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Indian Buildings Congress

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Number One
2025

Seminar on

"INNOVATIONS IN BUILT ENVIRONMENT"

April 11- 13, 2025
Hyderabad

आधुनिक तकनीक सुरक्षित निर्माण

INDIAN BUILDINGS CONGRESS

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Mid-Term Session
and
National Seminar
on

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V.R. Bansal
Honorary Secretary,

Indian Buildings Congress
Kama Koti Marg, Sector-VI, R.K. Puram,
New Delhi – 110022
Phone No: 011- 26169531, 26170197
E-mail: info@ibc.org.in, indianbldgscongress@gmail.com
Website: www.ibc.org.in

FOREWORD

We are living in times of rapid expansion of Built Environment and related infrastructure with development of Projects not only in the Housing sector but also in Health, Education, Civil Aviation, Tourism, Roads and Railways.

The geographical spread of developmental projects in various sectors have resulted in rapid expansion of existing urban areas and coming up of new urban areas. Thus, our country is experiencing rapid urbanization with growing urban population. It is anticipated that by 2030, more than 40% of the population will be living in urban areas and by 2050, urban population is expected to be over 50%. Such an unprecedented expansion of Built Environment and related infrastructure is invariably bound to be besieged with host of issues such as Environment issues, Climate change impacts unsustainable development, Resource management such as water scarcity, sanitization challenges, waste management and transportation.

For the past few years, lot of emphasis has been given on sustainable development by the various Public & Private agencies. Consequently, series of Innovations have taken place in Built Environment by the way of development of environment friendly building materials & construction technologies, use of Artificial Intelligence, BIM, Digital documentation process automation etc.

Innovation and Sustainability are interwind with Innovation giving impetus to the development of solutions to address environmental and social challenges, whereas sustainability evolves the framework for creating long term value and positive impact.

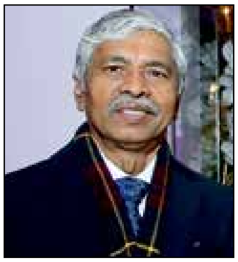
As we tread on the path of rapid developmental process, there is a need to give unstinted emphasis on sustainable development with Innovation as the driving factor. It is equally important that development of Innovations in Built Environment are disseminated amongst various Professionals connected with Built Environment and thus leading to there large scale awareness and adoption

It is with this view that IBC has organized Seminar on "Innovations in Built Environment" during its Mid term session at Hyderabad. Multifaceted Innovations in Built Environment are to be discussed in the one-day Seminar and I am sure that deliberations during these presentations shall evolve useful recommendations for the consideration of Government.

My sincere thanks to host R & B Department, Telangana Govt. & the Telangana State Chapter.

(Er C Debnath)
President, IBC

PREFACE



The construction industry is one of the largest and most complex sectors majorly contributing in the global economy however largely dependent on natural resources. Simultaneously, there are multiple stakeholders directly and indirectly involved in this sector globally. India being a large developing country needs large construction for all sections of the society with varying economic strata but natural resources available are limited hence it is the need of the hour to think about the sustainability of the construction sector by adopting innovations in the construction techniques, equipment and materials for timely availability of the qualitative infrastructure.

In this direction, our Engineers, Architects, Administrators, Builders, Planners, Vendors and Policy makers have to interact among themselves, make policies and implement the sustainability while planning and executing the upcoming infrastructure.

Considering the importance of the Sustainability and Innovations required in the construction sector, the topic selected for this year's Mid Term Seminar, "Innovations in Built Environment" is highly relevant. The response of the authors has also been encouraging as they have contributed valuable papers highlighting the importance of the subject and bringing out the work done by them in this field.

Though large number of papers were received however considering the papers related to the theme and the originality, twenty-one papers have been selected for publication and deliberation during the Mid Term Seminar being held at Hyderabad.It is expected that these will be presented during the Seminar by the authors and discussed at length by the delegates.

It is also hoped that the deliberation in the seminar will bring out useful recommendations for gainful utilisation by the stake holders in the construction industry.

I express my sincere thanks to my colleagues Sh. R. K. Majumder, Dr. O. P. Tripathi, Sh. P. S. Chadha, Sh. K. L. Mohan Rao, Dr Madhura Yadav, Sh. Vasu Dev Chhabra, and Shri I S Sidhu, Executive Director, IBC for their valuable support in the screening and selection of papers.

(Dr. K.M. Soni)
Chairman, Technical Committee, IBC &
Former Additional Director General, CPWD

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CONTENTS

STRATEGIZING BIM & DIGITAL ADOPTION IN INDIA'S BUILT ENVIRONMENT SECTOR

Dr. Amarnath CB*

Abstract

The integration of BIM (Building Information Modeling) and digital technologies is reshaping the built environment, driving improvements in efficiency, collaboration, and sustainability across building and infrastructure projects. However, successful adoption requires a strategic and structured approach that bridges technological capabilities, organizational workflows, and human factors. We present a comprehensive framework for strategizing BIM and digital adoption, focusing on phased implementation, capacity building, and fostering a culture of collaboration and innovation.

GLOBAL TRENDS

As of March 2025, BIM adoption has accelerated globally, supported by government mandates, industry standards, guidelines, education frameworks, and strategic initiatives. Countries like the UK, Germany, France, Italy, Spain, Norway, and the Netherlands have established BIM mandates for public projects, ensuring compliance with national strategies for digital construction. China, Japan, South Korea, and Singapore have implemented government-backed BIM frameworks that promote efficiency and sustainability in large-scale infrastructure. Australia, the UAE, Canada, and the US have adopted a mix of regulatory mandates and voluntary industry-driven strategies, with agencies like the GSA (US), CIDB (Malaysia), and BCA (Singapore) leading BIM implementation. Standards and guidelines such as National BIM Standards and ISO 19650provide interoperability and best practices, shaping adoption across industries. Education frameworks, including university programs and professional training courses, are expanding, with India, New Zealand, and Russia prioritizing BIM upskilling for workforce development. Industry strategies focus on smart city integration, digital twins, AI-enhanced BIM, and cloud-based collaboration, driving transformation in construction, real estate, and infrastructure. The Asia-Pacific, European, and North American regions are leading BIM adoption, ensuring that digital innovation, regulatory compliance, and workforce education support the global shift toward a fully digitized construction industry.

*President – India BIM Association

INTRODUCTION

BIM is all about generating and using the information generated during the project life cycle. Generating BIM is the first phase and using of generated BIM is the second phase activity. Generating BIM is a combined efforts of design and engineering team, whereas usage of generated BIM is an approach which each project team has to work out. BIM matures during the design, construction and operation phases with respect to graphical, parametric (dimensions, material, textures) and documents. Generated BIM becomes the single point of truth for project stakeholders and enables better coordination, collaboration and communication.

