multi-sided [27, 28]. Bends may also be allowed depending on architectural constraints. Sometimes bent pipes are used to achieve optimal system performance [29, 30]. The diffuser positioned at the exit aperture of MLP distributes the transmitted light uniformly over the target area. Transparent domes have been prominently used as daylight collectors. The easy shape, manufacturing ease, and relatively better lighting performance makes this design affordable for common households. Also, the curved shape of the collector helps in relatively less dust accumulation on the outer periphery. These factors make the dome collector a better choice than the flat plate collector [31]. However, a significant amount of low-altitude beam sunlight escapes the transparent dome casing and a little light enters MLP. On the contrary, at the high-altitude sun, the excess sunlight is the cause of heat and glare inside as shown in Fig. 2. A few commercialized technologies use hemispherical [32] or segmented [33] transparent domes integrated with MLP of high specular reflectance. An angled reflector may be located within the domed transparent surface to reflect low-altitude sunlight into MLP which otherwise would not have passed into the same [34]. The reflection losses across the entire length of the MLP depend on the reflectance and the length of the MLP. As shown in Fig. 3a, a ray with low altitude i.e., ray 2, meets multiple reflections while traveling the MLP length, leading to significant light losses. Contrary to that, ray 1 at a high altitude does not hit the MLP surface; hence, no losses are met. Therefore, during the morning and evening hours under low altitude sun, light losses across the MLP length rise. The reflectivity of the mirrored surface is a highly sensitive parameter and affects the lighting performance of a daylighting device. A small difference in the reflectivity of the mirrored surface results in a significant difference in the performance of the system as shown in Fig. 3b.

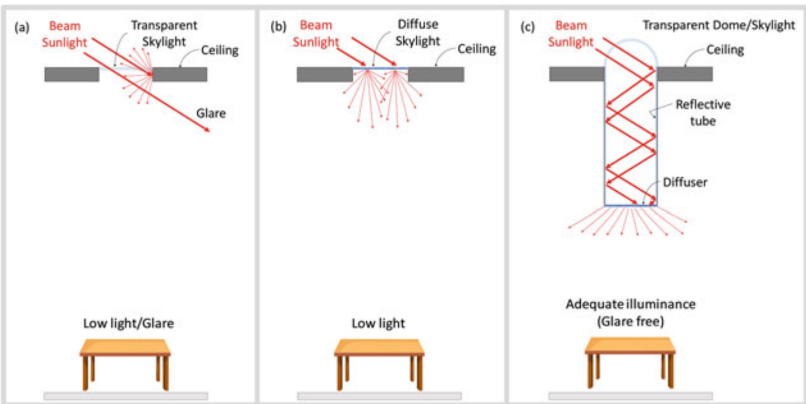

Fig. 1 Tubular daylighting system concept

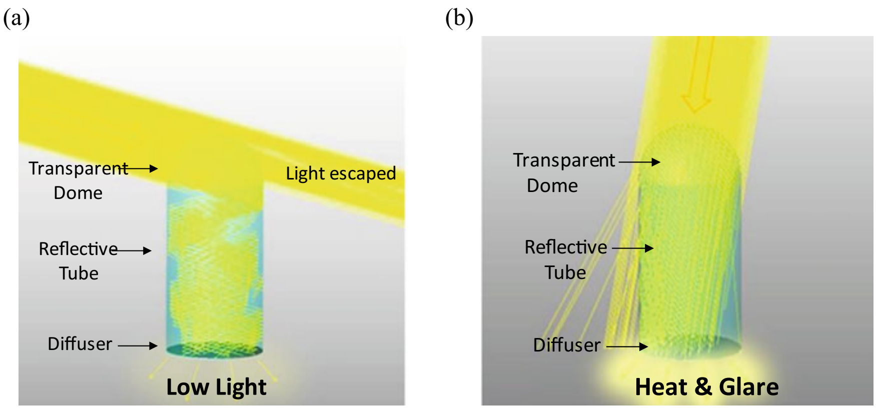

Fig. 2 Limitation of conventional dome-shaped daylight collectors **a** low levels of light during low altitude sun, **b** heat and glare during high altitude sun

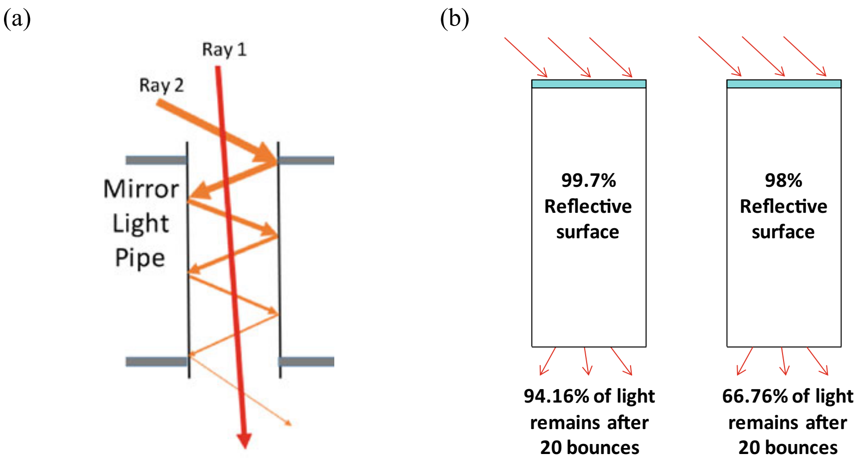

Fig. 3 **a** Number of reflections encountered in MLP decreases the luminous flux value of the incident light beam, **b** light output through MLP depending on the reflectivity of MLP and the number of bounces/reflections

3 Proposed TDGS with Tapered Neck Mirror Light Pipe

The proposed design comprises a hemispherical transparent dome mounted on a cylindrical MLP system with a tapered neck. The tapered region of the cylindrical MLP system has a varying cross-sectional area across the length of the neck region as shown in Figs. 4 and 6. In conventional MLP designs the tapered MLP system is generally a tilted MLP i.e. the circular cross-sectional area is constant across the length of the MLP [29]. The proposed daylight collector design is for a vertical MLP system for the Chandigarh, India (30.71° N and 76.78° E) region. As the location is in the northern hemisphere, the inner reflective lining, i.e., the mirrored surface of the tapered section of MLP, faces the south direction. This is because, for most of the day, the sun rays (beam sunlight) are incident from the south direction (also from south-east and south-west regions). These incident light rays, after getting reflected by a tapered section of MLP are redirected into MLP length with relatively high altitude as shown in Fig. 4. Moreover, the diffuse skylight incident from the sky vault is higher in magnitude from the south direction for the most part of the day. The circumsolar region of the sky vault has much higher luminance when perceived from the centre of the sky vault/observer's point of view. Further, a portion of the tapered neck MLP length facing the south direction is kept transparent in order to ingress more sunlight into the MLP aperture as shown in Figs. 4 and 6. It should be noted that the tilt of the reflective segment of the tapered neck region of MLP length varies ($\theta_{max} = 11°$ to zero) around the circumferential region as shown in Fig. 6. The low-altitude sun rays from the south direction will be efficiently transported across the MLP length due to less number of reflections. However, the proposed configuration of the collector restricts the passage for high altitude sun rays. For instance, for noon timing sun rays in June at an altitude of ~80° in Chandigarh, India region (latitude = 30.71° N) the passage in order to enter the MLP system is relatively lesser than the conventional design (Fig. 5). However, the restricted passage is expected not to affect the lighting performance in the interior as the illuminance levels are very high in ambience, more than 100,000 lx. In most cases the lighting levels reaching the interior are sufficient for visual performance provided moderate-length MLP systems. A restricted passage across the daylight collector during high-altitude sun is desirable in a few cases to avoid heat gain and glare problems [35]. A reflector on a specific part of the dome structure is also provided to enter further light from the south region of the sky vault into MLP. The reflector is mounted on the north-facing region of the dome with a height as half as the height of the dome. As the skylight incident from the north direction is much weaker than the rest of the sky vault region, the reflector's position does not restrict significant lighting from the north direction.

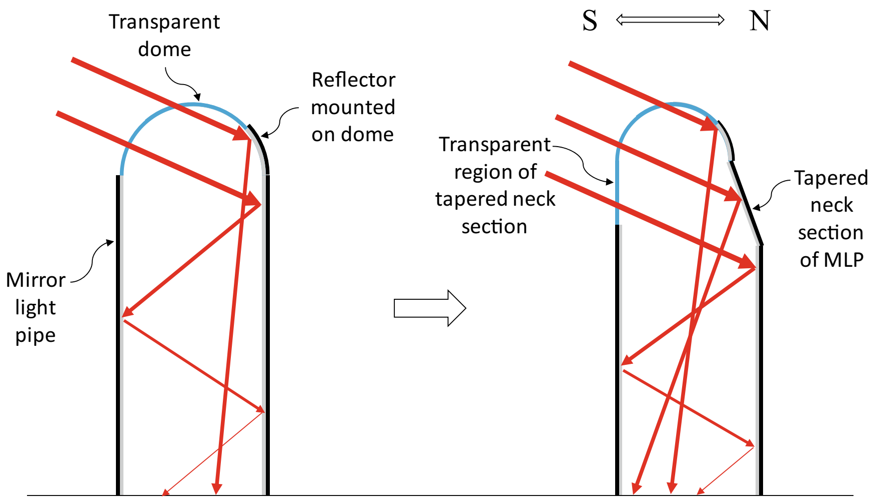

Fig. 4 Conventional transparent dome collector mounted on top of cylindrical MLP system transformed to tapered neck MLP system with a portion of south-facing transparent covering acting as a passage for low altitude sun rays incident from the south direction

4 Numerical Simulation

In order to model and analyze the lighting performance of the conventional and proposed daylighting system discussed in Sect. 3, the numerical simulations were performed using the TracePro software tool [36]. A few simulation setup components were modelled in SOLIDWORKS [37] and imported into TracePro after conversion. Simulation studies also offer design support for predicting the energy performance of buildings [38] and optomechanical devices [39]. In this study, the photometric analysis results were simulated for Chandigarh, India (30.71° N and 76.78° E) using the solar emulator utility module provided in TracePro. Figures 5 and 6 show the configured daylighting setups mounted on a three-floor building with their dimensions. The numerical simulation studies of the TDGS's performance under direct components of sunlight and diffuse skylight were done separately (as shown in Fig. 7) under the sun trajectory of 21 June and 21 December. The values of DNI and DHI were taken from experimental observations using a light meter. The sky conditions were relatively clear. The luminance pattern of the diffuse skylight for simulation results was considered as per the Igawa sky model [40]. The transparent dome material was given as acrylic (refractive index = 1.49). Zero absorption loss was considered for acrylic material. The reflectivity of the MLP surface was considered as 97%. Further, the numerical values of the various parameters of daylight collector designs and the simulated room details are shown in Tables 1 and 2, respectively. The length of the light transport system i.e. MLP was taken as 6m with a 90° bend involved at the bottom part i.e. just before the exit aperture of MLP. A diffuser was placed at the exit aperture of MLP. The diffuser uniformly distributes the light on the

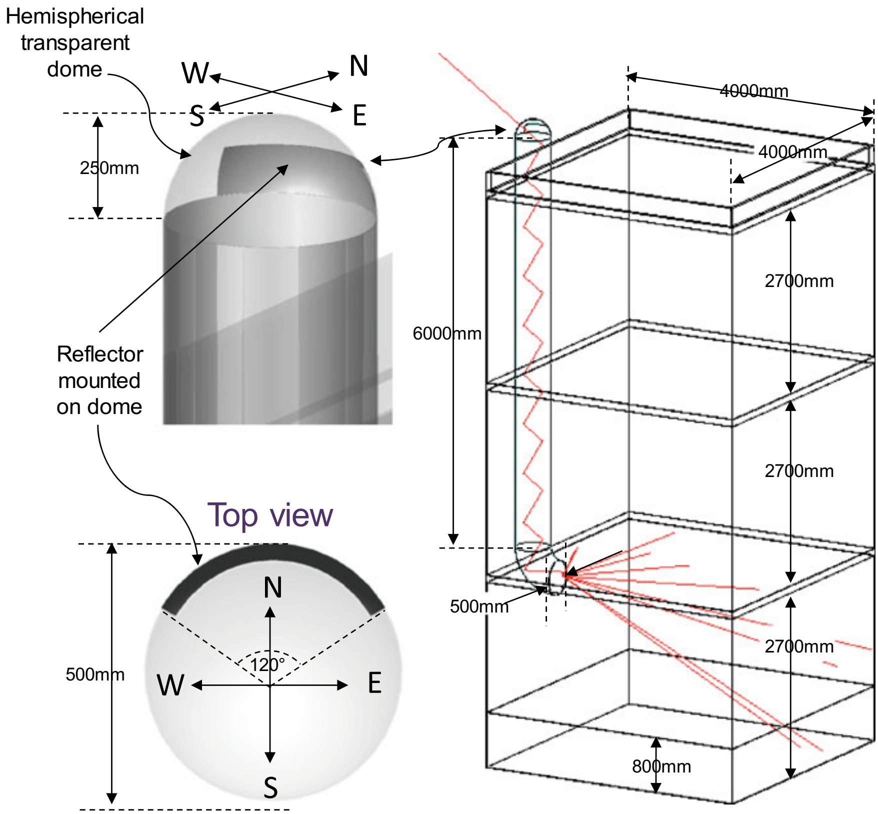

Fig. 5 Configuration of conventional TDGS simulated to find its light-transmitting ability inside the room

work plane. The diffuser used in simulations is Luminit (80° LSD) [41]. Figure 8a shows the transmittance value for various ray/light angles incident on the diffuser. Figure 8b shows the magnitude of light transmitted across the diffuser for the rays/light beam incident at 30°. The light leaving the diffuser is direct illuminance to the various room surfaces. Further, due to the diffuse reflectance of surfaces, the light keeps travelling from the room's surfaces until its flux becomes zero or too small to trace. The limiting flux value i.e. flux threshold was considered as 0.005 i.e. 0.5% in the simulations. The simulated average illuminance values on the work plane (at a height of 0.8m from the floor of the room) of the ground floor room were recorded. The illuminance observed on the work plane corresponds to the light incident on the surface (from top to bottom) facing the room's ceiling. Various parameters and recorded simulated results for the room and average illuminance on the work plane are shown in Tables 3 and 4. The direct/beam sunlight simulation was done under 200,000 uniformly distributed collimated rays. For simulating the diffuse skylight 12 million rays were traced.

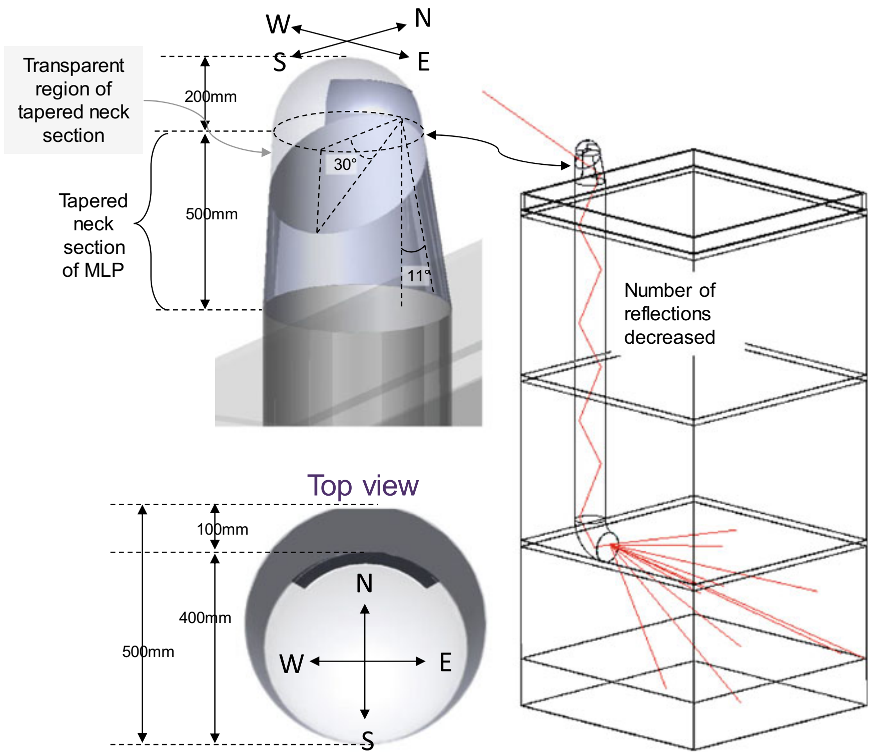

Fig. 6 Configuration of proposed TDGS simulated to find its light-transmitting ability inside the room

5 Results and Discussion

From the simulation results plotted in Fig. 9a for 21 June, it can be seen that the light output of both cylindrical MLP and tapered neck MLP is similar in the morning and evening hours while around noon timings the lighting performance of tapered neck MLP configuration is relatively lesser. But it is to be noted that the average illuminance value is more than ~300 lx most of the time. Therefore, during noon timings there is no compromise in the lighting levels required for appropriate visual performance of the occupants. On 21 December in Fig. 9b, the tapered neck MLP configuration performs better than the cylindrical MLP configuration throughout the

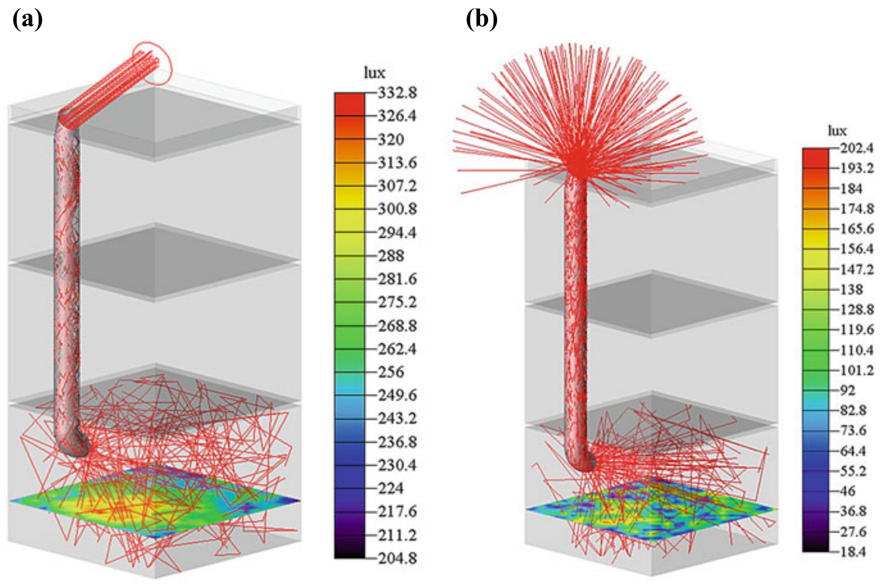

Fig. 7 Simulation setup under the **a** beam sunlight, and **b** diffuse skylight

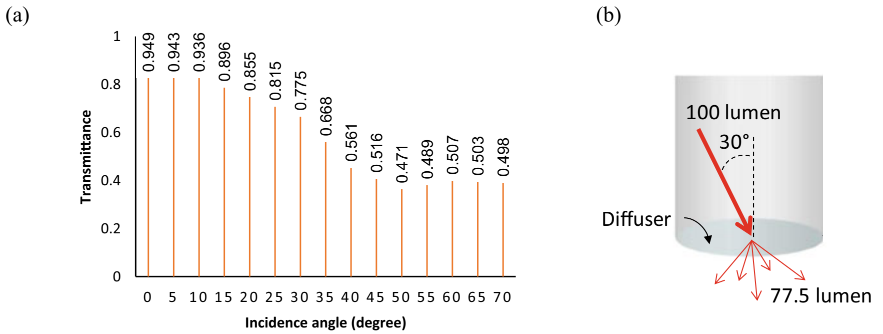

Fig. 8 Transmittance of Luminit 80° LSD diffuser **a** for various incidence angles, and **b** pictorial depiction of diffuser transmittance at an incidence angle of 30°

day regardless of the sun being at a low altitude for most of the day and the maximum solar altitude being the lowest. The proposed design having a tapered mirror light pipe (MLP) system is a good alternative to conventional designs especially for high latitude regions. The tilt angle of the tapered section of MLP can be further customized for effective lighting performance as per the latitude of the geographical location. The design applies to all building types where conventional daylighting systems are being installed provided there is unobstructed exposure to incident sunlight. The maximum

Table 1 Numerical value of the various parameters of conventional and proposed configurations of the daylight collector design for simulation

Parameter	Length of MLP (mm)	Diameter of MLP (mm)	Diameter of the hemispherical dome (mm)	Length of tapered neck section of MLP (mm)	Max. tilt of tapered neck region	Angle subtended by reflector mounted on the dome on azimuth plane towards the north
Conventional	6000	500	500	0	0°	120°
Proposed	6000	500	400	500	11°	120°

Table 2 Simulated room details

Details		Surface reflectance	
		Type	Value (%)
Room	Side walls	Diffuse	70
	Ceiling	Diffuse	80
	Floor	Diffuse	40
Mirror light pipe	Internal surface lining	Specular	97
Reflector placed on dome collector		Specular	97

length of the MLP to illuminate deep dark spaces majorly depends on the reflectivity of the reflective material and the aspect ratio of the MLP [42]. The maximum length of MLP (for satisfactory visual performance) can be up to ~15 m for a tube diameter of 530 mm [43]. The design of various segments of the tubular daylighting system depends on the geographical location (latitude), typical sky conditions, and building type. In the present study, the simulation results are for a vertically installed MLP system of 6 m in length with a 90° bend involved at the bottom part.

Table 3 Various parameters and numerical results for the simulated setup and average illuminance on the work plane using a dome collector mounted on cylindrical MLP and tapered neck cylindrical MLP on 21st June

Time	Altitude (°)	Azimuth (°)	Direct normal illuminance (lux)	Diffuse horizontal illuminance (lux)	Dome collector mounted on cylindrical MLP					Dome collector mounted on tapered neck cylindrical MLP				
					Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)	Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)
					Due to DNI	Due to DHI	Due to DNI	Due to DHI		Due to DNI	Due to DHI	Due to DNI	Due to DHI	
6:00	6.9	66.8	5969	7630	7	293	0.4	18	18.4	6	345	0.4	22	22.4
6:30	12.9	70.2	22,001	16,850	54	614	3	38	41	40	639	3	40	43
7:00	19	73.4	37,417	23,690	205	910	13	57	70	183	1043	11	65	76
7:30	25.2	76.6	49,549	29,620	541	1136	34	71	105	421	1399	26	87	113
8:00	31.5	79.7	58,765	31,860	1032	1172	65	73	138	725	1481	45	93	138
8:30	37.9	82.9	65,761	32,540	1614	1349	101	84	185	1240	1676	78	105	183
9:00	44.3	86.2	71,099	31,770	2283	1393	143	87	230	1891	1613	118	101	219
9:30	50.7	89.8	75,183	29,650	2946	1244	184	78	262	2384	1413	149	88	237
10:00	57.2	93.9	78,292	28,990	3817	1296	239	81	320	2658	1567	166	98	264
10:30	63.6	99	80,620	27,640	4807	1171	300	73	373	3403	1572	213	98	311
11:00	69.9	106	82,299	25,960	4690	1425	293	89	382	3553	1527	222	95	317
11:30	75.9	117.7	83,420	22,120	6277	1046	392	65	457	4445	1211	278	76	354
12:00	80.9	141.6	84,040	16,140	5385	721	337	45	382	3761	909	235	57	292
12:30	82.6	189.7	84,188	13,550	6191	662	387	41	428	4243	708	265	44	309
13:00	79.3	229.4	83,872	18,270	6084	865	380	54	434	4145	1024	259	64	323

(continued)

Table 3 (continued)

Time	Altitude (°)	Azimuth (°)	Direct normal illuminance (lux)	Diffuse horizontal illuminance (lux)	Dome collector mounted on cylindrical MLP					Dome collector mounted on tapered neck cylindrical MLP				
					Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)	Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)
					Due to DNI	Due to DHI	Due to DNI	Due to DHI		Due to DNI	Due to DHI	Due to DNI	Due to DHI	
13:30	73.8	247.4	83,077	24,020	5263	1129	329	71	400	3855	1415	241	88	329
14:00	67.6	256.8	81,763	26,840	5050	1186	316	74	390	3644	1473	228	92	320
14:30	61.3	263	79,863	28,380	4361	1234	273	77	350	3075	1458	192	91	283
15:00	54.9	267.7	77,272	29,120	3375	1210	211	76	287	2727	1344	170	84	254
15:30	48.4	271.6	73,839	30,280	2738	1400	171	88	259	2253	1594	141	100	241
16:00	42	275.1	69,342	32,110	2038	1302	127	81	208	1573	1604	98	100	198
16:30	35.6	278.3	63,461	32,750	1404	1188	88	74	162	1031	1464	64	92	156
17:00	29.2	281.4	55,741	31,240	833	1234	52	77	129	583	1452	36	91	127
17:30	23	284.5	45,558	26,550	400	1044	25	65	90	344	1299	22	81	103
18:00	16.8	287.7	32,229	22,760	134	835	8	52	60	120	1008	8	63	71
18:30	10.7	291	15,933	11,990	28	414	2	26	28	18	492	1	31	32
19:00	4.9	294.5	2104	5870	2	210	0.1	13	13.1	2	256	0.1	16	16.1

Table 4 Various parameters and numerical results for the simulated setup and average illuminance on the work plane using a dome collector mounted on cylindrical MLP and tapered neck cylindrical MLP on 21st December

Time	Altitude (°)	Azimuth (°)	Direct normal illuminance (lux)	Diffuse horizontal illuminance (lux)	Dome collector mounted on cylindrical MLP					Dome collector mounted on tapered neck cylindrical MLP				
					Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)	Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)
					Due to DNI	Due to DHI	Due to DNI	Due to DHI		Due to DNI	Due to DHI	Due to DNI	Due to DHI	
08:00	7.5	122.9	7198	9300	39	497	2	31	33	90	707	6	44	50
08:30	12.7	127.4	21,473	16,190	171	830	11	52	63	390	1194	24	75	99
09:00	17.6	132.3	34,276	20,200	401	1020	25	64	89	800	1578	50	99	149
09:30	22.2	137.8	44,059	26,800	729	1460	46	91	137	1286	2071	80	129	209
10:00	26.2	143.9	51,248	30,330	1107	1475	69	92	161	1680	2258	105	141	246
10:30	29.7	150.6	56,421	31,160	1428	1569	89	98	187	2234	2446	140	153	293
11:00	32.5	157.9	60,017	32,400	1732	1590	108	99	207	2492	2640	156	165	321
11:30	34.5	165.8	62,329	32,610	1938	1705	121	107	228	2708	2581	169	161	330
12:00	35.7	174.1	63,536	33,290	2059	1810	129	113	242	2898	2727	181	171	352
12:30	35.8	182.6	63,728	32,830	2070	1767	129	111	240	2927	2508	183	157	340
13:00	35.1	191	62,920	32,710	1992	1869	125	117	242	2813	2822	176	176	352
13:30	33.4	199.1	61,052	32,650	1815	1600	113	100	213	2650	2663	166	167	333
14:00	30.9	206.6	57,980	32,060	1555	1744	97	109	206	2256	2505	141	157	298
14:30	27.7	213.6	53,461	30,980	1224	1547	77	97	174	1930	2305	121	144	265
15:00	23.8	219.9	47,114	28,030	859	1572	54	98	152	1390	2317	87	145	232

(continued)

Table 4 (continued)

Time	Altitude (°)	Azimuth (°)	Direct normal illuminance (lux)	Diffuse horizontal illuminance (lux)	Dome collector mounted on cylindrical MLP					Dome collector mounted on tapered neck cylindrical MLP				
					Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)	Luminous Flux on work plane (Lumen)		Average illuminance on work plane (lux)		Total average illuminance on work plane (lux)
					Due to DNI	Due to DHI	Due to DNI	Due to DHI		Due to DNI	Due to DHI	Due to DNI	Due to DHI	
15:30	19.4	225.6	38,407	24,510	518	1257	32	79	111	986	2020	62	126	188
16:00	14.7	230.8	26,775	19,960	250	928	16	58	74	535	1525	33	95	128
16:30	9.5	235.4	12,560	11,090	78	603	5	38	43	181	853	11	53	64
17:00	4.2	239.7	1262	4050	6	205	0.4	13	13.4	12	306	1	19	20

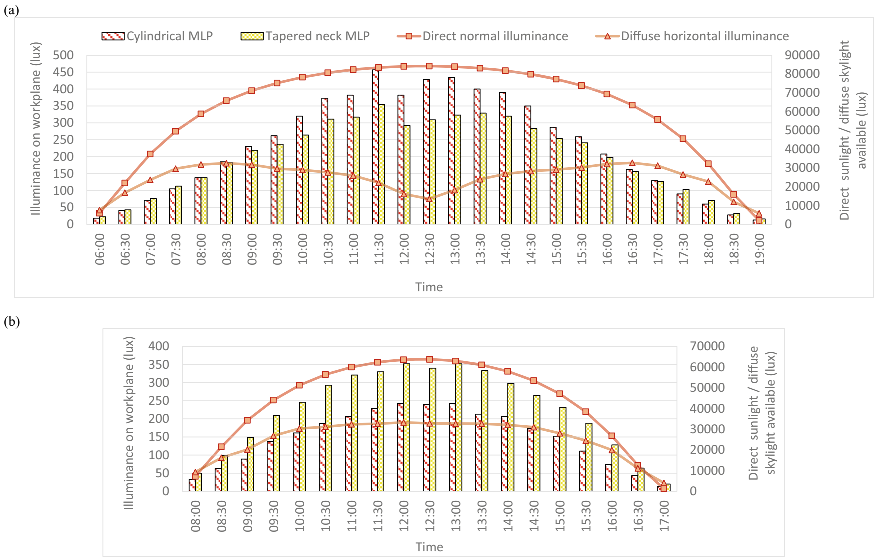

Fig. 9 Total average illuminance on the work plane (due to beam sunlight and diffuse skylight) for various timings of the day on **a** 21st June, and **b** 21st December

6 Conclusion

The paper presents a new TDGS design for the purpose of light collection for daylighting.

Two configurations of daylight collector were analyzed for lighting performance inside a confined room on the ground floor of a 3-floor building.

The proposed design involved a tapered neck MLP configuration coupled to cylindrical MLP. The performance of the simulated model was compared to that of a cylindrical MLP with a dome collector.

Results indicated no compromise in the lighting levels for desired visual performance on 21 June (summer solstice). Also, this suggested that when the sun is at a high altitude, we can afford to have a relatively lesser passage for incident sunlight as there is availability of high-intensity flux provided clear sky conditions are there.

The lighting performance of the proposed design was significantly enhanced on 21 December (winter solstice) in comparison to the conventional daylight collector setup by ~50%. Daylight autonomy (i.e. daylight is self-sufficient for the desired illumination) improved using the proposed design.

The lighting levels are sufficient for offices and school hours, and therefore the proposed design can be a good alternative when the consumption of electricity for lighting needs is maximum.

7 Future Work

The study covers lighting performance under clear skies, and these kinds of skies have a higher level of predictability and homogeneity, which makes them better suited for comparison with computer simulations. The proposed designs can be checked for intermediate skies though this involves great variability and complexity.