BIM is applicable to all type of building sector project such as residential, educational, institutional, assembly, business, mercantile, industrial, storage and hazardous projects. BIM can be enabled for a project by developing an information rich model and we can perform time (4D BIM) and cost (5D BIM) planning and monitoring, safety and risk assessment, procurement and logistics planning, design and engineering analysis such as structural, lighting, wind, earthquake and energy.

BIM will bring multiple stakeholders on a CDE – Platform to enable information management by project stakeholders to have a better experience by integrating BIM for experience (virtual, augmented and mixed reality). BIM lays a foundation for activating modular construction (3D printing, DFMA – Design for manufacture and assembly, pre-fabrication), reality capture (drone, 360° camera, robots and laser scanners) and digital twin (building automation with BIM and Internet of things (IoT) Integration).

BIM SKILLS & COMPETENCIES

It is important that project stakeholders from design, construction and operation teams are possessing the necessary BIM skills and competencies depending on the type and complexity of the project. It is clear that above set of professionals are categorized in production, management and leadership roles in BIM projects considering their qualification, experience and expertise in BIM Implementation and strategy. Each stakeholder works on Common Data Environment (CDE) platform.

Design Team

Design team in building projects comprises architects, structural, mechanical, electrical, plumbing, fire protection, vertical transport, acoustics, sustainability, health, safety and environmental specialists and interior designer. Each stakeholder in design team shall be good at generating and maturing BIM from LOD 100 to 500. And, they shall be skilled to use the BIM to activate appropriate BIM Uses.

- Architecture and landscape specialist use BIM for identifying design options, area and space program validation, sun studies, day lighting, lighting analysis, to generate design-construction-as built drawings.
- Structural engineers use BIM for structural analysis, shop drawing coordination, design-construction-as built drawing production.
- Mechanical, electrical, plumbing and fire protection (MEPF) engineers use BIM for clash detection, to analyse equipment and maintenance clearance space, mechanical and energy analysis, to generate digital details and mock-ups, for prefabrication, shop drawing coordination, and to generate design-construction-as built drawings.
- Interior designers use BIM for creating interiors in 3D and provide immersive experience to its clients through virtual reality and experience centre setup.
- Sustainability specialist use BIM for simulation of green building credits achievability, energy analysis and lean workflows.

All the above stakeholders can utilize BIM for coordination meetings, ensuring alignment and facilitating the resolution of clashes during design discussions. Design managers (BIM manager – Design) manages the team and their deliverables in this phase with BIM workflows. It is desirable that multi-disciplinary integration is initiated right from the concept design stage. To ensure proper implementation of the design, the design team, may be associated during the construction and handover stages.

Construction Team

Construction team in the building projects comprises planning engineers, quantity surveyors, quality assurance and control engineers, safety engineers, formwork specialist, the procurement & contracts team, as well as the stores, logistics and execution teams. The construction team should implement BIM for field activities.

- Execution team on site includes civil (architecture and structure), MEPF, interior engineers etc. These stakeholders shall be proficient in capturing field data and share with design team to update the BIM into an as-built model / digital twin i.e., LOD 500. They can use BIM for in-field construction layout.
- Planning engineers can use BIM for time (4D BIM) planning and monitoring.
- Quantity surveyors can use BIM for cost (5D BIM) planning and monitoring and cash flow analysis and reporting.
- Quality assurance and control engineers can use reality capture for quality assessments.
- Formwork specialist can use BIM for temporary structures modeling and simulation.
- Safety engineers can use BIM to perform virtual design and construction (VDC) simulations to understand the risk and safety measures and subsequently train the site team.
- Procurement and contracts, as well as stores and logistics team can use BIM to perform VDC simulations to understand look-ahead, construction material movement, labor sequencing, site planning for material delivery, staging and storage activities.
- Reality capture team captures existing conditions on site using laser scanners, drones, 360-degree camera and cyber dogs. Data capture is performed during the completion of each phase like Civil, MEPF and Architecture, landscape and interiors.
- Construction managers (field BIM manager) shall manage the construction team and their

deliverables and perform soft-landing of digital asset with physical asset during the handover stage.

This team shall be responsible to achieve satisfactory completion of the project in respect of all relevant project management functions like cost, time, quality, safety, etc. BIM Manager-Design shall be looped in actively during the project execution stage.

Operations Team

Operations team in building projects shall include the facility manager, building owners, occupants/ end-users, service providers, regulatory authorities, Suppliers/vendors, sustainability consultants and IT managers.

- Facility manager shall use digital twin for overseeing day-to-day operations, maintenance and management of the facility. BIM uses include model usage for maintenance and maintenance training.
- Building owners / end users can use digital twin integrated with IoT for building automation.
- Sustainability consultants can use digital twin to perform energy analysis. This guides the implementation of energy-efficient and sustainable practices within the facility.
- Suppliers/vendors can use digital twin to understand the materials, equipment and services for ongoing maintenance and operations.
- IT managers can use digital twin to manage the building including automation systems and networks. This is achieved by integrating Computerized Maintenance Management System (CMMS) and Computer-Aided Facility Management (CAFM) data models. This can also be used for security studies on built assets.

Operation, maintenance and repairs also require a multi-disciplinary approach to ensure that all the requirements of the users are satisfactorily met. During maintenance and repairs, the jobs requiring inter-disciplinary coordination have to be executed in such a manner so as not only to cause least inconvenience to the user but also to ensure that there is no mismatch or damage to the structure, finishing, fittings and fixtures, and to preserve integrity of other services.

GENERATING BIM AND USING IT.

Generating BIM

BIM model matures during the project life cycle and is measured as Level of Development (LOD). LOD includes graphical, non-graphical and documentation data. The Level of Development (LOD) in BIM is a framework that combines both the Level of Detail (LOD-d), which refers to the graphical representation of a model element, and the Level of Information (LOD-i), which addresses the non-graphical data associated with that element. Together, these components define the completeness and reliability of the information embedded in a BIM model at various stages of the project lifecycle. For instance, at lower levels of development (e.g., LOD 100), the model element may have basic geometry and conceptual data, whereas at higher levels (e.g., LOD 400 or LOD 500), the geometry becomes highly detailed, and the associated information is precise, actionable, and suitable for construction or facilities management. This dual focus ensures that stakeholders can make informed decisions, coordinate effectively, and achieve accurate project outcomes. By aligning expectations across disciplines, the LOD concept promotes clarity and efficiency throughout the design, construction, and operational phases.

LOD is measured in the scale of LOD 100, 200, 300, 350, 400, 500 and 500+. For, detailed understanding on LOD, please refer to BIM Forum's Level of Development (LOD) Specifications – 2024 version. The BIM Forum LOD Specification 2024 provides clear definitions for the LOD to standardize expectations for model elements during the project lifecycle.

Production team so called BIM Modelers will convert CAD to BIM i.e., LOD 100-500. BIM Modelers are from professional background such as Architectural, Landscape, Interior design, Civil, Structural, Mechanical, Electrical, Plumbing, Fire protection, Electrical Alarm System, IT, Security & AV. BIM Modelers do produce BIM objects and family / library creation.