The configuration of the light pipe simulated for a parametric study of the proposed design is for a vertically installed MLP system. Other parameters that can be included are pipe bends/tilt (depending on the architectural constraints), collector type, and diffuser type.

The parametric study for effective lighting performance can be done for other latitude regions of interest and regional sky conditions.

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References

1. Power Sector INDIA (2020). https://powermin.gov.in/en/content/power-sector-glance-all-india. Accessed 11 Sep 2020
2. India's LED Lighting Story. https://www.prayaspune.org/peg/india-s-led-lighting-story. Accessed 16 May 2021
3. Boyce PR (2014) Human factors in lighting, 3rd ed. CRC Press. https://doi.org/10.1201/b16707
4. IEA (2001). http://www.iea-ebc.org/Data/publications/EBC_Annex_29_Application_Guide.pdf. Accessed 03 Feb 2021
5. Mayhoub MS (2019) Fifty years of building core sunlighting systems—eight lessons learned. Sol Energy 184:440–453. https://doi.org/10.1016/j.solener.2019.03.097
6. Nair M, Ramamurthy K, Ganesan A (2014) Classification of indoor daylight enhancement systems. Light Res Technol 46(3), Art no 3. https://doi.org/10.1177/1477153513483299
7. Wong IL (2017) A review of daylighting design and implementation in buildings. Renew Sustain Energy Rev 74:959–968. https://doi.org/10.1016/j.rser.2017.03.061
8. Littlefair PJ (1990) Review paper: innovative daylighting: review of systems and evaluation methods. Light Res Technol 22(1):1–17. https://doi.org/10.1177/096032719002200101
9. Malet-Damour B, Bigot D, Boyer H (2020) Technological Review of tubular daylight guide system from 1982 to 2020. EJERS 5(3):375–386. https://doi.org/10.24018/ejers.2020.5.3.1809
10. Malet-Damour B, Bigot D, Guichard S, Boyer H (2019) Photometrical analysis of mirrored light pipe: from state-of-the-art on experimental results (1990–2019) to the proposition of new experimental observations in high solar potential climates. Sol Energy 193:637–653. https://doi.org/10.1016/j.solener.2019.09.082
11. Kim JT, Kim G (2010) Overview and new developments in optical daylighting systems for building a healthy indoor environment. Build Environ 45(2):256–269. https://doi.org/10.1016/j.buildenv.2009.08.024
12. Kischkoweit-Lopin M (2002) An overview of daylighting systems. Solar Energy 73(2), Art no 2. https://doi.org/10.1016/S0038-092X(02)00036-1
13. Onubogu NO, Chong K-K, Tan M-H (2021) Review of active and passive daylighting technologies for sustainable building. Int J Photoenergy 2021:1–27. https://doi.org/10.1155/2021/8802691

14. Garg H, Bisht D, Sharma K, Kumar V, Kaur K, Garg N (2022) Analysis, evaluation and integration of modular natural illumination system using a rectangular Fresnel lens for high performance. Light Res Technol p 147715352110636. https://doi.org/10.1177/14771535211063624
15. Kumar V, Sharma K, Bisht DS, Garg H (2022) Optimum concentration ratio for plastic optical fiber-based Fresnel lens daylighting system. In: Jain VK, Gomes C, Verma A (eds) Renewable energy and storage devices for sustainable development. Springer Proceedings in Energy. Springer, Singapore, pp 169–179. https://doi.org/10.1007/978-981-16-9280-2_21
16. Bisht DS, Singh S, Sharma K, Garg H, Shravana Kumar RR (2021) Performance analysis of a passive tubular skylight using rectilinear parabolic-profile integrated with plane reflectors and wedge prism. Solar Energy 222:235–258. https://doi.org/10.1016/j.solener.2021.05.015
17. Singh S, Bisht DS, Garg H (2021) A novel method for making laser cut panel based daylight collector coupled to a tubular light guide. Sol Energy 218:532–543. https://doi.org/10.1016/j.solener.2021.02.015
18. Bisht D, Garg H, Shravana Kumar R, Karar V (2019) Enhancing the performance of a passive tubular daylighting device using a parabolic-profile collector. Light Res Technol 52(4), Art no 4. https://doi.org/10.1177/1477153519872794
19. Singh S, Bisht D, Garg H (2020) Designing a laser-cut panel for light collection for daylighting using a generalised mathematical model. Light Res Technol 1477153520932626. https://doi.org/10.1177/1477153520932626
20. Singh G, Sharma K, Mehta JS, Garg, H (2020) Enhanced daylight system with acrylic based collimator. Mater Today Proc 28:1996–2002. https://doi.org/10.1016/j.matpr.2020.05.576.
21. Bisht DS, Kumar V, Singh S, Garg H, Kumar, RS(2023) Computational analysis and optimization of daylight collector geometry for removal of hotspots in circular mirror light pipe. Solar Energy 264:112066. https://doi.org/10.1016/j.solener.2023.112066
22. Kumar V, Bisht DS, Garg H (2023) Mean wavelength-based Fresnel lens solar collector for eliminating the hotpot problem in daylighting systems. Appl Opt 62(34):9188. https://doi.org/10.1364/AO.503622
23. Kumar V, Bisht DS, Garg H (2023) Design, analysis and validation of customised homocentric fresnel collector based on longest wavelength of visible spectrum. Light Res Technol. https://journals.sagepub.com/doi/abs/10.1177/14771535231207099
24. AyersBEng MJ, Carter DJ (1995) Remote source electric lighting systems: a review. Int J Light Res Technol 27(1):1–15. https://doi.org/10.1177/14771535950270010501
25. Ullah I, Whang A (2015) Development of optical fiber-based daylighting system and its comparison. Energies 8(7):7185–7201. https://doi.org/10.3390/en8077185
26. Carter D (2014) LRT digest 2 tubular daylight guidance systems. Light Res Technol 46(4):369–387. https://doi.org/10.1177/1477153514526081
27. Samuhatananon S, Chirarattananon S, Chirarattananon P (2011) An experimental and analytical study of transmission of daylight through circular light pipes. LEUKOS 7(4):203–219. https://doi.org/10.1080/15502724.2011.10732147
28. Edmonds I (2010) Transmission of mirror light pipes with triangular, rectangular, rhombic and hexagonal cross section. Sol Energy 84(6):928–938. https://doi.org/10.1016/j.solener.2010.03.001
29. Kocifaj M, Kundracik F, Darula S, Kittler R (2012) Availability of luminous flux below a bended light-pipe: design modelling under optimal daylight conditions. Sol Energy 86(9):2753–2761. https://doi.org/10.1016/j.solener.2012.06.017
30. Bisht DS, Garg H, Shravana Kumar RR, Karar V (2020) Study and analysis of parameters affecting tubular daylighting device. In: Jain VK, Kumar V, Verma A (eds) Advances in solar power generation and energy harvesting. Springer Singapore, Singapore, pp 73–92
31. Sharma K, Kumar V, Bisht DS, Garg H (2021) Comparative study of acrylic flat plate and dome shaped collector for summer and winter solstice conditions. Mater Today Proc. https://doi.org/10.1016/j.matpr.2021.02.200
32. Lightway (2014). https://www.lightwaydaylight.co.uk/products/silver/. Accessed 26 Mar 2021

33. VELUX sun tunnels (2020). https://www.velux.co.uk/products/sun-tunnels/flat-roof. Accessed 14 Oct 2020
34. Sutton SM (2022) SKYLIGHT', US5099622A, Mar 31, 1992. https://patentimages.storage.googleapis.com/a5/79/b2/8217a23b7115af/US5099622.pdf. Accessed 25 Feb 2022
35. Wienold J, Iwata T, Sarey Khanie M, Erell E, Kaftan E, Rodriguez RG, Yamin Garreton JA, Tzempelikos T, Konstantzos I, Christoffersen J, Kuhn TE, Pierson C, Andersen M (2019) Cross-validation and robustness of daylight glare metrics. Light Res Technol 51(7):983–1013. https://journals.sagepub.com/doi/10.1177/1477153519826003
36. Tracepro, illumination and non-imaging optical design & analysis tool (2020). https://www.lambdares.com/tracepro/. Accessed 14 Feb 2020
37. 3D CAD Design Software | SOLIDWORKS (2020). https://www.solidworks.com/. Accessed 14 Feb 2020
38. Pisello AL, Taylor JE, Xu X, Cotana F (2012) Inter-building effect: Simulating the impact of a network of buildings on the accuracy of building energy performance predictions. Build Environ 58:37–45. https://doi.org/10.1016/j.buildenv.2012.06.017
39. Kumar V, Bisht DS, Garg H (2023) Modeling a UVC irradiation standalone system for inactivating Mycobacterium tuberculosis from indoor spaces. Appll Opt 62(25):6652–6660. https://doi.org/10.1364/AO.498255
40. Igawa N, Nakamura H, Matsuura K (1999) Sky luminance distribution model for simulation of day lit environment. http://www.ibpsa.org/proceedings/BS1999/BS99_PB-01.pdf
41. Luminit LIGHT SHAPING SOLUTIONS—Download Technical Data for BTDF AND BSDF—Luminit LLC. https://www.luminitco.com/downloads/btdf-bsdf-data. Accessed 13 May 2022
42. Carter D (2014) LRT digest 2 tubular daylight guidance systems. Light Res Technol 46(4), Art no 4. https://doi.org/10.1177/1477153514526081
43. Solatube-commercial-product-guide-book. https://solatube.com/wp-content/uploads/2021/02/954250-v1.2_Commercial-Product-Guide-Book.pdf. Accessed 24 Jul 2023

Managing Risks Related to the Adoption of New Technologies by Various Stakeholders in Indian Construction Sector

Divya Negi, Deepak Bajaj, and Anil Sawhney

1 Introduction

The Indian construction sector is struggling with slight underperformance toward achieving equilibrium between four key elements, i.e., time, money, quality, and end-user satisfaction. The main reason behind not being able to do so is the amount of risk which usually arises knowingly or unknowingly to almost any construction project disrupting a great deal of efforts and resources. For decades the practice of risk management in construction projects has been subjective to phases of identification, analysis, mitigation, and control which are followed more or less in a similar order [14]. Undoubtedly, the process has continued to lead good results in effectively managing risks in small-scale projects and multi-scale industrial projects equally but since every construction project is distinct to one another and require different approach to address and treat their risks, the strategies which were developed earlier got tremendously evolved in due course of time.

Risk as a basic concept is slowly being understood by many and has taken a step forward toward updating themselves, keeping regular checks on what can possibly go wrong and has gone wrong in their projects. However, this is still not true for small players of Tier II and III cities and towns. Bigger engineering, procurement, and construction (EPC) companies in the country are mostly engaged in fully-fledged risk management. Their planning, activities, and tasks are made future-proof by either implementing innovative strategies or by introducing new technologies into their systems. The overall success of their projects lies in either or both being incorporated

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successfully by their team and managers. After the year 2020, the entire sector witnessed a moral obligation to transform and today incorporating new technologies in construction projects and firms is considered to be one of the best ways among all the strategies which is propagating at a very fast rate from companies to companies and professionals to individuals [15].

1.1 The Global Concept of Industry 4.0 in Construction Sector

The growth of industries together has lead to a complete revolution and this should clearly be credited to advancement in research and innovation. "From the technical point of view, Industry 4.0 can be described as the increasing digitization and automation of the manufacturing environment as well as the creation of a digital value chain to enable the communication between products and their environment and business partners. As a result, simultaneous planning of products and production processes leads to improvements in product quality and decrease time-to-market" [13]. The global concept of Industry 4.0 emerged in Indian construction sector as well and is talked through but seems still far from practicality as there are several risk factors attached to it.

2 The Purpose of the Study

With the growing focus on construction sector, reducing the susceptibility of the industry to equally enlarged and varied risks of today's world is a huge challenge in itself. It is critical for executives to predict and judge to what the future will hold for them in terms of profits, changes in scenarios, business models, or in the entire business framework. The purpose of this study is to determine the present state of technology adoption in organizations and also to identify the key risk factors affecting the adoption by performing an analysis of the technology adoption risk factors.

Based on previous studies the possible challenges for construction industry in terms of technologies are listed below [13, 17]:

- Willingness to adopt a new technology: This could be either due to high initial investment costs and maintenance costs or non-clarity on its benefits
- High implementation costs: This is due to costs on associated peripherals, IT facilities, training and education, external consultation fees, etc.
- Organizational and process changes: Due to implementation of a disruptive technology the business models and processes change significantly and thus it becomes difficult to re-evaluate and re-design at different levels

- Need for hiring skilled professionals: New technology requires specific skill and knowledge and creating a pool of workforce of the right competencies is a great challenge for construction sector
- Knowledge management: Lack of codified and shared project knowledge makes it tough to automate data management, handling enormous data without monitoring and verification restricts the use of technology
- Lack of reference, standards, and architecture: There exists a lack of standards, references, and certifications when it comes to new technology. There is a need for an industry-specific reference architecture and increased participation, collaboration, and accreditation from the government.
- Acceptance: The construction industry's conservatism, strong sense of ownership, resistance to change and not reaching toward a common consensus make it nearly impossible for new technology to infiltrate the system.
- Higher requirements for computing equipments and facilities: High-end technology requires more advanced computing devices and allied facilities which are usually low in portability and flexibility to carry from one point to another on sites. The safety, accessibility, and availability of counterparts possess another challenge
- Data security and data protection: Due to increased volumes of data, information sharing, and mobility it has become a very essential for companies to protect their sensitive data and maintain privacy from fraudulent on servers and clouds
- Enhancement of existing communication networks: Accesses to fast and reliable internet in isolated locations makes it difficult to use equipments, sensors, and mobile devices
- Legal and contractual uncertainty and regulatory compliance: Another barrier is the concern over legality, responsibility, and compliance related to the usability of new technologies
- Fear of heavy lay-offs due to smart processes of new technologies
- Increased protection of sensitive devices from dust and pollutants present on-site
- Need to establish research and development facilities for better results in innovations
- Need to ensure proper monitoring, inspection, and validation of technologies and services.

2.1 Technology Areas

The primary focus of almost all industries is to prioritize their need for adopting a suitable technology based on certain justified reasons and conditions. For say, there could be some motivating factors for the contractors, developers, consultants, or any other related professional that encourage them to assess their options and survey through the technology market so as to reach a conclusion and decide on whether to take trials and safely invest or completely abandon the idea. These reasons may range between earning more profits, growing businesses, competing among competitors, increasing speed, accuracy, and quality of projects, gaining trust and maintaining transparency of processes, increasing risk appetite, effectively managing and monitoring different projects at the same time, enhancing value chain, become more inclusive and become environmentally sustainable for future. Depending upon such reasons and purposes the demand for technology adoption varies and similarly the notion of being ‘new’ to a technology from company to company also varies. The technology that is current or is available in the latest versions can also be considered as new, and a technology which was never used earlier from the perspective of the user can also be termed as new. Therefore, we can say that being ‘new’ is a relative term for technologies and it is irrespective of the time frame.

In order to summarize key technologies which have found their purpose in the construction industry Table 1 is developed showcasing systematic differentiation of fundamental disciplines/sciences and technologies under interdisciplinary, evolving, and advanced level areas (in short Technology Areas), where the latter shares the common roots of origins from the previous. These technology areas are realms of various sets of methods, systems, processes, and devices which may be categorized based on their application, capability, utility, functionality, current state of development, and scientific knowledge domain. Also, there exists an ever-growing list of technologies that are deemed fit into the Technology Areas of Future where the research and development is still underway.

3 Literature Review

There are many studies existing related to new technologies who have shaped the face of Indian construction sector, including those of current technological trends and evolution of Industry 3.0 to 4.0. For example, Ribeirinho et al. [15], [6] [4, 17, 16] have indicated several positive signs on a transformation and digitalization of the industry as a whole. The list of possible disruptive technologies has been shared along with their likely benefits and deliverables. Even authors have tried to address the problems and issues faced by companies and stakeholders while making firm decisions on adoption and implementation of these technologies into their projects and systems, such as [1, 12] for BIM-related adoption challenges in India, [5] for the perceptions on drones being adopted in Indian construction projects, and [2] tells exactly how 3D printing was welcomed for experimentation but still is far from its absorption on the field. Also there are unlimited literatures on application of new technologies in a mixed form to achieve targets in a project, for example [19, 18] stated that using a combination of building information modeling BIM (4D, 5D), virtual and augmented reality, Internet of Things, teleoperation, soft skills, artificial intelligence applied to big data and cybersecurity to manage risks related to occupational safety and health on construction sites. Further Basir et al. [3, 20] devised solution of integrating BIM and GIS in order to improve the entire life cycle of the construction project.

Table 1 List* of fundamental disciplines/sciences and technology areas

S. no	Fundamental discipline/science (generic)	S. no.	Technology areas (in context with construction sector)
1	*Engineering*:	1	*Evolved technology areas*:
1.1	Information and communication	1.1	Architecture and interior design
1.2	Construction	1.2	Cloud computing and storage
1.3	Electronics	1.3	Construction capital, funding, and investment
1.4	Mechanical	1.4	(FinTech)
1.5	Electrical	1.5	Data analytics
1.6	Design	1.6	Digital assessment and training
		1.7	Digital payments and banking
		1.8	Earthquake resistant technology
		1.9	Industrial manufacturing and production
		1.10	Facility management
		1.11	Financial data analytics and reporting
		1.12	Planning, scheduling, and management tools
			Mobile communication and devices
2	*Applied sciences*:	2	*Interdisciplinary technology areas*:
2.1	Computer science	2.1	Augmented and virtual reality
2.2	Data science	2.2	Assistive performance technology
2.3	Energy science	2.3	Enterprise resource planning (ERP)
2.4	Environment science	2.4	Green and clean technology
2.5	Geology and geomorphology	2.5	Construction biochemical technology
2.6	Material science	2.6	Internet of Things (IoT)
2.7	Medical science—ergonomics	2.7	Simulation
		2.8	Smart operative systems
		2.9	Transportation technology and logistics
		2.10	Robotics and automation
		2.11	Network and data security
		2.12	Underground and underwater construction Technology
3	Applied Mathematics	3	*Advanced technology areas*:
4	Management	3.1	Advance construction technology
5	Banking and Finance	3.2	Advance construction materials
6	Law	3.3	Building information modeling
7	Market and sales	3.4	Business intelligence and risk management
8	Education and Research	3.5	Distributed ledger technology (blockchain)
		3.6	Enterprise regulatory technology
		3.7	Geographical information system (GIS)
		3.8	Rapid prototyping technology
		3.9	Robotic process automation
		3.10	SCADA technology

(continued)

Table 1 (continued)

S. no	Fundamental discipline/science (generic)	S. no.	Technology areas (in context with construction sector)
		4 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8	*Future technology areas*: Artificial intelligence Cloud banking technology Digital twin technology Internet of everything (IoE) Immersive reality and display Lean manufacturing Supply chain technology Smart materials

**Note* the above list is not exhaustive in terms of technologies available for construction sector
Source Author's/author's computation

So far, the literatures are exploratory when it comes to building a technique that can measure the intensity of risk exposure on construction projects. Few authors suggested a method of combining work breakdown structure and simultaneously its risk breakdown structure in the form of a two-dimensional matrix. [7] was the first literature who explain about risk breakdown matrix and how to use it for managing risks which includes numerous parameters. Several others build upon this taking their cases such as [9, 11, 10] WBS-RBS on EPC projects and for bridge construction and identifying hierarchy of fatal incidents on site.

4 Methodology

Although many literatures suggested the possible use of risk breakdown matrix (RBM) for a combination of work packages of construction projects (at y-axis) and risk breakdown structure (at x-axis) of the same [7], but there is no literature that suggests how to measure the overall risk exposure of projects by a new technology adoption. Therefore, in order to analyze quantitatively this contemporary structure a proposed version of RBM is introduced to systematically analyze the required parameters, where a modified risk breakdown matrix is constructed for a combination of technology areas (at y-axis) and risks of technology adoption (at x-axis) for all types of construction projects. A risk matrix [8] is also constructed for the likelihood of technology adoption against the impact of its adoption.

For better understanding of the modified RBM, the following Table 2 may be referred. The nomenclature given for project risk sources is RS1-15 and technology areas is TA1-15.

Under this matrix, every individual cell represents two values Pi, n and Im, j where P stands for probability of occurrence of technology adoption risk in the project and I stands for impact of adoption of that technology area (TA) on the project. The general formula for obtaining degree of criticality $(R)^{TA}$ is given by;

Table 2 Sample modified risk breakdown matrix for measuring risk exposure

Risk breakdown matrix												
			Risk breakdown structure									Values for TA
			Project risk sources									
			Task									
			RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9	
			Pi, 1	Pi,2	Pi, 3	Pi, 4	Pi, 5	Pi, 6	Pi, 7	Pi, 8	… Pi, n	ΣR i, j
Technology under the areas	TA1	I1, j										
	TA2	I2, j										
	TA3	I3, j				P 4,3 × I 3,4						
	TA4	I 4, j										
	TA5	I5, j										
	TA6	I6, j										
	TA7	I7, j										
	TA8	I8, j										
	TA9	I9, j										
	TA10	I10, j										
	TA11	I11, j										
	TA12	I12, j										
	TA13	I13, j										
	TA14	I14, j										
	TA15	…Im, j										
Risk sources evaluation		ΣR i, j										

Source Hillson, D., Grimaldi, S., and Rafele, C. (2006). Managing Project Risks Using a Cross Risk Breakdown Matrix. *Risk Management*, *8*(1), 61–76. https://doi.org/10.1057/palgrave.rm.825000

$$(R)^{TA}, i = \sum_{j=1}^{n} Pi, j * Ii, j \tag{1}$$

where $(R)^{TA}$, i is the global incidence of risks in *TA i; P i, j* is the probability of occurrence of risk-j in *TA-i*; *I i, j* is the impact of risk-j in *TA-i.*

Similarly, the sum of the values for each column identifies the relationship of all TAs of the project to a particular source of risk (RS) or the presence of risks in different TAs. The general formula is given by;

$$(R)^{RS}, j = \sum_{i=1}^{n} Pi, j * Ii, j \tag{2}$$

where $(R)^{RS}, j$ is the total effect of risk source risk-j in the whole project. The value obtained by summing columns using the second formula allows a classification of sources of technology adoption risks in terms of their influence on the project [7].

From both the Eqs. (1) and (2), the risk probability number (RPN) and probability number (PN) are calculated on each axis.

4.1 Data Collection

To gather values of probabilities and impact factors for each technology and associated risk, a detailed structured questionnaire was prepared on Google forms using Likert scale (low, medium, high and yes, no, maybe) and was sent to nearly 90 professionals working on construction projects in India out of which 40 responses were found to be appropriate for the analysis. Also, a telephonic survey was taken from 7 respondents who preferred guided filling of the same Google survey form for more clarity on thoughts.

5 Result

Each response of this pilot survey was translated into a formulation of a modified risk breakdown matrix, where a randomly selected response is represented as a sample analysis matrix in Table 3.

In the modified RBM, the risk source order shows risk probability number (RPN) obtained by $(R)^{RS}, 1$, $(R)^{RS}, 9$, and $(R)^{RS}, 2$ to be of the value 1, 2, and 3, respectively. These ranks clearly outline the importance of such technology adoption risks having the potential to significantly affect a project's growth. The technology area order shows probability number (PN) of $(R)^{TA}, 17$, $(R)^{TA}, 20$, and $(R)^{TA}, 6$ of values 1, 2, and 3, respectively [9]. And these ranks list down the technology areas which are least likely to be adopted newly to a construction project because of their higher impacts than others. Therefore, the technologies like Rapid Prototyping Technology (includes additive/subtractive manufacturing and 3D concrete printing), Artificial Intelligence, and Building Information Modeling are perceived as the top three most challenging new technologies to be adopted by any stakeholder for their projects of any scale in India. And having said that should definitely not be understood as adoption of these are not likely to happen in future. They will be adopted sooner or later. Further, the top three reasons and challenges came out to be initial investment and maintenance costs, hiring of qualified and subject-related professionals especially at the ground level, and the need to establish a strong information collection, distribution, use, and management mechanism in organizations hindering them for not getting picked up so fast in the construction sector. Also, the bottom four least risky technologies, having risk probability number (RPN = 22), are mobile communication devices and applications, smart personal protection equipments and suits (including wearables

Table 3 Modified risk breakdown matrix developed from responses of a respondent

Risk breakdown matrix									
				Risk breakdown structure					
				Project risk sources					
				RS1	RS2	RS3	RS4	RS5	RS6
				initial investment and maintenance costs	hiring qualified and subject relevent professionals, especially at the ground level	attitude towards learning new technological concepts	heavy lay-offs due to smart processes of new technologies	safety issues arising due to manhandling of systems and devices	need to establish a strong information collection, distribution, use, and management mechanism
				Pi, 1	Pi,2	Pi, 3	Pi, 4	Pi, 5	Pi, 6
	TA1	Basic and specialized softwares and tools	I1, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 3, I = 1	P = 2, I = 2
Technology under the areas	TA2	Smart PPE and exoskeleton suits	I2, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA3	Mobile communication devices and applications	I3, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA4	Data analytics tools and reporting	I 4, j	P = 3, I = 2	P = 3, I = 2	P = 1, I = 1	P = 3, I = 3	P = 1, I = 1	P = 2, I = 1
	TA5	Cloud computing and storage	I5, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	P = 3, I = 2	P = 1, I = 1	P = 1, I = 1

(continued)

Table 3 (continued)

Risk breakdown matrix									
				Risk breakdown structure					
				Project risk sources					
	TA6	Building information modelling	I6, j	P = 3, I = 3	P = 3, I = 3	P = 1, I = 1	P = 3, I = 3	P = 1, I = 1	P = 3, I = 3
	TA7	IoT tools	I7, j	P = 3, I = 2	P = 3, I = 2	P = 1, I = 1	P = 2, I = 2	P = 1, I = 1	P = 3, I = 2
	TA8	Simulation tools	I8, j	P = 3, I = 1	P = 3, I = 2	P = 1, I = 1	P = 2, I = 1	P = 1, I = 1	P = 3, I = 1
	TA9	Augmented and virtual reality tools	I9, j	P = 3, I = 3	P = 3, I = 3	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 2, I = 2
	TA10	Network and data security services and tools	I10, j	P = 3, I = 3	P = 3, I = 2	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 2, I = 2
	TA11	Interior design and decoration tools	I11, j	P = 3, I = 1	P = 3, I = 3	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA12	GIS (geographical information system), satellite navigation and mapping tools	I12, j	P = 3, I = 2	P = 3, I = 2	P = 1, I = 1	P = 2, I = 1	P = 1, I = 1	P = 2, I = 2
	TA13	Database management system (DBMS) and frameworks	I13, j	P = 3, I = 3	P = 3, I = 1	P = 1, I = 1	P = 2, I = 2	P = 1, I = 1	P = 2, I = 2
	TA14	Customer relationship management (CRM) tools	I14, j	P = 3, I = 3	P = 3, I = 2	P = 1, I = 1	P = 2, I = 2	P = 1, I = 1	P = 2, I = 2

(continued)

Table 3 (continued)

Risk breakdown matrix									
				Risk breakdown structure					
				Project risk sources					
	TA15	Enterprise resource planning (ERP) tools	I15, j	P = 2, I = 2	P = 3, I = 2	P = 1, I = 1	P = 2, I = 2	P = 1, I = 1	P = 2, I = 1
	TA16	Green technology	I16, j	P = 2, I = 2	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA17	Rapid prototyping technology	I17, j	P = 3, I = 3	P = 3, I = 2	P = 1, I = 1	P = 3, I = 3	P = 1, I = 1	P = 3, I = 3
	TA18	Construction biochemical technology	I18, j	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA19	Earthquake and seismic technology	I19, j	P = 3, I = 3	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA20	Artificial intelligence	I20, j	P = 3, I = 3	P = 3, I = 3	P = 1, I = 1	P = 3, I = 3	P = 1, I = 1	P = 1, I = 1
	TA21	Offsite manufacturing	I21, j	P = 3, I = 3	P = 3, I = 3	P = 1, I = 1	P = 3, I = 2	P = 3, I = 1	P = 1, I = 1
	TA22	Education and training tools	I22, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA23	SCADA	I23, j	P = 3, I = 3	P = 2, I = 2	P = 1, I = 1	P = 3, I = 2	P = 3, I = 1	P = 3, I = 3
	TA24	Robotics and automation	I24, j	P = 3, I = 2	P = 2, I = 1	P = 1, I = 1	P = 3, I = 3	P = 3, I = 1	P = 2, I = 1
	TA25	Smart operative systems	I25, j	P = 3, I = 2	P = 2, I = 1	P = 1, I = 1	P = 2, I = 1	P = 3, I = 1	P = 2, I = 1

(continued)

Table 3 (continued)

Risk breakdown matrix									
				Risk breakdown structure					
				Project risk sources					
	TA26	Multifunctional machines and equipments	I26, j	P = 3, I = 1	P = 2, I = 1	P = 1, I = 1	P = 2, I = 1	P = 3, I = 1	P = 1, I = 1
	TA27	Advance surveying technology	I27, j	P = 3, I = 3	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	P = 3, I = 1	P = 1, I = 1
	TA28	Robotic process automation	I28, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	P = 3, I = 1	P = 1, I = 1	P = 3, I = 2
	TA29	Distributed ledger technology (blockchain)	I29, j	P = 3, I = 1	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 2, I = 2
	TA30	Enterprise regulatory technology	I30, j	P = 3, I = 1	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 3, I = 2
	TA31	Logistics and transportation technology	I31, j	P = 3, I = 1	P = 2, I = 2	P = 1, I = 1	P = 2, I = 1	P = 1, I = 1	P = 2, I = 2
	TA32	Digital payments and banking tools	I32, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA33	Modern formwork systems	I33, j	P = 3, I = 2	P = 3, I = 2	P = 1, I = 1	P = 1, I = 1	P = 3, I = 1	P = 1, I = 1

(continued)

Table 3 (continued)

	Risk sources evaluation			171	130	33	107	49	102
	Risk sources order			1	3	13	5	10	6
				RS7	RS8	RS9	RS10	RS11	RS12
				increased protection of sensitive devices from dust and pollutants present on-site	providing contractors and sub-contractors the necessary skills and understanding of the processes	need to ensure proper monitoring, inspection, and validation of services	Lack of regulation, standards, and certifications	getting a common consensus on the adoption from the employees and management	need to establish research and development facilities
				Pi, 7	Pi, 8	Pi, 9	Pi, 10	Pi, 11	Pi, 12
Technology under the areas	TA1	Basic and specialized softwares and tools	I1, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 2	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1
	TA2	Smart PPE and exoskeleton suits	I2, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA3	Mobile communication devices and applications	I3, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA4	Data analytics tools and reporting	I 4, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 2	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1
	TA5	Cloud computing and storage	I5, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1
	TA6	Building information modelling	I6, j	P = 1, I = 1	P = 2, I = 1	P = 3, I = 3	P = 2, I = 1	P = 1, I = 1	P = 2, I = 1

(continued)

Table 3 (continued)