Using the Generated BIM

Using the generated BIM can be strategized by each project team. Project team here refers to design, construction and operations team. Each project stakeholder or team uses the generated BIM in such a way that it eases his work and adds to qualitative and quantitative benefits during project life cycle. Return on Investment (ROI) can be realized at CAPEX and OPEX by strategizing the way generated BIM is utilized by project stakeholders. It is important that project stakeholders from design, construction and operation teams are possessing the necessary BIM skills and competencies depending on the type and complexity of the project.

To realize benefits of using generated BIM within the project execution process, it is essential to perform a set of BIM Uses. BIM Uses such as 2D documentation, 3D detailing, BIM/GIS overlapping, energy simulation, sustainability analysis and whole life cycle analysis can occur in six to seven stages of the project lifecycle. Few of these BIM uses are fundamental for the delivery of BIM projects. The primary BIM uses are design authoring, 2D documentation, clash detection, cost estimation, structural analysis, construction planning, BIM for facility management integration, among others. Moreover, for some of these BIM uses to be executed, it is essential to have other sets of BIM uses executed as a prerequisite. The criticality of any BIM use depends on the project type and its complexity. Each project type demands a different set of BIM uses as critical ones. It is a prerequisite to understand the project type, project goals, and BIM uses relationships to choose the right set of BIM uses for any project delivery.

Data Storage and Backup

Data in BIM as well as all allied Project Data, it's storage and backups must be secure and reliable on the Indian Soil and by an Indian Origin Data Handling Company only.

- Data Residency

  Specify Model data residency requirements in contracts, strictly complying with Indian regulations. Clarify responsibilities for data storage and backup.

- Backup and Recovery

  Require regular automated backups, with clear recovery point objectives (RPOs) and recovery time objectives (RTOs).

  Store backups in multiple secure locations – consider a combination of on-site, off-site, and cloud-based backups with Indian servers.Regularly test backups to ensure they are restorable and meet RTOs.

- BIM Data Retention

  Establish clear data retention policies, considering legal, regulatory, and business needs – consult legal counsel for guidance. Implement a secure archiving process for long-term data storage.

- Data Privacy

  Protecting the data in BIM is a legal and ethical obligation. To enable BIM and digital transformation, an appointing party organization (such as a client, developer, or asset owner) needs the right software, hardware, and equipment.

SOFTWARE, EQUIPMENT AND BIM PROFESSIONALS

Software

A well-defined software strategy is essential for Construction sector organization undergoing digital transformation, ensuring that BIM solutions align with business objectives and industry needs. With hundreds of BIM tools available, selecting the right software requires careful consideration of factors such as interoperability with existing systems, cost-effectiveness, industry-specific applicability, and the availability of skilled professionals. A strategic approach helps organizations maximize efficiency, streamline workflows, and enhance collaboration, ultimately driving better project outcomes.BIM Software/s has several capabilities such as briefing, workflow, authoring, integration, collaboration, analysis, visualization, planning, costing etc. All the capabilities of BIM software/s are discussed below.

➢ Project Definition and Coordination

- Briefing – Defining project scope, objectives, and requirements.
- Workflow – Managing project processes and team coordination.

➢ Site Data Collection

- Surveying – Capturing site conditions using traditional methods.
- Scanning – Using laser scanning or photogrammetry for as-built documentation.

➢ BIM Modeling and Development

- Design – Creating architectural, structural, and MEP models.
- Authoring – Developing detailed BIM models in discipline-specific software.

- Integrating – Combining multiple models for coordination and interoperability.

➢ Collaboration and Quality Control

- Collaboration – Enabling multidisciplinary teamwork and data exchange.
- Reviewing – Conducting design reviews and model audits.
- Checking – Performing model validation and compliance checks.
- Commenting – Annotating and providing feedback on BIM models.

➢ Analysis and Visualization

- Analysis – Conducting simulations (structural, energy, thermal, etc.).
- Visualization/Rendering – Generating 3D visuals and presentations.

➢ Construction Planning and Management

- Planning – Creating construction schedules and logistics plans.
- Costing – Estimating quantities and expenses using BIM data.
- Tracking – Monitoring on-site progress against the BIM model.
- Progress Reviewing – Comparing actual vs. planned progress.
- Viewing – Accessing models on-site for reference and validation.

➢ Prefabrication and Procurement

- Manufacturing – Producing prefabricated components from BIM data.
- Ordering – Managing procurement and supply chain integration.

➢ Operations and Maintenance

- Analysis Planning – Evaluating operational performance for efficiency improvements.
- Measuring – Capturing real-time building performance data.
- Recording – Documenting maintenance activities and updates.
- Validating – Ensuring as-built conditions match BIM data.
- Publishing – Sharing finalized models for facility management and future use.

Equipment

Hardware or Equipment are key for organization during their transformation journey. This section guides you through the set of hardware and equipment required for BIM & Digital implementation. Hardware and equipment needed for BIM, including high-performance workstations, mobile devices, Experience /control center, Jaibot, laser scanner, drone, 360 camera, total station, VR & AR devices, Cyber dog, 3D printer & plotter.

➢ Workstation, Laptop, Tablet & Mobile Devices

- Hardware specifications including processor, RAM, hard disk, graphics card, browser, connectivity, operating system, and compatibility.
- Pricing considerations for cost-effective solutions in BIM applications.
- Data exchange formats to ensure interoperability within the BIM ecosystem.
- Market awareness of available brands for easy integration with BIM workflows.

➢ Experience Center and Control Rooms

- Enables project teams to work in an interactive virtual environment.
- Provides a 1:1 project experience with realistic visualization of data.
- Utilizes VR technology to allow multiple users to collaborate.
- BIM Experience Center can be set up for coordination meetings and project reviews.

➢ BIM to Field, Reality Capture, and Visualization

➢ BIM to field equipment:

- Jai-bot & total station for semi-automated overhead drilling for MEP works.
- Laser scanner for progress monitoring and accurate as-built model creation.

➢ Visualization tools

- Virtual reality for immersive project experiences.
- Augmented reality for site training, coordination, quality control, and progress monitoring.
- Total station for BIM-guided site surveys and as-built model updates.

➢ Reality Capture Devices – Drone, 360 Camera, and Cyber Dog

- Drone technology for aerial mapping and construction site management.
- 360-degree camera for reality capture and site progress tracking.
- Cyber dog for scanning, quality control, and site progress monitoring.
- Indoor scanners fordetail interior scanning, enabling visualization, measurements, snag lists, and reporting.
- Reality capture applications include pre-site surveys, enhanced site logistics, earthwork quantification, milestone tracking, document control, quality assurance, and BIM model comparisons.