	Risk sources evaluation			171	130	33	107	49	102
	Risk sources order			1	3	13	5	10	6
	TA7	IoT tools	I7, j	P = 1, I = 1	P = 2, I = 1	P = 3, I = 2	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1
	TA8	Simulation tools	I8, j	P = 1, I = 1	P = 2, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA9	Augmented and virtual reality tools	I9, j	P = 1, I = 1	P = 2, I = 1	P = 2, I = 2	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1
	TA10	Network and data security services and tools	I10, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 2	P = 3, I = 3	P = 1, I = 1	P = 1, I = 1
	TA11	Interior design and decoration tools	I11, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA12	GIS (geographical information system), satellite navigation and mapping tools	I12, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 3	P = 3, I = 3	P = 1, I = 1	P = 1, I = 1
	TA13	Database management system (DBMS) and frameworks	I13, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 3	P = 3, I = 2	P = 1, I = 1	P = 1, I = 1
	TA14	Customer relationship management (CRM) tools	I14, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 2	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1

(continued)

Table 3 (continued)

	Risk sources evaluation			171	130	33	107	49	102
	Risk sources order			1	3	13	5	10	6
	TA15	Enterprise resource planning (ERP) tools	I15, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 2	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1
	TA16	Green technology	I16, j	P = 1, I = 1	P = 2, I = 2	P = 2, I = 1	P = 2, I = 2	P = 1, I = 1	P = 2, I = 1
	TA17	Rapid prototyping technology	I17, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 3	P = 3, I = 3	P = 1, I = 1	P = 2, I = 1
	TA18	Construction biochemical technology	I18, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 2	P = 3, I = 3	P = 1, I = 1	P = 2, I = 1
	TA19	Earthquake and seismic technology	I19, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 2	P = 3, I = 3	P = 1, I = 1	P = 1, I = 1
	TA20	Artificial intelligence	I20, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 1	P = 3, I = 2	P = 1, I = 1	P = 1, I = 1
	TA21	Offsite manufacturing	I21, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 3	P = 3, I = 2	P = 1, I = 1	P = 1, I = 1
	TA22	Education and training tools	I22, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA23	SCADA	I23, j	P = 1, I = 1	P = 2, I = 1	P = 2, I = 2	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1
	TA24	Robotics and automation	I24, j	P = 1, I = 1	P = 2, I = 1	P = 2, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1
	TA25	Smart operative systems	I25, j	P = 1, I = 1	P = 2, I = 1	P = 1, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1

(continued)

Table 3 (continued)

	Risk sources evaluation			171	130	33	107	49	102
	Risk sources order			1	3	13	5	10	6
	TA26	Multifunctional machines and equipments	I26, j	P = 1, I = 1	P = 2, I = 1	P = 2, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1
	TA27	Advance surveying technology	I27, j	P = 1, I = 1	P = 2, I = 1	P = 3, I = 3	P = 3, I = 2	P = 1, I = 1	P = 1, I = 1
	TA28	Robotic process automation	I28, j	P = 1, I = 1	P = 2, I = 1	P = 1, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1
	TA29	Distributed ledger technology (blockchain)	I29, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1
	TA30	Enterprise regulatory technology	I30, j	P = 1, I = 1	P = 2, I = 1	P = 2, I = 1	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1
	TA31	Logistics and transportation technology	I31, j	P = 1, I = 1	P = 2, I = 1	P = 2, I = 1	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1
	TA32	Digital payments and banking tools	I32, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1
	TA33	Modern formwork systems	I33, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1

(continued)

Table 3 (continued)

	Risk sources evaluation			33	43	133	121	33	37
	Risk sources order			13	11	2	4	13	12
				RS13	R14	RS15	Values for TA	TA Order	
				proper internet connectivity and other IT facilities and services	significant organizational and process change	govermental policy change and legalities			
				Pi, 13	Pi, 14	Pi, 15			
Technology under the areas	TA1	Basic and specialized softwares and tools	I1, j	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	31	17	
	TA2	Smart PPE and exoskeleton suits	I2, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	17	22	
	TA3	Mobile communication devices and applications	I3, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	17	22	
	TA4	Data analytics tools and reporting	I 4, j	P = 2, I = 1	P = 1, I = 1	P = 1, I = 1	39	15	
	TA5	Cloud computing and storage	I5, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	26	21	
	TA6	Building information modelling	I6, j	P = 3, I = 1	P = 2, I = 2	P = 1, I = 1	63	3	
	TA7	IoT tools	I7, j	P = 3, I = 1	P = 2, I = 1	P = 1, I = 1	43	11	
	TA8	Simulation tools	I8, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	30	18	
	TA9	Augmented and virtual reality tools	I9, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	41	13	
	TA10	Network and data security services and tools	I10, j	P = 3, I = 1	P = 1, I = 1	P = 2, I = 1	47	8	
	TA11	Interior design and decoration tools	I11, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	30	18	
	TA12	GIS (geographical information system), satellite navigation and mapping tools	I12, j	P = 3, I = 1	P = 2, I = 1	P = 2, I = 1	49	7	
	TA13	Database management system (DBMS) and frameworks	I13, j	P = 3, I = 1	P = 3, I = 2	P = 1, I = 1	46	9	
	TA14	Customer relationship management (CRM) tools	I14, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	42	12	
	TA15	Enterprise resource planning (ERP) tools	I15, j	P = 3, I = 1	P = 2, I = 1	P = 1, I = 1	36	16	

(continued)

Table 3 (continued)

	Risk sources evaluation			33	43	133	121	33	37
	Risk sources order			13	11	2	4	13	12
	TA16	Green technology	I16, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 1	30	18	
	TA17	Rapid prototyping technology	I17, j	P = 1, I = 1	P = 3, I = 3	P = 2, I = 1	70	1	
	TA18	Construction biochemical technology	I18, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	30	18	
	TA19	Earthquake and seismic technology	I19, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 1	40	14	
	TA20	Artificial intelligence	I20, j	P = 3, I = 1	P = 3, I = 3	P = 2, I = 1	65	2	
	TA21	Offsite manufacturing	I21, j	P = 1, I = 1	P = 1, I = 1	P = 2, I = 1	52	5	
	TA22	Education and training tools	I22, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	17	22	
	TA23	SCADA	I23, j	P = 3, I = 3	P = 2, I = 2	P = 1, I = 1	57	4	
	TA24	Robotics and automation	I24, j	P = 2, I = 2	P = 2, I = 2	P = 3, I = 3	50	6	
	TA25	Smart operative systems	I25, j	P = 3, I = 2	P = 2, I = 2	P = 2, I = 2	39	15	
	TA26	Multifunctional machines and equipments	I26, j	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	26	21	
	TA27	Advance surveying technology	I27, j	P = 2, I = 2	P = 1, I = 1	P = 1, I = 1	45	10	
	TA28	Robotic process automation	I28, j	P = 3, I = 1	P = 2, I = 1	P = 1, I = 1	30	18	
	TA29	Distributed ledger technology (blockchain)	I29, j	P = 3, I = 1	P = 1, I = 1	P = 2, I = 1	27	20	
	TA30	Enterprise regulatory technology	I30, j	P = 3, I = 1	P = 1, I = 1	P = 2, I = 1	30	18	
	TA31	Logistics and transportation technology	I31, j	P = 3, I = 1	P = 1, I = 1	P = 1, I = 1	29	19	
	TA32	Digital payments and banking tools	I32, j	P = 1, I = 1	P = 1, I = 1	P = 3, I = 1	17	22	
	TA33	Modern formwork systems	I33, j	P = 1, I = 1	P = 1, I = 1	P = 1, I = 1	27	20	
	Risk sources evaluation			94	69	55			
	Risk sources order			7	8	9			

Source Author's/Author's Computation

such as armbands, health trackers, smart helmets, goggles, gloves, safety harness, etc.), digital training and assessment tools, and digital payments and banking tools. The risk matrix is developed for all the 33 technology areas mentioned in Table 4 as per the same response received from the survey. It depicts the level of acceptance of technologies in the sector from his/her perspective, where Mobile Communication and Devices TA3, Augmented and Virtual Reality Tools TA9, Customer Relationship Management (CRM) Tools TA14, Green and Clean Technology TA16, Rapid Prototyping Technology TA17, Earthquake Resistant Technology TA19, Offsite Manufacturing TA21, Advance Surveying Tools TA27, and Digital Payments and Banking Tools TA32 are among the technologies having a greater chance of adoption (not in the same order of importance) regardless of the construction risks they are capable of managing in projects and organizations.

Similarly, the rest of the survey responses were analyzed and the technology area having the highest chances of being adopted is Mobile Communication and Devices TA3 (Total count = 39/40). This was simply derived based on the total number of counts appearing in either of the bottom three TA order ranks from each modified RBM. The highest chance of a technology area not being adopted came out to be SCADA TA23 (Total count = 2/40). The technology adoption risk factor being the highest is investment and maintenance cost R1 (Total count = 32/40), and the least is the increased protection of sensitive devices from dust and pollutants on site R7 (Total count = 6/40).

Table 4 Risk matrix of technology areas based on survey response

<table>
<tr><th colspan="4">RISK matrix of technology area</th></tr>
<tr><td rowspan="2">Likelyhood of being adopted</td><td colspan="3">Impact of adoption on project</td></tr>
<tr><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td rowspan="2">Unlikely</td><td>TA1, TA4, TA5, TA6, TA7, TA8, TA10,TA11</td><td rowspan="2"></td><td rowspan="2">TA30</td></tr>
<tr><td>TA13, TA20, TA23, TA25, TA28, TA29, TA31</td></tr>
<tr><td rowspan="2">Likely</td><td>TA12, TA15,</td><td>TA18, TA26,</td><td rowspan="2">TA2</td></tr>
<tr><td>TA22, TA24</td><td>TA33</td></tr>
<tr><td rowspan="2">Certain</td><td rowspan="2"></td><td rowspan="2"></td><td>TA3, TA9, TA14, TA16, TA17,</td></tr>
<tr><td>TA19,TA21, TA27, TA32</td></tr>
</table>

Source Hussey, D. E. (1978). Portfolio analysis: Practical experience with the Directional Policy Matrix. *Long Range Planning*, *11*(4), 2–8. https://doi.org/10.1016/0024-6301(78)90001-8

6 Conclusion

It is unarguably the adoption risks of the technologies or technology areas which are dragging down the pace of the construction sector in India. Therefore, based on the above findings of the study it may be concluded that both the analysis techniques together can measure which type of new technology (or technology area) is being gravely affected by which type of adoption risk and thus influencing the overall likelihood of the adoption in projects from the viewpoint of the stakeholder. In other words, this pilot research study tried to reveal the present case scenario of the adoption of various new technologies in India.

7 Limitations and Future Scope of Study

The overall scope of this study is limited to when there is a need to gauge each technology area on the level of its complete potential vis-à-vis its exact utility as a risk factor for its adoption. Also, there was seen as an unquestionable relation between the technology adoption and the type of organizations, and type of project, such as residential, commercial, institutional, industrial, infrastructure, agriculture, etc., along with the scale of the organizations involved. The future progress in the study can be made by testing the feasibility of the analysis method for another set of adoption risks with some other set of new technologies or futuristic technologies. The data collection can also be further enhanced by introducing Delphi technique, personal interview, or any other suitable form of survey.

References

1. Ahuja R, Jain M, Sawhney A, Arif M (2016) Adoption of BIM by architectural firms in India: technology–organization–environment perspective. Archit Eng Des Manage 12(4):311–330. https://doi.org/10.1080/17452007.2016.1186589
2. Anjum T, Dongre P, Misbah F, Nanyam VPSN (2017) Purview of 3DP in the Indian built environment sector. Proc Eng 196(June):228–235. https://doi.org/10.1016/j.proeng.2017.07.194
3. Basir WNFWA, Majid Z, Ujang U, Chong A (2018) Integration of GIS and BIM techniques in construction project management—a review. Int Arch Photogram Rem Sens Spat Inf Sci ISPRS Arch 42(4/W9):307–316. https://doi.org/10.5194/isprs-archives-XLII-4-W9-307-2018
4. Benz SM (1997) The project manager's CADD survival guide. The Project Manager's CADD Survival Guide, May. https://doi.org/10.1061/9780784402474
5. Charlesraj VPC, Rakshith N (2020) Stakeholder perspectives on the adoption of drones in construction projects. In: Proceedings of the 37th international symposium on automation and robotics in construction, ISARC 2020: from demonstration to practical use—to new stage of construction robot, October, pp 1227–1234. https://doi.org/10.22260/isarc2020/0168
6. Digitalisation in construction report 2022 RESEARCH IP i Digitalisation in construction report 2022

7. Hillson D, Grimaldi S, Rafele C (2006) Managing project risks using a cross risk breakdown matrix. Risk Manage 8(1):61–76. https://doi.org/10.1057/palgrave.rm.8250004
8. Hussey DE (1978) Portfolio analysis: practical experience with the directional policy matrix. Long Range Plan 11(4):2–8. https://doi.org/10.1016/0024-6301(78)90001-8
9. Iranmanesh H, Jalili M, Pirmoradi Z (2007) Developing a new structure for determining time risk priority using risk breakdown matrix in EPC projects. In: IEEM 2007: 2007 IEEE international conference on industrial engineering and engineering management, 1, 999–1003. https://doi.org/10.1109/IEEM.2007.4419342
10. Jeong J, Jeong J (2021) Novel approach of the integrated work & risk breakdown structure for identifying the hierarchy of fatal incident in construction industry. J Build Eng 41:102406. https://doi.org/10.1016/j.jobe.2021.102406
11. Li QF, Zhang P, Fu YC (2013) Risk identification for the construction phases of the large bridge based on WBS-RBS. Res J Appl Sci Eng Technol 6(9):1523–1530. https://doi.org/10.19026/rjaset.6.3863
12. Mohanta A, Das S (2022) Causal analysis of slow BIM adoption in Eastern India with a special focus on green building sector. J Inst Eng (India) Ser A 103(1):319–337. https://doi.org/10.1007/s40030-021-00561-w
13. Oesterreich TD, Teuteberg F (2016) Understanding the implications of digitisation and automation in the context of Industry 4.0: a triangulation approach and elements of a research agenda for the construction industry. Comput Ind 83:121–139. https://doi.org/10.1016/j.compind.2016.09.006
14. Project Management Institute (nd) The standard for project management and a guide to the project management body of knowledge (PMBOK guide)
15. Ribeirinho MJ, Blanco JL, Mischke J, Rockhill D, Sjödin E, Strube G, Palter R, Andersson T (2020) The next normal in construction. Mckinsey & Company, p 84
16. Sawhney A, Riley M, Irizarry J, Pérez CT (2020) A proposed framework for Construction 4.0 based on a review of literature. 1, 301–291. https://doi.org/10.29007/4nk3
17. Singh A, Kumar V, Verma P, Kandasamy J (2022) Identification and severity assessment of challenges in the adoption of industry 4.0 in Indian construction industry. Asia Pac Manage Rev. https://doi.org/10.1016/j.apmrv.2022.10.007
18. Tender M, Couto JP (2022) Prevention of occupational risks in a construction site using BIM. In: Studies in systems, decision and control, vol 406. https://doi.org/10.1007/978-3-030-89617-1_6
19. Tender M, Couto JP, Gibb A, Fuller P, Yeomans S (2022) Emerging technologies for health, safety and well-being in construction industry. In: Structural integrity, vol. 20. https://doi.org/10.1007/978-3-030-82430-3_16
20. Wan Abdul Basir WNFA, Ujang U, Majid Z, Azri S, Choon TL (2020) The integration of bim and gis in construction project—a data consistency review. Int Arch Photogram Rem Sens Spat Inf Sci ISPRS Arch 44(4/W3):107–116. https://doi.org/10.5194/isprs-archives-XLIV-4-W3-2020-107-2020

Study on Suitability, Effectiveness, and Acceptability of Structural Health Monitoring Systems in Indian Construction Industry

Pavan Prasad Bolla and Fozail Misbah

1 Introduction

Structural Health Monitoring being a potential tool offer real-time data on the state and performance of structures. structural health monitoring (SHM) has become an important subject of research in the construction industry. In recent years, there has been a surge of interest in the Indian construction sector in using SHM systems to assure the safety and longevity of structures. The purpose of this research article is to investigate the appropriateness, efficacy, and acceptance of SHM systems in the Indian construction sector.

The construction sector in India has grown significantly in recent years, and as building activities have increased, so has the demand for dependable and cost-effective monitoring systems. According to Bhide and Choudhary, the construction sector in India would increase at a 7.1% annual pace from 2019 to 2023. The use of SHM systems can aid in the early detection of structural faults, the prevention of catastrophic failures, and the general performance of the structure [1].

The current situation of the Indian construction sector and the necessity for SHM systems will be reviewed first in this study paper. After that, the article will present an overview of SHM technology, covering the many types of sensors and data analysis methodologies employed. The study will then look into the applicability of SHM systems in the Indian construction sector, as well as the obstacles and constraints of putting such systems in place.

The efficiency of SHM systems in the Indian construction sector, particularly the accuracy and dependability of data collected from such systems, will also be assessed. SHM approaches, according to Islam and Kumar, have been found to be successful in recognizing deterioration in civil infrastructure. The research will then look into the

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acceptability of SHM systems in the Indian construction sector, including industry experts' attitudes and views of such systems [2–6].

This study focuses (Objective) on deriving Factors impacting adoption of SHM systems, Factors contributing to adoption of SHM systems, and also it gives the interdependency between each variable which justifies the title. By which the reader can come to a conclusion and understand the driving factors which help to adopt SHM in the Indian Construction Industry.

2 Review of Literature

Structural Health Monitoring (SHM) systems have become a crucial instrument in the construction industry for assuring the safety and longevity of structures. The use of SHM systems can aid in the early detection of structural faults, the prevention of catastrophic failures, and the general performance of the structure.

2.1 Structural Health Monitoring (SHM)

Sensors are used in SHM technology to collect data on the condition and performance of structures. The obtained data is evaluated to detect any structural damage or degeneration. Strain gauges, accelerometers, and displacement sensors are examples of sensors utilized in SHM systems. Statistical analysis, signal processing, and machine learning algorithms are among the data analysis approaches employed (Bhuyan and Chakraborty) [4, 7–9].

2.2 Construction Accidents in India

In recent years, India's construction sector has grown significantly, but it is also connected with a high rate of accidents. The construction business has the largest number of deaths in India, according to the National Crime Records Bureau (NCRB) [10]. A big contributor to these incidents is a lack of effective structure maintenance and monitoring.

2.3 Factors Impacting Adoption of SHM

Notwithstanding the advantages of SHM systems, various variables impact their use in the construction sector. These factors include installation costs, a lack of understanding among industry professionals, and the technology's complexity. Furthermore, the lack of rules requiring the use of SHM systems is a hurdle to their implementation (Wang et al.) [3].

2.4 Acceptance of SHM in India

SHM system acceptability in the Indian construction sector is still in its early phases. While there is an increasing understanding of the benefits of SHM systems, there are currently no rules mandating their usage. Nevertheless, the expense of deployment remains a substantial obstacle to their widespread acceptance. Yet, industry professionals are rapidly realizing the value of SHM systems in assuring structural safety and longevity (Zhang and Liu) [11].

2.5 Correlation Matrix as Analysis Tool

In recent years, there has been an increasing interest in using correlation matrix analysis to better understand the link between various factors that influence the utilization of Structural Health Monitoring (SHM) systems in the Indian construction sector. Correlation matrix analysis is a statistical approach used to determine the degree and direction of a link between two or more variables. Researchers may use this method to determine the important variables influencing the use of SHM systems in the Indian construction sector and design strategies to address these problems.

Many studies have utilized correlation matrix analysis to uncover the characteristics that influence SHM system acceptance and usage in the Indian construction sector. For example, Singh and Gupta [14] employed correlation matrix analysis to determine the link between cost, dependability, and convenience of use and the adoption of SHM systems in the Indian construction sector. According to the survey, the most important elements influencing the adoption of SHM systems in India are cost and dependability [13]. Similarly, Sharma et al. 13 employed correlation matrix analysis to determine the parameters impacting SHM system deployment in the Indian construction sector. The study found numerous critical factors influencing the deployment of SHM systems in India, including awareness, government backing, and standardization [12].

Kumar et al. 12 conducted another study that employed correlation matrix analysis to determine the association between several factors such as construction accidents and aging infrastructure and the requirement for SHM systems in the Indian construction sector. The study discovered that the main cause of the variables contributing to the deployment of SHM systems in India was outdated infrastructure and an increase in high-rise buildings [11].

Overall, these studies show how correlation matrix analysis may be used to determine the characteristics that influence the use of SHM systems in the Indian construction sector. Policymakers, industry leaders, and other stakeholders may design strategies to support the safe, dependable, and sustainable growth of the Indian construction sector by identifying the important variables influencing the adoption and implementation of SHM systems in India [13–15].

3 Research Methodology

This study focuses on 2 major objectives that are to understand the Factors impacting and Factors contributing to the adoption of Structural Health Monitoring Systems in the Indian Construction Industry. And also, this study involves a literature study to understand the various factors apart from the method used below.

This study will involve a survey among real estate professionals and users to get their thoughts on the possible advantages, obstacles, and efficiency of applying SHM in the structures to avoid damage, enhance maintenance practices, and save costs. And focus group interviews with property owners and real estate professionals to get their thoughts on the usage of SHM in the sector in order to assess its acceptability.

In addition, we will poll a wider sample of property owners and real estate professionals to get additional quantitative data on their perspectives regarding SHM implementation. To assess the acceptance of SHM Systems in the Indian market, we will use the classic Technological Acceptance Model (TAM) in conjunction with factors such as User Experience, Effectiveness of SHM, etc.

As this study involves two major study areas, i.e., Factors Impacting adoption of SHM Systems and Factors Contributing to adoption of SHM systems. The methodology adopted for both the study areas is given below in two different flow charts (Figs. 1 and 2).

The ranking of the factors as given in the above Flowchart is done by the Relative Importance Index (RII).

The Relative Importance Index (RII) method was used to determine the factors that impact the usage of Structural Health Monitoring (SHM) systems in the Indian construction industry. A survey was conducted among 70 construction professionals, including engineers, architects, project managers, and contractors, who have experience in implementing or using SHM systems in their projects. They were asked to rate the importance of 10 factors on a scale of 1–5, where 1 denotes least important and 5 denotes most important.

The process of calculating the RII is using the formula given below

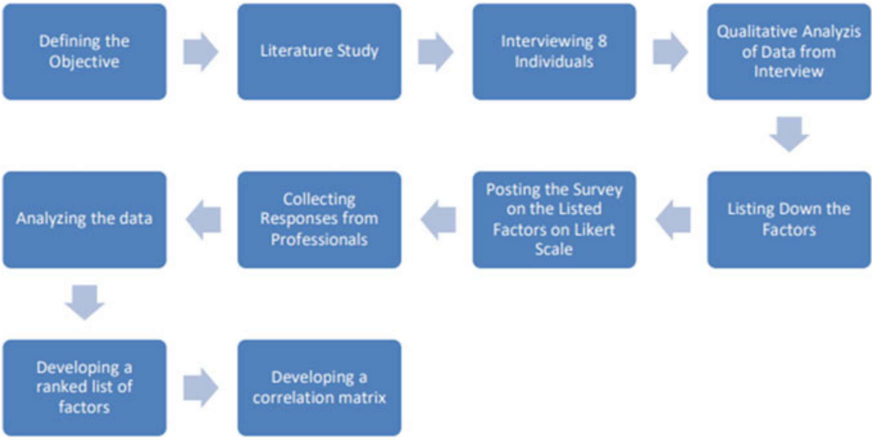

Fig. 1 Methodology for identifying factors contributing to adoption of SHM

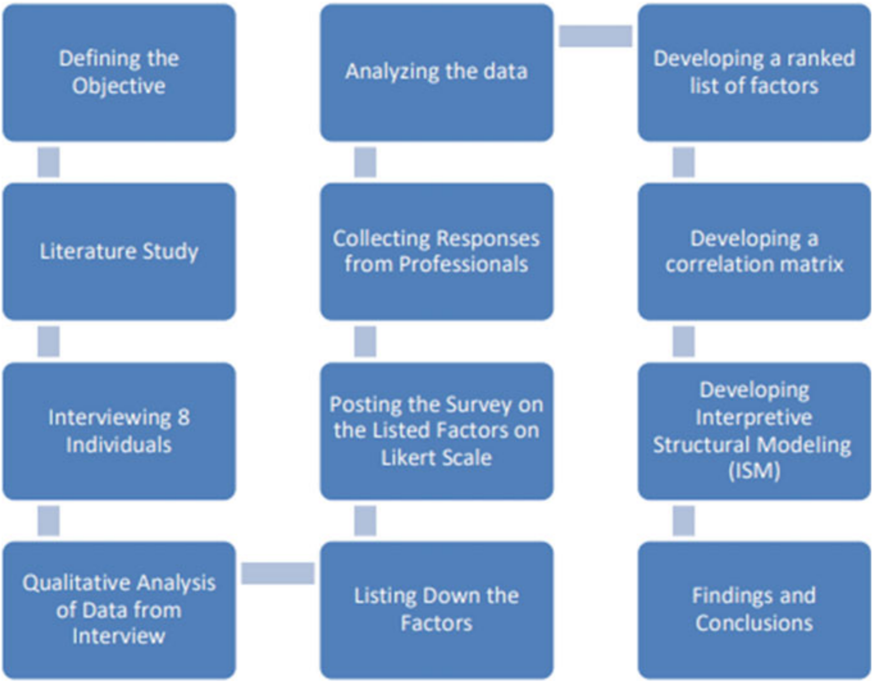

Fig. 2 Methodology for identifying factors impacting adoption of SHM

$$\mathrm{RII} = \frac{\sum W}{A * N}$$

where W = Weightage given by the participants

A = Highest Weightage (A = 5 in this case)

N = Sample size.

And for the factors derived after the ranking correlations are studied using a correlation matrix for the high impacting factors and high contributing factors and they are analyzed based on correlation values between factors. This correlation matrix can help the reader to understand the relationship between independent factors. This table is generated from the results obtained from the survey on a scale of 1–5, and the results are analyzed using a correlation formula.

$$r = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{}[n\sum x^2 - \left(\sum x\right)^2][n\sum y^2 - \left(\sum y\right)^2]}$$

where r = Correlation between two variables

n = Sample size

x = Result of Variable-1

y = Result of Variable-2.

4 Results

The survey was conducted among 70 construction professionals, including engineers, architects, project managers, and contractors, who have experience in implementing or using SHM systems in their projects. They were asked to rate the importance of 10 factors on a scale of 1–5, where 1 denotes least important and 5 denotes most important. The below results are tabulated after ranking them using RII (Formula mentioned in the methodology).

Table 1 shows the Factors which are impacting the adoption of SHM systems in India.

Table 2 shows the Factors which are contributing to the adoption of SHM systems in India.

And for the top 8 highly ranked factors, correlation was found out using the survey data and the correlation matrix is tabulated below for both the Factors (Formula is discussed in methodology). This correlation matrix is used to understand the mutual relationship between all the factors which will help in understanding the factors which are dependable on each other and how strong the relationship is.

Table 3 shows the Correlation between the Factors which are impacting the adoption of SHM systems in India.

Table 1 Factors impacting adoption of SHM

S.no	Factors	RII	Classification
1	Government support	0.90000	High impacting factors
2	Standardization	0.90000	
3	Resistance to change	0.89231	
4	Lack of trust	0.87692	
5	Cost	0.86923	
6	Awareness	0.86923	
7	Regulations	0.86923	
8	Maintenance	0.86154	
9	Funding	0.86154	
10	Integration with existing systems	0.83846	Moderately impacting factors
11	Infrastructure	0.83077	
12	Dependence on foreign technologies	0.83077	
13	Interoperability	0.83077	
14	Integration with other systems	0.80769	
15	Data management	0.80000	
16	Limited research and development	0.79231	Low impacting factors
17	Technical competence	0.77692	
18	Data privacy and security	0.77692	
19	Lack of case studies	0.71538	

Table 4 shows the Correlation between Factors which are contributing to the adoption of SHM systems in India.

For all the results obtained the analysis is made in Sect. 5.

5 Analysis and Discussion of Results

For the Factors impacting adoption of SHM systems in India are

- All the factors are positively correlated except government support and regulations because both the things are taken care of by the government, so it is having a negative correlation, but it is near to zero which means both are independent.
- In the matrix Awareness and Standardization are having high correlation value ($r = 0.638$), which is saying that both the factors are strongly related/dependent on each other.

Table 2 Factors contributing to adoption of SHM

S.no	Factors	RII	Classification
1	High rise constructions	0.90000	High contributing factors
2	Aging infrastructure	0.90000	
3	Increase in construction accidents	0.89231	
4	Increase in construction activities	0.87692	
5	Risk of structural failure	0.86923	
6	Improved longetivity and durability of Structures	0.86923	
7	Cost efficiency	0.86153	
8	Benificial for diasaster management	0.85384	
9	Growth in transportation network	0.84615	
10	Need for efficient maintenance	0.83846	Moderately contributing factors
11	Improved safety standards	0.83846	
12	Sustainability goals of country	0.83076	
13	Real-time structural analysis	0.83076	
14	Awareness and understanding of SHM benefits	0.83076	
15	Sustainability of economy	0.80769	
16	Reduce carbon footprint	0.80000	Low contributing factors
17	Integrate with IoT and AI	0.79230	
18	Seismic activity	0.77692	
19	Technological advancements	0.77692	
20	Certification and accrediation	0.73846	
21	100% Utilization of structure	0.71538	

- We can observe that government support and standardization are also strongly related to each other ($r = 0.61$)
- So, we can draw many conclusions from the correlation matrix, which helps people to understand the root cause as well as the dependency of one factor on another.

For the Factors contributing to adoption of SHM systems in India

- All the factors analyzed are positively correlated, which means all the factors are dependent to each other.
- Here High-rise Constructions and Aging infrastructure are having high correlation ($r = 0.619$) which means these two are strongly dependent on each other.

Table 3 Correlation matrix for factors impacting adoption of SHM

Factors	Cost	Awareness	Resistance to change	Government support	Standardization	Lack of trust	Regulations	Maintenance	Funding
Cost	1								
Awareness	0.3268	1							
Resistance to change	0.4235	0.2798857	1						
Government support	0.1649	0.5398687	0.19082601	1					
Standardization	0.055	0.6380267	0.19082601	0.61904762	1				
Lack of trust	0.2593	0.1403621	0.47752932	0.08852144	0.17704289	1			
Regulations	0.3731	0.0755106	0.07020768	−0.0414103	0.20705152	0.11843	1		
Maintenance	0.2015	0.2606886	0.49473053	0.39144554	0.23486732	0.06717	0.01571	1	
Funding	0.1112	0.0993099	0.33786475	0.07828911	0.31315643	0.358241	0.21996	0.16336634	1

Table 4 Correlation matrix for factors contributing to adoption of SHM

Factors	Risk of structural failure	Increase in construction accidents	High rise constructions	Aging infrastructure	Increase in construction activities	Benificial for diasaster management	Improved longetivity and durability of structures	Cost-efficiency	Growth in Transportation Network
Risk of structural failure	1								
Increase in construction accidents	0.423486	1							
High rise constructions	0.164857	0.190826009	1						
Aging infrastructure	0.054953	0.190826009	0.619048	1					
Increase in construction activities	0.259313	0.47752932	0.088521	0.177043	1				
Benificial for diasaster management	0.351746	0.57789778	0.042607	0.042607	0.499600791	1			
Improved longetivity and durability of structures	0.371271	0.070207681	−0.04141	0.207052	0.118430305	0.339169016	1		
Cost-efficiency	0.20154	0.494730532	0.391446	0.234867	0.067170258	0.199371854	0.015711114	1	
Growth in transportation network	0.158734	0.159853026	0.500688	0.143054	0.046026323	0.152613102	−0.004784689	0.420629	1

- By understanding the correlations among all the factors, we can come to conclusion that which factor is the major important factor which is contributing to adoption of SHM systems in India.
- And also we can draw many conclusions and can understand relationships between different variables.