➢ 3D Printer, Plotter, Presenter, Holo-Table, Wall, and Room

- 3D printer for large-scale automated construction of buildings and structural components.
- Plotter for high-quality, large-format printing of drawings, plans, and graphics.
- Holographic presenters for interactive indoor visualization.
- Holo-table (2x2m) providing a bird's eye view of realistic 3D data, useful for landscape visualization and real-time tracking.
- Holo-wall (2x3.5m) displaying 3D information and bridging real and virtual environments, with holograms extending up to 4m.
- Holo-room (4x5m) offering a fully immersive, life-size simulation space compatible with all 3D file types.

BIM Professionals

BIM & Digitalization roles are broadly classified into production, management and leadership. Client, General Contractor, Sub-Contractors, Consulting firms, Asset Operations and government agencies all of them need BIM team. The BIM roles required in each type of organization varies. Broader set of BIM roles applicable for appointing, lead appointed and appointed parties are discussed in this section. Skill & capacity building for each BIM roles at production, management & leadership level varies.

➢ BIM Production & Specialist Roles

These roles enhance the efficiency, accuracy, and innovation in BIM workflows across the project lifecycle.

- BIM Production roles

Focus on modelling, documentation, coordination & collaboration, quality control & delivery. BIM Modelers for Architectural, Landscape, Interior design, Civil, Structural, Mechanical, Electrical, Plumbing, Fire protection, Electrical Alarm System, IT, Security & AV. BIM Engineer for object / family / library creation.

- BIM Specialist roles

(i) 4D BIM – Construction planning and monitoring

(ii) 5D BIM – Cost planning and monitoring

(iii) Immersive Experience – Virtual and augmented reality applications

(iv) VDC Simulations – Virtual Design and Construction workflows

(v) Reality Capture – Using laser scanning and photogrammetry for as-built

(vi) Lean and Green BIM – Sustainability and efficiency optimization

(vii) Geo-BIM – Integration of geospatial data with BIM models

(viii) Smart Contracts – Automating transactions using blockchain in BIM

(ix) ROI Analysis – Evaluating return on investment in BIM adoption

(x) Safety and Risk Management – Identifying and mitigating hazards

(xi) Procurement and Logistics – Optimizing material and resource management

(xii) Digital Twin – Creating real-time digital replicas of physical assets

(xiii) Building Automation – Integrating smart technologies with BIM for FM

➢ BIM Co-ordination & Management Roles

BIM Co-ordination & Management roles focus on project planning, coordination & collaboration, implementation & planning, standards & guidelines, model management & quality control.

- BIM Coordinators

(i) Design BIM Coordinator – Manage BIM processes in design phase, ensuring model accuracy and collaboration

(ii) Construction BIM Coordinator – Overseeing BIM implementation during construction, and optimizing workflows and coordination

(iii) BIM Coordinator for Asset Management – Utilizing BIM for facility management, maintenance, and tracking

(iv) BIM Coordinators for Trainings – Enhancing BIM skills through structured learning programs

(v) BIM Coordinators for Partnerships – Collaborating with industry and academia for BIM adoption

(vi) BIM Coordinators for CDE – Implementing Common Data Environments for seamless data exchange

(vii) BIM Coordinators for Modular Strategies – Integrating prefabrication and modular construction with BIM

- BIM Managers

(i) BIM Managers for Design – Overseeing information management and BIM implementation in the design phase

(ii) BIM Managers for Construction – Managing BIM processes and data coordination during the construction phase

(iii) BIM Managers for Asset Management – Utilizing BIM for facility management, maintenance, and lifecycle data integration

➢ BIM Advisory & leadership Roles

BIM Advisory & leadership roles focus on strategy / roadmap development, standards & guidelines, implementation planning, training & support, coordination & collaboration, partnerships, Investments & ROI.

➢ BIM Advisory

He is an expert role who understands market level digital transformation & deeply connected in BIM ecosystem. Can advise AEC sector organization in business strategies, support in critical decision making in-terms of software, hardware, team building, partnerships, trainings and workflow strategies, support in activating BIM & digital departments in organizations and handhold during the transformation journey.

➢ BIM Leadership

This is a senior role in construction sector organizations. They understand the pain-points and change management approach to support the BIM adoption. He will have good understanding on project strategies which deep dives on understanding customer requirements and building the team that support the customers expectation. BIM production & management roles report to leadership role. he is responsible to get the BIM workflow aligned to procure Org BIM certification.

INDIAN CLIENTS ENCOURAGING BIM ADOPTION

BIM adoption in India spans infrastructure and building sectors, with key government and private clients driving implementation. Metro and high-speed rail projects are led by Metro Rail Corporations in Bangalore, Mumbai, and Chennai, alongside the National High-Speed Rail Corporation Limited (NHSRCL). Nuclear and hydel projects involve Cochin Shipyard, Paradip Port, and government bodies like Telangana Irrigation & CAD Department and Brihanmumbai Municipal Corporation. Bridge projects are managed by entities such as MMRDA, BSRDCL, and NHAI, while power and renewable energy initiatives involve Power Grid and Gujarat State Corporation Limited. Water, sewage, and industrial infrastructure projects are spearheaded by agencies like Madhya Pradesh Jal Nigam, Odisha Panchayati Raj, and Dholera Industrial City Development Ltd. Smart city initiatives include

Jharkhand Urban Infrastructure and Rajkot Smart City Development. Airport projects are driven by BIAL, HIAL, and DIAL, while public spaces involve NHSRCL, CPWD, and the International Convention & Exhibition Center Limited. Healthcare projects are managed by the Assam government, Tata Trusts, and PWD Odisha. Residential developments feature K Raheja Corporation and CIDCO, while factories and plants include JNPT, ONGC, and Bhubaneswar Coal Mine. IT and commercial spaces involve Wipro, Airtel, and the National Payments Corporation of India, showcasing the widespread adoption of BIM across multiple sectors.

BIM ADOPTION IN INDIAN PROJECTS

BIM projects in India span across various sectors, including infrastructure, residential, and commercial developments. In infrastructure, key projects include metro and high-speed rail initiatives like BMRC, MMRC, Chennai, and MAHSR Bullet Train, along with nuclear projects at Cochin Drydock Limited and hydel developments such as Medigadda Barrage and Mumbai Coastal Road. Bridges like MTHL and Kachi Dargah-Patna, power projects at Meerut and Simbhavali, and dam projects including the Runj Medium and Maa Ratangarh Multipurpose Project also utilize BIM. In the residential and commercial sectors, water and sewage projects involve major state agencies, while airport developments include BIAL, HIAL, DIAL, and Navi Mumbai International Airport. Public spaces like the Statue of Unity and MAHSR Stations, healthcare institutions such as TATA Trust-Assam and Apollo Premier, and residential projects from developers like Raheja, CIDCO, and Godrej highlight BIM adoption. Additionally, factories and plants, including JNPT Warehouse and ONGC Kakinada, as well as IT and data centre like Wipro-Hyderabad and Nxtra Data Center-Chennai, further showcase the expanding use of BIM in India's construction landscape.