6 Conclusion and Recommendations

In conclusion, this study emphasizes the crucial need of deploying Structural Health Monitoring (SHM) systems in the Indian construction sector. The demand for dependable and effective monitoring systems has been exacerbated by aging infrastructure and the fast increase in high-rise building. Findings from the study show that SHM technologies have the potential to improve the Indian construction industry's safety, dependability, and sustainability.

This research also highlights three important elements influencing the use of SHM systems in India: awareness, government assistance, and standardization. Despite increased recognition of the importance of SHM systems in the construction sector, there is still a large knowledge gap among stakeholders. As a result, focused outreach and education campaigns to raise awareness and promote the benefits of SHM systems are required.

Additionally, government assistance is essential for encouraging the implementation of SHM systems in India. According to the findings, regulatory frameworks and standards must be tightened to ensure the safety, quality, and consistency of SHM systems, while also taking into account the specific demands and context of the Indian construction sector.

Furthermore, standardization is critical for expanding the use of SHM systems in India. SHM system dependability and cost-effectiveness are hampered by a lack of uniformity in their design, installation, and maintenance. As a result, industry-wide standards that enable the development of SHM systems and promote their long-term usage are required.

In conclusion, this study highlights the root causes of the need for SHM systems in India, namely aging infrastructure and the rapid increase in high-rise constructions. We also identify critical factors that impact the usage of SHM systems in India, including awareness, government support, and standardization. By addressing these factors, we can promote the safe, reliable, and sustainable growth of the Indian construction industry, ensuring that it remains a key driver of India's economic development.

As per the whole study conducted the suggestions prescribed by us are:

- Examine the potential of SHM systems in addressing specific safety problems in the Indian construction sector, such as earthquake and other natural catastrophe risks.
- Do a comparison of SHM systems used in other countries to better understand their relevance and efficacy in the Indian setting.

- Investigate the potential of new technologies like the Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML) to improve the efficacy and cost-effectiveness of SHM systems in the Indian construction sector as these technologies help to reduce the cost of the technologies.
- Do a research to determine the economic benefits of deploying SHM systems in the Indian construction sector, such as lower maintenance costs, enhanced efficiency, and better asset management.
- Research and create solutions to overcome the social and cultural hurdles to the implementation of SHM systems in the Indian construction sector.
- Assess the influence of government policies and regulations on the adoption and implementation of SHM systems in the Indian construction sector.
- Examine the role of public–private partnerships (PPPs) in encouraging the adoption and deployment of SHM systems in the Indian construction sector.
- Do research on the ethical and legal implications of deploying SHM systems in the Indian construction sector, including privacy, data protection, and liability concerns.
- Provide a framework for assessing the success of SHM systems in the Indian construction sector, taking variables such as dependability, cost-efficiency, and safety into account.
- Examine the potential of SHM systems to promote sustainable building practices in the Indian construction sector, such as lowering carbon emissions and encouraging circular economy concepts.

These study ideas can help us better understand the problems and possibilities associated with the adoption and deployment of SHM systems in the Indian construction sector. We can encourage the safe, dependable, and sustainable expansion of the Indian construction sector by solving these research gaps, ensuring that it remains a significant driver of India's economic development [16–20].

References

1. Bhide A, Choudhary S (2019) Construction industry in India: current scenario and future prospects. J Constr Eng Manage 145(8):04019044. https://doi.org/10.1061/(asce)co.1943-7862.0001669
2. Islam MR, Kumar A (2018) Structural health monitoring techniques: a review. Int J Civ Eng Technol 9(8):2474–2481
3. Wang D, Deierlein GG, Feng MQ (2013) Review of structural health monitoring research in civil engineering in China. Struct Health Monit 12(5–6):378–398. https://doi.org/10.1177/1475921712474483
4. Liu Y, Li H (2016) Design and implementation of a remote structural health monitoring system for a long-span suspension bridge. J Sens 2016:1–11. https://doi.org/10.1155/2016/1949753
5. Ni YQ, Ko JM, Li Z (2006) Structural health monitoring of Tsing Ma bridge: background, system and instrumentation. J Sound Vib 293(1–2):24–49. https://doi.org/10.1016/j.jsv.2005.10.039

6. Zhang B, Liu H (2019) Structural health monitoring and damage detection of railway bridges in China: a review. Struct Infrastruct Eng 15(7):841–859. https://doi.org/10.1080/15732479.2018.1509765
7. Bhuyan M, Chakraborty M (2018) Recent advances in structural health monitoring of civil infrastructure. Measurement 127:516–539. https://doi.org/10.1016/j.measurement.2018.05.059
8. Park HJ, Yun CB (2016) Structural health monitoring for long-span bridges: recent advances and future directions. Sensors 16(12):2079. https://doi.org/10.3390/s16122079
9. Duan JG, Liu J (2016) Structural health monitoring for high-speed railway bridges in China: recent advances and future directions. Shock Vib 2016:1–18. https://doi.org/10.1155/2016/3832304
10. National Crime Records Bureau (2020) Accidental deaths and suicides in India 2019. Retrieved from https://ncrb.gov.in/en/accidental-deaths-suicides-india-2019
11. Zhang B, Liu H (2019) Structural health monitoring and damage detection of railway bridges in China: a review. Struct Infrastruct Eng 15(7):886–903. https://doi.org/10.1080/15732479.2019.1575117
12. Kumar R, Singh V, Singh P (2017) Structural health monitoring for indian infrastructure: need and challenges. J Mater Environ Sci 8(4):1278–1286
13. Sharma A, Das M, Ray PK (2019) Structural health monitoring for infrastructure safety: a review of indian perspectives. J Struct Integrity Maint 4(1):35–41
14. Singh V, Gupta A (2020) Structural health monitoring for infrastructure safety: Indian perspective. In: Handbook of materials failure analysis with case studies from the chemicals, concrete and power industries. Elsevier, pp 451–463
15. Thakur RK, Kappagantu R (2020) Barriers to the adoption of structural health monitoring in construction: a review. J Constr Eng Manage 146(4):04020022
16. Bhattacharya S, Maji S (2017) Government policies and the adoption of green buildings: a case study from India. J Clean Prod 164:524–535
17. Li Z, Li Y, Lu Y (2019) Public-private partnerships in construction: a systematic review. J Clean Prod 229:609–623
18. Rehman T, Pervaiz S (2019) Ethics of using smart technologies for managing construction projects. J Constr Eng Manage 145(6):04019023
19. Wang H, Luo H, Li H (2020) A comprehensive evaluation framework for structural health monitoring systems. J Constr Eng Manage 146(11):04020107
20. Hosseini MR, Manesh MS (2019) Review of sustainability practices in construction industry with regard to circular economy principles. J Clean Prod 232:1245–1257

Sustainability Assessment of Construction and Demolition Waste Management Solutions

Grace George and S. J. Sushanth

1 Introduction

U.S. Environmental Protection Agency (EPA) defines construction and demolition (C&D) waste as one that includes the waste materials generated during the processes of construction, demolition, and renovation of buildings, roads, etc. C&D materials often include materials like concrete, asphalt, gypsum, wood, metals, salvaged building components, plastics, etc. By 2030, the built-up area is expected to be around 104 billion sq. ft which is around five times the built-up area that was in the year 2005 (according to Centre for Science and Environment). This indicates that, such a huge growth in built-up area can lead to a considerable and dangerous increase in the Construction and Demolition waste that is likely to be generated. In such a scenario there emerges an urgent need for proper waste management solutions that can prove to be environmentally friendly and sustainable as well in the long run. The paper tries to look into this matter through a different perspective. Instead of coming up with a solution, the paper tries to develop a method to arrive at the solution, that could prove to be successful in different contexts.

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2 Objectives

The aim was to develop a framework for assessing the sustainability of construction and demolition waste management solutions.

The objective was:

- To study and evaluate the impacts of current practices of construction and demolition waste management.
- To determine the parameters that determine the sustainability of C&D waste management strategies.
- To develop a framework for the evaluation of sustainability of C&D waste management strategies.

The limitation of the study is that it focuses only on one aspect of sustainability, i.e.: the environmental aspects only, and does not cover the economic and social aspects.

3 Methodology

Initially, a detailed literature study was carried out to understand the current practices of C&D waste management, the impacts of such practices, the guidelines in place, and the plans and proposals for sustainable C&D waste management in the country. Later focus was put on the state of Kerala. It was observed that, though a number of solutions and ideas were in place, there is no way to understand which solution is best suitable for a particular context of interest. The study intends to address this lacuna (Fig. 1).

For this, each of the strategies has to be evaluated based on a number of factors. The factors were identified from secondary sources which were further made into a matrix. Each parameter had to be assigned with a weightage, which would further help in choosing the best strategy for a particular context. This was achieved with the help of AHP (Analytic Hierarchy Process). In this process, a pairwise matrix was created with the identified parameters. Elements (A, B) of each pair were analyzed to decide which is more important, and by how much, on a scale of 1–9 where 1 represents equal importance and 9 represents extreme importance. These values were given based on surveys with subject experts. After completing the process, the consistency ratio was checked to confirm the results. In this way, the weightage was assigned to the factors or parameters to finish the sustainability assessment matrix. By using this matrix, we can evaluate the possible methods of C&D waste management available and decide which is best for the context considered.

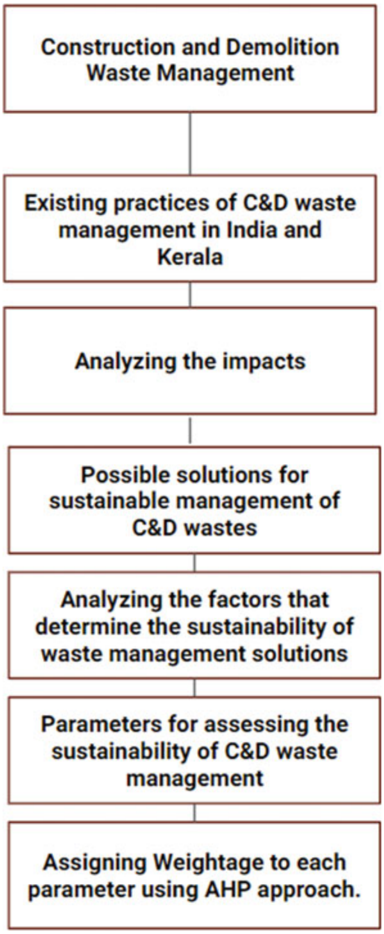

Fig. 1 Methodology adopted. *Source* Author's

4 Present Scenario

4.1 Present Scenario of Construction and Demolition Waste in India

One of the major emitters of greenhouse gases is found to be the construction sector [41]. Over 34% of the energy demand as well as around 37% of energy and process-related CO_2 emissions was from this sector in 2021 [1]. From the total purchased materials, about 9% turn out as waste [26].

About 150 MT construction waste is generated in India. It comes to around 35%–40% of the annual global construction and demolition waste [21, 26]. India recycled only 1% of its generated C&D waste as estimated by Centre for Science and Environment [8]. The current recycling centers in India can recycle only 6500 tons in a day.

4.2 Present Scenario of Construction and Demolition Waste in Kerala

One of the main challenges faced by the state of Kerala is Solid waste management. Construction and Demolition waste and its careless handling is posing a great threat to the initiatives related to cleanliness, implemented by the state and its authorities. At present materials including window & door frames, steel, roofing tiles wood, etc., which are reusable C&D waste materials, are being collected by various scrap dealers. But at the same time, the sad truth is that, a major portion of the concrete waste generated are being used in the road construction and related activities for ground leveling. Illegal filling up of water bodies and wetlands with C&D wastes occurs at a high rate around urban centers. A number of cases are being reported.

To tackle such issues and to recover and recycle the C&D wastes in the state, the government of Kerala is planning to introduce an elaborate system for C&D waste management. A set of guidelines for the disposal of construction and demolition waste has also been issued. According to the new plan, multiple districts will have one treatment plant that works for their needs. Moreover, each local body will have an elaborate waste collection system. In this system, mobile waste collection units would collect debris. Also, the building owners can deliver the waste at the waste collection units.

According to the proposed system, for building waste below two tons, there will be no collection fees. If the debris is above 20 tons, the building owner should pay for and deliver the waste at collection centers besides remitting a fee for its treatment. If C&D waste is mixed with other types of waste or is being dumped in public places, a fine of Rs 10,000 and of Rs 20,000 would be imposed, respectively. A huge fine up to Rs. 2,00,000 or an imprisonment of up to three years is the punishment set for throwing construction waste in water bodies.

(Guidelines for Managing Construction and Demolition Waste in Kerala).

5 C&D Waste Management and Its Effects

5.1 Environmental Effects of C&D Landfill

Construction and demolition waste that is generated around the world annually is about 100 billion tons. Out of this around 35% goes for disposal to landfills [28, 37]. Countries such as India, China, and South Africa that are developing have high landfilling rates.

The main environmental problems caused by improper management of C&D wastes such as landfilling is that it can lead to leaching as well as H_2S gas emissions. Even though there are several technologies that help mitigate the environmental impacts caused by the improper management of C&D wastes, the optimal solution is to adopt the more sustainable "3R" principle that can help to alter the waste flow from landfills [10]. The dumping of C&D waste in landfills could lead to groundwater and surface water contamination. This in turn affects people's health when the contaminated water reaches the households. Moreover, aquatic life as well as the life of terrestrial animals consuming water directly from the ponds and rivers may be at risk as they can be affected by the contaminated surface water that gets its way to water bodies [34].

Improper C&D waste management practices such as dumping of waste in water bodies can lead to several adverse impacts on the environment. Polluting the water bodies can affect the natural habitat of aquatic flora and fauna by affecting them negatively. The illegal dumping can also lead to floods in the nearby areas, as it increases the level of water. C&D waste might also bring particulate matter like PM10, dust, asbestos, and other pollutants. This may lead to air pollution [34].

5.2 On-Site Recycling

In this process, C&D waste is treated directly at the source. In case of off-site recycling, the processes are being done in a controlled environment and thus it is more environment friendly [12]. Yet, off-site recycling exhibits certain drawbacks in the form of huge investments, high transportation costs, high demand for land occupation, etc. [5].

5.3 Environmental Impacts of Recycling Process

Studies show that while considering many categories, recycling is more environmentally beneficial than landfilling. Even though there are some environmental impacts from the recycling process, they get gradually decreased when the avoided transport is increased. The production of recycled materials has some negative impacts than the natural materials production. However, recycling is more environmentally friendly due to the effects of avoided transportation. The usage of treated water in the recycling plants gave the process more benefits in case of water consumption [22]. By using cleaner sources of electricity, the carbon emissions related to the recycling process are reduced even further.

Studies conducted show that, the recycling process of C&D waste performed worse in certain environmental impact categories. Eutrophication can occur as a result of burning fossil fuels as well as pollutants from mining of coal [19].

5.4 Carbon Emissions Due to Different C&D Waste Management Solutions

Studies show that the global C&D waste will be increased drastically in the coming years. It shows that the 12.7 billion metric tons of C&D waste generated will increase to 27 billion metric tons by 2050 [33]. This brings up an urgent need for implementing practices that restrict C&D waste and the related CO_2 emissions. A significant reduction of carbon emissions can be achieved by proper waste recycling practices that can help promote sustainable development.