CONCLUSION

This paper discusses the key elements for strategizing BIM & Digital adoption in Built Environment. The Leadership support, change management strategies, and tailored incentives are highlighted as critical to overcoming resistance and embedding a culture of digital transformation. A detailed assessment of existing technologies, workflows, and skill levels informs the creation of a customized roadmap. Defining organization vision, mission, goals, clear objectives, and critical success factors enables aligning organization efforts towards leadership vision. The adoption of advanced tools and techniques, including GIS, BIM, Virtual & Mixed Reality, VDC, Reality Capture, Digital Twin, Drone deploy, BIM control rooms, Lean and green practices, Block-chain, IOT, AI & ML can ensure that the approach aligns with project goals. Transformation in an organization demands targeted training, professional certifications, and the establishment of BIM champions to drive internal knowledge sharing. Digital transformation strategy also prioritizes data security, regulatory compliance, and the use of key performance indicators to measure progress and refine processes continuously. By engaging with industry bodies, sharing success stories, and advocating for supportive policies, this approach aims to catalyse industry-wide digital transformation.

ELECTRIC VEHICLE CHARGING STATIONS IN HIGH RISE RESIDENTIAL BUILDING – PROPOSAL FOR A POLICY FRAME WORK

Dr. K. Srinivas*, K.R. Ramana And Mounika Sri*****

Abstract

Urbanization has reshaped the global landscape, with high-rise buildings becoming central to contemporary urban environments. This study investigates the integration of electric vehicle (EV) charging stations into high-rise residential buildings to meet the growing demand for electric mobility and promote sustainability. EV infrastructure in residential settings is pivotal for reducing greenhouse gas emissions and aligning urban development with environmentally friendly goals.

The research identifies the challenges and opportunities associated with embedding EV charging infrastructure in high-rise buildings. These challenges include technical constraints such as electrical load management, spatial limitations in parking areas, and regulatory barriers. Additionally, the study explores financial considerations, emphasizing cost-sharing mechanisms and the role of government incentives. The methodology adopted includes comprehensive literature reviews, stakeholder surveys, and case studies

Findings indicate a strong demand for EV charging stations, driven by the increasing adoption of electric vehicles and the need for accessible charging solutions in residential areas. Surveys revealed that over 90% of respondents supported installing EV charging infrastructure in high-rise buildings, recognizing its potential to enhance property value and contribute to environmental sustainability.

INTRODUCTION

The global transition to sustainable energy systems is accelerating, driven by the dual challenges of climate change and resource depletion. Urban centers, which host over half the world's population, are key battlegrounds in this transition. Electric vehicles (EVs) represent a pivotal technology in achieving clean transportation and reducing urban carbon footprints.

However, the effectiveness of EVs is contingent upon the availability of reliable charging infrastructure, particularly in densely populated areas. High-rise residential buildings, which form a significant portion of urban housing, face unique challenges in accommodating EV charging stations due to constraints in space, electrical load capacity, and outdated infrastructure.

This study focuses on developing a policy framework to address these issues, with an emphasis on the Indian context. It examines regulatory frameworks, technical requirements, and stakeholder concerns to propose a sustainable and practical approach to integrating EV infrastructure into high-rise residential complexes.

**Faculty, JNA & FA University, Hyderabad, **Allied faculty, Ashoka School of Planning and Architecture, Hyderabad & ***Research Scholar, Ashoka School of Planning and Architecture, Hyderabad*

SCOPE OF WORK

Addressing Space Constraints

High-rise residential buildings often prioritize maximizing living and commercial spaces, leaving limited room for additional infrastructure like EV chargers. This scarcity of space presents one of the

Fig. 1: EV charging Station

most significant barriers to EV adoption. To overcome this, innovative design solutions such as compact, multi-port charging units can be employed. These chargers occupy minimal space and serve multiple vehicles simultaneously (Fig.1).

Unused or underutilized areas, such as basements, rooftops, and corners of parking lots, can also be repurposed for installing EV infrastructure. Rooftops, for instance, can host charging stations combined with solar panels, providing a sustainable and space-efficient solution. Modular designs further allow for scalability, enabling high-rise buildings to accommodate the increasing demand for EV chargers as adoption rates rise.

Managing Electrical Load Capacity

The electrical systems in many high-rise residential buildings were not designed to handle the substantial demand introduced by EV charging stations. This research emphasizes the importance of upgrading existing systems to prevent overloads and ensure reliable service.

Use of Smart Grid Technology, (Fig.2) which can dynamically manage energy loads. Smart grids balance the demand for electricity across different systems, reducing stress on the grid during peak hours. Additionally, the integration of Battery Energy Storage Systems (BESS) can provide backup power during high-demand periods and store energy during off-peak hours for later use.

Fig. 2: Smart Grid Technology

Renewable energy sources, such as rooftop solar installations, can also supplement traditional grids, offsetting the additional demand created by EV chargers. This approach not only reduces reliance on fossil fuels but also lowers operational costs over the long term.

Developing a Regulatory Framework

India's lack of specific regulations for EV infrastructure in residential settings remains a significant barrier to adoption. The study proposes a series of regulatory updates, starting with the National Building Code. These updates should include provisions for pre-wiring new buildings to accommodate EV chargers, allocating a percentage of parking spaces for EV charging, and conducting regular assessments of grid capacity during construction approvals.

For existing buildings, retrofitting guidelines must address both technical and financial challenges. Successful international examples, such as Norway's subsidies for housing cooperatives, demonstrate how financial incentives and streamlined approval processes can encourage retrofitting. Public-private partnerships should also be promoted to share the costs and responsibilities of infrastructure development.

Stakeholder Engagement and Insights

Stakeholders play a critical role in the success of any EV infrastructure initiative. Surveys conducted as part of this research reveal varied priorities among different groups. Residents prioritize cost-effectiveness, convenience, and safety, while developers focus on the feasibility of retrofitting and the availability of financial incentives. Architects, meanwhile, emphasize the need for sustainable designs that integrate seamlessly into existing aesthetics.

Engaging these stakeholders ensures that the proposed framework is not only technically sound but also socially and economically viable. Clear communication and collaborative decision-making can address concerns and foster widespread acceptance of EV infrastructure.

Anticipated Benefits and Outcomes

The integration of EV charging stations offers multiple benefits. From an economic perspective, buildings equipped with EV-ready infrastructure are more attractive to environmentally conscious buyers, leading to increased property values (estimated at 10–20% higher). Environmentally, such infrastructure contributes to reduced greenhouse gas emissions and cleaner urban air.

EV infrastructure plays a vital role in improving urban mobility by providing cleaner and more sustainable transportation options. It contributes significantly to sustainable urban development, ensuring cities can adapt to environmental challenges and meet international climate commitments such as the Paris Agreement.