The implementation of the circular economy concept in the construction sector puts forward a potential for more emissions reduction. Studies are being done on the carbon sequestration potential of C&D waste [24].

6 Sustainable Strategies for C&D Waste Management

6.1 Guidelines on Environmental Management of C&D Wastes [7]

As per the Guidelines on Environmental Management of C&D Waste by Central Pollution Control Board, several steps must be taken in order to effectively manage construction and demolition waste generated in India. Initially, the amount of waste generated has to be properly estimated and more C&D processing facilities have to come up to manage the huge amount of wastes. Specifications for recycled C&D waste products must be brought to ensure quality acceptance as well and the use of recycled products must be increased. Penalties must be introduced for illegal landfilling and filling up of water bodies. More research must come up in C&D waste management as well as recycling options. Moreover, awareness is the key to effective waste management.

6.2 The Concept of Circular Economy

There is an increasing demand for primary materials such as minerals, sand, stone, aluminum, iron ore, timber, etc., in the construction industry. The extraction and production of such materials have caused huge environmental impacts. A substantial part of naturally sourced materials can be substituted by the recycled and reused C&D waste.

The pressure of mining and the extraction of virgin material can become unsustainable. This issue can be addressed by the concept of circular economy. The environmental footprint of the buildings and infrastructure and the energy intensity in new construction can be reduced by executing a well-planned strategy for reduction, reuse, and recycling of construction and demolition waste. (Another Brick off the Wall: Improving Construction and Demolition Waste Management in Indian Cities).

7 Results and Discussions

7.1 Parameters for Sustainability Assessment

The following parameters were identified from the studies. These parameters help to identify a sustainable waste management solution for C&D wastes in a particular context.

- Carbon emissions
- Embodied Energy
- Human toxicity potential
- Terrestrial toxicity potential
- Global warming potential
- Ozone depletion potential
- Acidification potential
- Aquatic toxicity potential

Young et al. [40] developed the environmental impact factors which was calculated using the Waste Reduction (WAR) algorithm. (Green Chemistry and Engineering).

7.2 Matrix for Sustainability Assessment

With the parameters derived for the sustainability assessment, a matrix or framework was formulated for assessing a particular waste management strategy which can prove to be a sustainable solution to that particular place (Tables 1 and 2).

Table 1 Matrix for sustainability assessment

	Carbon emissions	Environmental impacts						Embodied energy
		Human toxicity potential	Terrestrial toxicity potential	Aquatic toxicity potential	Global warming potential	Ozone depletion potential	Acidification potential	
Waste management strategy 01								
Waste management strategy 02								
Waste management strategy 03								
Waste management strategy 04								

Source Author's

Table 2 Sample matrix

	Carbon emissions	Environmental impacts						Embodied energy
		Human toxicity potential	Terrestrial toxicity potential	Aquatic toxicity potential	Global warming potential	Ozone depletion potential	Acidification potential	
Landfill on site								
Offsite landfill								
Recycling on site								
Recycling off site								

Source Author's

7.3 Weightage of the Parameters

Each parameter identified was given a weightage in order to understand their importance in deciding a sustainable C&D waste management solution. Through the Analytic Hierarchy Process, weightage was calculated for the parameters for sustainability assessment. The values for the process were obtained from surveys conducted among the subject experts. The Consistency Ratio (CR) was found to be 7.6% (Tables 3 and 4 and Fig. 2).

8 Conclusion

The study tries to address the issue of construction and demolition waste and its management. To get the larger perspective of the issue the existing conditions of C&D wastes and its management were studied in the context of India as well as Kerala. The existing practices were analyzed to understand the possible impacts both positive and negative. Other possible solutions of management were looked into. From the studies it was understood that, in order to come up with the sustainable solution for construction and demolition waste management, several parameters have to be checked.

The current studies available looked into either the embodied energy aspects or the environmental impacts through LCA methods. The sustainability assessment of C&D waste management strategies was not looked into or studied in detail. In order to fill in this gap, further studies were done to come up with the parameters and understand their criticality in assessing the sustainability of C&D waste management solutions.

A total of eight parameters were identified, out of which the global warming potential was found to be the most critical (16.7% weightage) followed by human toxicity potential (15%) and carbon emissions (14.2%). The parameters identified and the weightage assigned help to assess the sustainability of a construction and demolition waste management strategy. This in turn helps to come up with waste management solutions for C&D wastes that prove to be sustainable and specific solutions for the context in consideration.

Table 3 Calculation matrix for AHP (Klaus D. Goepel, http://bpmsg.com)

Matrix		Carbon emissions	Human toxicity potential	Terrestrial toxicity potential	Aquatic toxicity potential	Global warming potential	Ozone depletion potential	Acidification potential	Embodied energy
		1	2	3	4	5	6	7	8
Carbon emissions	1	1	1	2	1 1/5	1	1 2/5	1 1/9	1 3/4
Human toxicity potential	2	1	1	4 2/3	1	6/7	1 8/9	1 1/8	3/5
Terrestrial toxicity potential	3	1/2	1/5	1	1 2/5	1/2	1/2	1/2	3/5
Aquatic toxicity potential	4	5/6	1	5/7	1	1	1 3/8	5/8	4/9
Global warming potential	5	1	1 1/6	2 1/7	1	1	2 1/3	1 2/7	2 1/3
Ozone depletion potential	6	5/7	1/2	2 1/7	3/4	3/7	1	2	3
Acidification potential	7	1	8/9	2 1/7	1 3/5	7/9	1/2	1	2
Embodied energy	8	4/7	1 2/3	1 5/8	2 1/5	3/7	1/3	1/2	1

Table 4 Weightage of parameters

Criterion		Weights (%)
1	Carbon emissions	14.20
2	Human toxicity potential	15.00
3	Terrestrial toxicity potential	6.70
4	Aquatic toxicity potential	10.20
5	Global warming potential	16.70
6	Ozone depletion potential	13.60
7	Acidification potential	12.60
8	Embodied energy	11.00

Source Author's

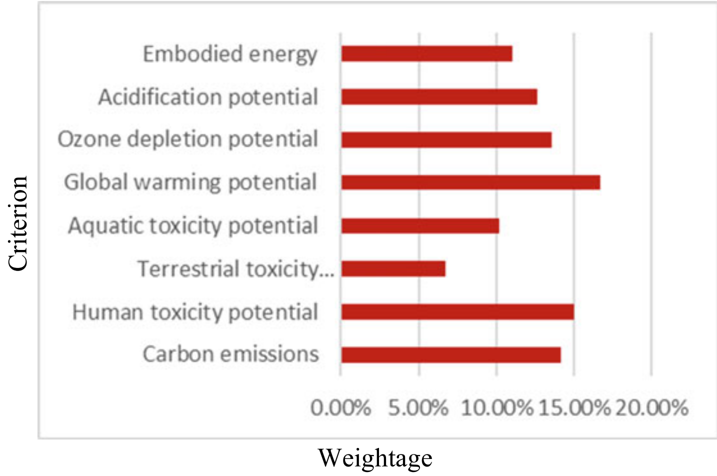

Fig. 2 Weightage of parameters. *Source* Author's

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References

1. 2022 Global Status Report for Buildings and Construction (2022, November 9) UNEP—UN Environment Programme. http://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction
2. Roychowdhury A, Somvanshi A, Verma A (2020) Another brick off the wall: improving construction and demolition waste management in indian cities. Centre for Science and Environment, New Delhi

3. Bao Z, Lee WMW, Lu W (2020) Implementing on-site construction waste recycling in Hong Kong: barriers and facilitators. Sci Total Environ 747:141091. https://doi.org/10.1016/j.scitotenv.2020.141091
4. Bao Z, Lu W (2020) Developing efficient circularity for construction and demolition waste management in fast emerging economies: lessons learned from Shenzhe,n China. Sci Total Environ 724:138264. https://doi.org/10.1016/j.scitotenv.2020.138264
5. Bao Z, Lu W, Chi B, Yuan H, Hao J (2019) Procurement innovation for a circular economy of construction and demolition waste: lessons learnt from Suzhou, China. Waste Manage 99:12–21. https://doi.org/10.1016/j.wasman.2019.08.031
6. Building Materials & Technology Promotion Council Ministry of Housing & Urban Affairs Government of India (2018) Utilisation of recycled produce of construction & demolition waste, a ready reckoner. Building Materials & Technology Promotion Council Ministry of Housing & Urban Affairs Government of India
7. Central Pollution Control Board (2017) Guidelines on environmental management of construction & demolition (C&D) Wastes. Central Pollution Control Board (Ministry Of Environment, Forests & Climate Change)
8. Centre for Science and Environment (2014) Construction and demolition waste. Centre for Science and Environment
9. Chen K, Wang J, Yu B et al (2021) Critical evaluation of construction and demolition waste and associated environmental impacts: a scientometric analysis. J Clean Prod 287:125071. https://doi.org/10.1016/j.jclepro.2020.125071
10. Chen Z, Feng Q, Yue R, Chen Z, Moselhi O, Soliman A, Hammad A, An C (2022) Construction, renovation, and demolition waste in landfill: a review of waste characteristics, environmental impacts, and mitigation measures. Environ Sci Pollut Res 29(31):46509–46526. https://doi.org/10.1007/s11356-022-20479-5
11. CPCB | Central Pollution Control Board. In: CPCB|Central pollution control board. https://www.cpcb.nic.in
12. Earle J, Ergun D, Gorgolewski M, Canada (n.d.) Barriers for deconstruction and reuse/recycling of construction materials in Canada. https://www.irbnet.de/daten/iconda/CIB_DC29789.pdf
13. Environmental Impact Factor—an overview|ScienceDirect Topics (n.d.) www.sciencedirect.com. https://www.sciencedirect.com/topics/engineering/environmental-impact-factor#:~:text
14. EPA (2018, August 22) Sustainable management of construction and demolition materials|US EPA. US EPA. https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials
15. Goepel KD (2018) Implementation of an online software tool for the analytic hierarchy process (AHP-OS). Int J Anal Hierarchy Process 10(3). https://doi.org/10.13033/ijahp.v10i3.590
16. Government of Kerala (2022) Guidelines for managing construction & demolition waste in Kerala. Government of Kerala
17. Green Chemistry and Engineering. In: Green chemistry and engineering|ScienceDirect. http://www.sciencedirect.com:5070/book/9780123725325/green-chemistry-and-engineering
18. Guidelines Sustainable Habitat|PDF|Concrete|Flooring (n.d.) Scribd. Retrieved 12 August 2023, from https://www.scribd.com/document/323705038/Guideleines-Sustainable-Habitat
19. Günkaya Z, Özdemir A, Özkan A, Banar M (2016) Environmental performance of electricity generation based on resources: a life cycle assessment case study in Turkey. Sustainability 8(11):1097. https://doi.org/10.3390/su8111097
20. Haider H, AlMarshod SY, AlSaleem SS, Ali AAM, Alinizzi M, Alresheedi MT, Shafiquzzaman Md (2022) Life cycle assessment of construction and demolition waste management in Riyadh, Saudi Arabia. Int J Environ Res Public Health 19(12), 7382. https://doi.org/10.3390/ijerph19127382
21. Jain MS (2021) A mini review on generation, handling, and initiatives to tackle construction and demolition waste in India. Environ Technol Innov 22:101490. https://doi.org/10.1016/j.eti.2021.101490
22. Jain S, Singhal S, Pandey S (2020) Environmental life cycle assessment of construction and demolition waste recycling: a case of urban India. Resour Conserv Recycl 155:104642. https://doi.org/10.1016/j.resconrec.2019.104642

23. Swarna Swetha K, Tezeswi TP, Siva Kumar MVN (2022) Implementing construction waste management in India: an extended theory of planned behaviour approach. Environ Technol Innov 27, 102401. https://doi.org/10.1016/j.eti.2022.102401
24. Kaliyavaradhan SK, Ling T-C (2017) Potential of CO_2 sequestration through construction and demolition (C&D) waste—An overview. J CO_2 Util 20, 234–242. https://doi.org/10.1016/j.jcou.2017.05.014
25. Klaus D. Goepel. http://bpmsg.com
26. Kolaventi SS, Tezeswi T, Siva Kumar M (2019) An assessment of construction waste management in India: a statistical approach. Waste Manage Res: J Sustain Circ Econ 38:444–459. https://doi.org/10.1177/0734242x19867754
27. Land Acquisition Sreekariyam Fly over -SIA Final Report|District Thiruvananthapuram, Government of Kerala|India (n.d.) Retrieved 12 August 2023, from https://trivandrum.nic.in/en/document/land-acquisition-sreekariyam-fly-over-sia-final-report/
28. Menegaki M, Damigos D (2018) A review on current situation and challenges of construction and demolition waste management. Curr Opin Green Sustain Chem 13:8–15. https://doi.org/10.1016/j.cogsc.2018.02.010
29. Mesa JA, Fúquene-Retamoso C, Maury-Ramírez A (2021) Life cycle assessment on construction and demolition waste: a systematic literature review. In: MDPI. https://www.mdpi.com/2071-1050/13/14/7676
30. Pvt. Ltd. NM (2015) C&D waste processing in India–Delhi shows the way. In: C&D waste processing in India–Delhi shows the way. https://www.nbmcw.com/equipment-machinery/crushing-screening-washing-m-sand/c-d-waste-processing-in-india-delhi-shows-the-way.html
31. RTS (2020, December 8) What is sustainable waste management? Recycle Track Systems. https://www.rts.com/blog/what-is-sustainable-waste-management/
32. Rakesh S, Keshava M (2019) A study on embodied energy of recycled aggregates obtained from processed demolition waste
33. Singh N, Singh SP (2016) Carbonation resistance and microstructural analysis of low and high volume fly ash self compacting concrete containing recycled concrete aggregates. Constr Build Mater 127:828–842. https://doi.org/10.1016/j.conbuildmat.2016.10.067
34. Suman S (2020) Construction and demolition waste and its impact on environment. Int J Creative Res Thoughts 8, 2320–2882. https://ijcrt.org/papers/IJCRT2008437.pdf
35. Waste Reduction Algorithm—an overview|ScienceDirect Topics. In: Waste reduction algorithm—an overview|ScienceDirect topics. https://www.sciencedirect.com/topics/engineering/waste-reduction-algorithm
36. LLC, PT (n.d.) What is the analytic hierarchy process (AHP)? www.passagetechnology.com. https://www.passagetechnology.com/what-is-the-analytic-hierarchy-process
37. Wu H, Zuo J, Zillante G, Wang J, Yuan H (2019) Status quo and future directions of construction and demolition waste research: a critical review. J Clean Prod 240:118163. https://doi.org/10.1016/j.jclepro.2019.118163
38. www.ETRealty.com (n.d.) Kerala government to launch elaborate system to manage construction & demolition waste—ET RealEstate. ETRealty.com. Retrieved 12 August 2023, from https://realty.economictimes.indiatimes.com/news/infrastructure/kerala-government-to-launch-elaborate-system-to-manage-construction-demolition-waste/93523542
39. Xu J, Shi Y, Xie Y, Zhao S (2019) A BIM-based construction and demolition waste information management system for greenhouse gas quantification and reduction. J Clean Prod 229:308–324. https://doi.org/10.1016/j.jclepro.2019.04.158
40. Young D, Scharp R, Cabezas H (2000) The waste reduction (WAR) algorithm: environmental impacts, energy consumption, and engineering economics. Waste Manage 20(8):605–615. https://doi.org/10.1016/s0956-053x(00)00047-7
41. Zhang G, Zhang Y, Tian W et al (2021) Bridging the intention-behavior gap: effect of altruistic motives on developers' action towards green redevelopment of industrial brownfields. Sustainability 13:977. https://doi.org/10.3390/su13020977