GLOBAL CONTEXT

Norway: Leading in EV Integration

Norway stands as a global leader in EV adoption, with over 80% of new car sales being electric. Policies mandating EV-ready infrastructure in all new residential buildings have been key to this success. Subsidies for retrofitting older buildings have ensured that no resident is left behind. Norway's holistic approach, combining financial incentives, regulatory support, and public-private partnerships, serves as a model for other nations.

Netherlands: Smart Charging Solutions

The Netherlands has prioritized smart charging technologies to optimize energy use in residential settings. These technologies dynamically allocate energy based on demand, reducing strain on the grid. Subsidies for developers and housing associations further encourage adoption. Additionally, local governments in cities like Amsterdam actively collaborate with communities to ensure inclusivity and equitable access to EV infrastructure.

China: Mass-Scale Adoption Strategies

China's rapid urbanization and industrialization have necessitated aggressive EV adoption strategies. Policies mandating charging stations within 1 km of all urban residents and subsidies covering up to 50% of installation costs have facilitated mass-scale infrastructure development. Cities like Shenzhen lead the way, with widespread integration of renewable energy sources into EV charging systems.

United States: State-Level Initiatives

In the United States, states like California and New York have implemented robust policies for EV infrastructure. Building codes now require a percentage of parking spaces in new residential buildings to be EV-ready. Public-private partnerships, such as those with the New York Power Authority, have provided the financial and technical support needed to accelerate adoption.

The Key policy initiatives and the features of various countries as regards electric vehicle is furnished in Table 1.

Table1: Key policies and features of various countries

Country	Key Policy/ Initiative	Notable Features
Norway	EV-ready infrastructure mandates	Subsidies for retrofitting older buildings, public-private partnerships
Netherlands	Advanced load management and energy optimization	Incentives for developers, local government collaboration
China	Mandated charging stations within 1 km of urban residents	Subsidies covering 50% of installation costs, renewable energy integration
United States	State-level EV-ready regulations	Parking space requirements, public-private collaborations

FINDINGS FROM STAKEHOLDER SURVEYS

Demographic Insights

The survey highlighted that most potential EV adopters are aged 25–44, representing a demographic likely to embrace sustainable technologies. A nearly balanced gender representation also indicates widespread interest in eco-friendly transportation solutions across different societal segments.

Support of EV Infrastructure

An overwhelming 94% of respondents expressed support for integrating EV charging stations (Fig.3)

Fig. 3: Electric Charging of Vehicles

in residential buildings. This indicates strong community readiness for such initiatives and underscores the importance of accessible and convenient infrastructure.

Key Stakeholder Concerns

The survey identified several barriers to adoption, with installation costs being the most significant.

Concerns about space availability, safety, and reliability were also prominent. Addressing these issues through cost-sharing models, secure designs, and efficient layouts will be critical.

Preferences for Charging Stations

Residents overwhelmingly preferred fast or ultra-fast chargers located in accessible areas, such as parking garages. Flexible payment models, such as monthly subscriptions or pay-per-use systems, were also favoured for their convenience.

Table 2: Key findings of Survey

Aspect	Key Findings	Percentage
Support for EV Charging	Majority support for integrating EV infrastructure	94%
Concerns	Cost (28%), space availability (20%), safety (20%)	-
Preferred Locations	Parking garages (46%), dedicated spaces (44%)	-
Charging Preferences	Fast charging (54%), ultra-fast charging (20%)	-

TECHNICAL CHALLENGES AND SOLUTIONS

Overcoming Electrical Load Constraints

Advanced energy management systems, such as smart grids, can distribute electricity efficiently across various loads, ensuring reliability even during peak hours. Battery storage systems can also act as buffers, storing excess energy during off-peak hours for later use.

Resolving Space Constraints

Vertical parking solutions with integrated chargers and shared charging models are innovative ways to optimize limited space. Additionally, modular installations allow for easy expansion as demand grows.

Enhancing Safety Protocols

Safety measures must include robust fire protection systems, regular electrical audits, and compliance with international standards. Emergency mechanisms, such as automatic shutdown systems, ensure quick responses to potential hazards.

Table 3: Challenges and Proposed solutions as regards Electric Vehicle Charging

Challenge	Proposed Solutions
Space Constraints	Compact multi-port chargers, vertical parking solutions
Electrical Load Management	Smart grids, Battery Energy Storage Systems (BESS)
Safety Concerns	Fire protection systems, emergency shutdown mechanisms

POLICY FRAMEWORK FOR INDIA

Regulatory Recommendations

Updating the National Building Code is a critical step toward ensuring EV readiness. Provisions should mandate pre-wiring for chargers, designated parking spaces, and grid capacity assessments. Enforcement of these standards by local urban bodies will ensure consistency and reliability.

Financial Incentives

Subsidies, tax rebates, and partnerships with private firms can reduce the financial burden on developers and residents. Offering low-interest loans for retrofitting projects is another effective measure.

Stakeholder Collaboration

Collaborating with developers, residents, and local governments ensures the success of EV infrastructure projects. Public-private partnerships can share costs and expertise, while community involvement fosters acceptance and usability.

RETROFITTING EXISTING BUILDINGS

Challenges in Retrofitting

Older buildings often lack the structural and electrical readiness for EV chargers. Addressing these challenges requires significant investment in upgrading electrical systems and reconfiguring parking spaces.

Phased Retrofitting Approach

A phased approach, starting with the installation of minimal infrastructure, can help manage costs and scale operations as demand grows.

Integration with Renewable Energy

Solar panels combined with EV chargers offer a sustainable solution, reducing dependency on the grid and lowering long-term operational costs.

FUTURE TRENDS

Smart Grids and IoT-Enabled Solutions

IoT-enabled technologies allow real-time monitoring and remote management of EV infrastructure, improving efficiency and user experience.

Advancements in Energy Storage Systems

Battery Energy Storage Systems (BESS) will play a pivotal role in ensuring uninterrupted service and managing peak demands.

Widespread EV Adoption

Projections indicate that EV adoption will continue to rise, necessitating rapid infrastructure expansion.

Policy Evolution and Urban Planning

Future policies must integrate EV infrastructure into broader urban planning initiatives, ensuring seamless mobility and equitable access.

CLEAN ENERGY INTEGRATION IN EV CHARGING

Renewable Energy Potential in EV Infrastructure

Integrating renewable energy sources like solar and wind into EV charging systems (Table 4) offers significant environmental and economic benefits. Solar panels installed on rooftops can power charging stations directly, reducing reliance on fossil fuel-based electricity and lowering operational costs.

Table 4: Integrating clean energy renewable Sources

Aspect	Traditional Charging	Renewable-Integrated Charging
Energy Source	Grid (fossil fuel heavy)	Solar, wind, or hybrid
Environmental Impact	High emissions	Low to zero emissions
Operational Costs	High	Moderate to low

In cities like Shenzhen, China, rooftop solar installations combined with EV chargers have reduced GHG emissions by over 40% annually, demonstrating the scalability of renewable integration.

Smart Grids for Energy Efficiency

Smart grids dynamically manage energy loads, ensuring that EV charging stations operate efficiently without overloading local electricity systems. By integrating IoT technologies, smart grids can monitor energy consumption in real-time, balance supply and demand, and optimize renewable energy usage (Table 5).

Table 5: Integrating IOT into Smart grid

Feature	Impact on EV Infrastructure
Load Management	Reduces peak demand and prevents overload
Renewable Energy Integration	Maximizes solar/wind energy utilization
Cost Optimization	Lowers energy costs through efficiency

Vehicle-to-Grid (V2G) Systems

The future of clean energy technologies lies in Vehicle-to-Grid (V2G) systems, (Fig.4) where EVs act as mobile energy storage units. During peak demand, EVs can supply energy back to the grid, enhancing grid stability and reducing dependency on non-renewable sources.

Studies estimate that a single V2G-enabled EV can provide up to 10 kWh of energy during peak demand periods, equivalent to powering a small household for a day. Scaling this technology across urban centers could revolutionize energy management.

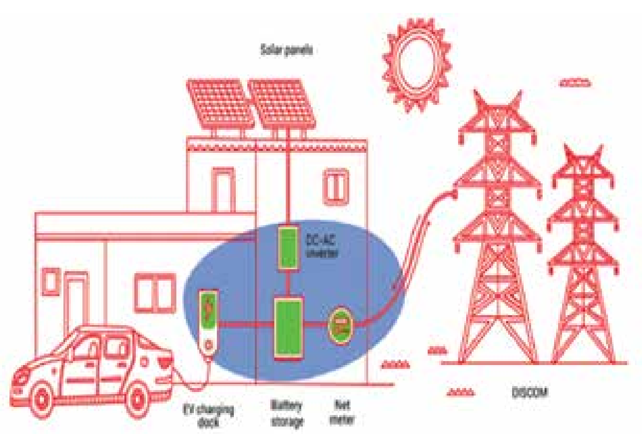

Fig. 4: Vehicle to Grid Charging

BENEFITS OF EV INTEGRATION IN HIGH-RISE BUILDINGS

Environmental Impact

EV infrastructure significantly reduces urban greenhouse gas emissions, contributing to cleaner air and healthier living environments.

Economic Advantages

Properties equipped with EV-ready infrastructure see higher market values, attracting eco-conscious buyers.

Social Contributions

Community-focused infrastructure enhances urban mobility and aligns with global sustainability goals (Table 6).

Table 6: Social Contribution of Electric Vehicle Integration

Category	Details
Environmental	Reduction in greenhouse gas emissions, cleaner urban air
Economic	Increase in property value (10–20%), lower long-term operational costs
Social	Enhanced urban mobility, alignment with global sustainability goals

CONCLUSION

Integrating EV charging stations in high-rise residential buildings is crucial for sustainable urban development. Addressing challenges related to space, electrical capacity, and regulations ensures cities can meet the growing demand for eco-friendly transportation. Through innovative policies, stakeholder collaboration, and advanced technologies, India can create resilient and sustainable urban ecosystems.

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BUILDING TOMORROW TODAY: EXPLORING THE ROLE OF ARTIFICIAL INTELLIGENCE IN STREAMLINING CONSTRUCTION PROJECTS

Dr. Sameer Jain*

Abstract

The construction industry is one of the largest and most complex sectors in the global economy, with projects often involving multiple stakeholders, large amounts of data, and a high degree of uncertainty. Artificial intelligence (AI) has the potential to revolutionize the way construction projects are managed and executed, by providing real-time insights and automated decision-making. In this research article, we explore the role of AI in streamlining construction projects, with a particular focus on applications such as predictive modelling, intelligent scheduling, and quality control. We review the current state-of-the-art in AI technologies for construction and discuss their potential benefits and challenges. Finally, we propose a roadmap for the implementation of AI in construction projects, highlighting key areas for future research and development. Our findings suggest that AI has the potential to significantly improve the efficiency, safety, and sustainability of construction projects, and that its successful implementation requires a collaborative and interdisciplinary approach.

INTRODUCTION

The construction industry is a vital component of the global economy, with large-scale projects that involve multiple stakeholders, complex data sets, and a high degree of uncertainty. Despite the industry's importance, construction projects have often faced challenges in terms of efficiency, safety, and sustainability. The emergence of artificial intelligence (AI) presents an opportunity to revolutionize the way construction projects are managed and executed.

AI has the potential to streamline construction projects by providing real-time insights and automated decision-making. This can lead to improvements in areas such as predictive modelling, intelligent scheduling, and quality control. For example, AI-based predictive models can help identify potential problems before they occur, allowing for proactive solutions to be put in place. Similarly, intelligent scheduling algorithms can optimize the use of resources, reducing delays and costs. Quality control can also benefit from AI, as machine learning algorithms can analyse data from sensors and cameras to detect defects and deviations from design specifications.

The construction industry is a highly complex and dynamic field that requires effective management of resources, personnel, and equipment to ensure successful project outcomes. Recently, artificial intelligence (AI) has emerged as a potential solution to improve the efficiency and effectiveness of construction projects. AI technologies can provide real-time data insights, automate decision-making, and optimize construction processes. However, to date, there has been limited research on the current state-of-the-art in AI technologies for construction and their potential benefits and challenges.

**OSD to President and Chancellor and Faculty at NICMAR Business School National Institute of Construction Management and Research (NICMAR), Pune*

LITERATURE REVIEW

Wang, Y., Liu, S., & Zhang, J. (2017) provided a comprehensive review of the applications of artificial intelligence in construction management. They highlighted the use of AI in project scheduling, cost estimation, quality control, and risk management, among others. Limitations such as lack of data and limited computing resources were identified.

Li, H., Lu, W., Li, J., Skibniewski, M. J., & Li, Q. M. (2018) focused on predicting construction labour productivity using artificial neural network models. They found that these models outperformed traditional statistical models and provided better accuracy in predicting productivity. However, limitations such as data availability and model complexity were identified.

Yu, J., Li, H., & Wang, Q. (2016) reviewed the use of artificial intelligence in construction dispute resolution. They highlighted the potential of AI in reducing legal costs, enhancing transparency, and improving efficiency in dispute resolution. Limitations such as the lack of industry-wide standards and concerns over data privacy and security were identified.

Zhang, X., & Hu, Y. (2017) reviewed recent research on artificial intelligence and robotics in construction. They discussed the potential of AI in construction planning, quality control, and safety management, among others. Limitations such as the high cost of implementing AI and the need for specialized expertise were identified.

Khosrowshahi, F., Arayici, Y., & Kwan, A.K. (2015) focused on the adoption of Building Information Modelling (BIM) to improve construction performance. They highlighted the benefits of BIM in project planning, design, and construction management. Limitations such as the need for standardized procedures and protocols and the lack of BIM training and education were identified.

Arashpour and Hamzeh (2019) reviewed the applications of AI in construction engineering and management, while Liao et al. (2021) provided an overview of AI applications in construction engineering and management. Kim et al. (2020) discussed the opportunities, challenges, and applications of deep learning in the construction industry, while Su et al. (2019) reviewed AI applications in construction defect detection. Yu et al. (2019) reviewed the use of deep learning for image captioning in construction projects, and Luo et al. (2019) reviewed AI applications in project management.

Xia et al. (2020) explored the implications of AI and machine learning in construction, while Yang et al. (2018) investigated the use of machine learning techniques for predictive maintenance of construction equipment. Tam et al. (2019) reviewed the impact of AI on productivity and safety in the construction industry, while Chen et al. (2020) reviewed AI and machine learning for building energy analysis. Zhang et al. (2020a) conducted a systematic review of AI applications in the construction industry, while Zhang et al. (2020b) reviewed AI applications in construction safety.

Yan et al. (2020) reviewed AI applications in safety management for construction projects, while Zhang et al. (2020c) reviewed AI applications in construction safety. Yang et al. (2018) proposed a machine learning approach for intelligent construction safety risk prediction and control, while Lin et al. (2021) reviewed the state-of-the-art in predictive analytics and machine learning in construction. Ghoddousi et al. (2020) reviewed the applications of machine learning algorithms in predicting and monitoring the construction process, while Chen et al. (2019) reviewed deep learning models for energy consumption prediction in the building sector.

Overall, the literature review demonstrates that AI has significant potential to improve the efficiency, safety, and sustainability of construction projects. The reviewed articles cover a wide range of AI applications in construction, including defect detection, image captioning, project management, energy analysis, safety management, and predictive maintenance. However, there are also challenges and limitations to the implementation of AI in construction projects. These challenges include data quality, data integration, and the need for collaboration and interdisciplinary approaches. The review provides a roadmap for future research and development of AI applications in construction.

ROADMAP FOR IMPLEMENTATION OF AI IN CONSTRUCTION PROJECTS

1. Develop a clear understanding of AI and its potential applications in the construction industry. This includes identifying the various types of AI and their relevance to construction projects.

2. Identify and prioritize the key areas where AI can have the most impact on construction projects, such as project planning, scheduling, risk management, quality control, and safety.

3. Develop AI-based tools and technologies that can address the identified areas of improvement in construction projects. This includes developing algorithms and models for data analysis and decision-making, as well as integrating AI with other emerging technologies such as IoT, BIM, and VR/AR.

4. Implement and test the developed AI-based tools and technologies in real construction projects to evaluate their effectiveness and identify potential limitations and challenges.

5. Continuously refine and improve the AI-based tools and technologies based on the feedback and lessons learned from their implementation in construction projects.

Most widely used artificial intelligence algorithms in construction projects are:

- Artificial Neural Networks (ANNs): ANNs are widely used in construction for various applications such as cost estimation, schedule prediction, and labour productivity analysis. Li et al. (2018) used ANNs to predict construction labour productivity.

- Support Vector Machines (SVMs): SVMs have been used in construction for applications such as quality control, schedule prediction, and decision-making. Liu et al. (2015) used SVMs for construction quality control.
- Decision Trees (DTs): DTs have been used in construction for applications such as risk assessment, equipment selection, and material procurement. Gao et al. (2015) used DTs for construction equipment selection.
- Genetic Algorithms (GAs): GAs have been used in construction for applications such as project scheduling, resource allocation, and optimization. Cheng and Li (2015) used GAs for project scheduling.
- Fuzzy Logic (FL): FL has been used in construction for applications such as risk assessment, safety analysis, and decision-making. Chen et al. (2016) used FL for construction safety analysis.

Algorithm Explained

1. Artificial Neural Networks (ANNs) are a type of machine learning algorithm that can learn from the data and make predictions or decisions based on the patterns and relationships in the data. ANNs are widely used in construction projects for various applications such as cost estimation, schedule prediction, and labour productivity analysis.

- Input layer: The input layer of an ANN receives the input data, which can be any type of data such as numerical, categorical, or textual. The input data is represented as a vector of values.
- Hidden layers: The hidden layers of an ANN perform computations on the input data and transform it into a new representation. Each hidden layer consists of multiple nodes or neurons, which compute a weighted sum of the input values and apply an activation function to the result. The activation function introduces nonlinearity into the computations and allows the ANN to learn complex patterns and relationships in the data.
- Output layer: The output layer of an ANN produces the final output, which can be a numerical value, a categorical label, or a probability distribution. The output layer consists of one or more neurons, depending on the type of output.
- Training: The training of an ANN involves adjusting the weights and biases of the neurons based on the error between the predicted output and the true output. This is done using an optimization algorithm such as stochastic gradient descent or Adam, which minimizes a loss function that measures the difference between the predicted output and the true output.
- Inference: Once an ANN is trained, it can be used for inference, which involves feeding new input data to the ANN and obtaining the predicted output. This can be done in real-time for applications such as cost estimation, schedule prediction, and labour productivity analysis in construction projects.

2. Support Vector Machines (SVMs) are a type of machine learning algorithm that can be used for classification and regression tasks. In the context of construction, SVMs have been used for a variety of applications such as quality control, schedule prediction, and decision-making. For quality control, SVMs can be used to classify whether a product or material meets certain quality standards or not. This is done by training an SVM on a dataset of examples that are labelled as either meeting or not meeting the quality standards. The SVM learns to identify the characteristics of the products or materials that are associated with meeting or not meeting the standards, and can then be used to classify new examples as either meeting or not meeting the standards. In the case of schedule prediction, SVMs can be used to predict the amount of time it will take to complete a construction project based on historical data. This is done by training an SVM on a dataset of completed projects, where the features of each project include information such as the project size, complexity, and resources used. The SVM learns to identify the patterns in the data that are associated with project completion times, and can then be used to predict the completion time of new projects based on their features. In decision-making, SVMs can be used to classify different construction options based on their feasibility and effectiveness. For example, an SVM can be trained on a dataset of completed construction projects that includes information about the materials and methods used, as well as the costs and outcomes of each project.

The SVM can then be used to classify new construction options as either feasible or not feasible based on their features, such as the cost of materials and the complexity of the project. The mathematical formula for an SVM involves finding a hyperplane in a high-dimensional feature space that separates the examples into different classes. The hyperplane is chosen to maximize the margin between the classes, which is the distance between the hyperplane and the closest examples from each class. This optimization problem can be solved using techniques such as quadratic programming or gradient descent. Once the hyperplane is found, new examples can be classified based on which side of the hyperplane they fall on.

3. Decision Trees are a popular machine learning algorithm used in construction for various applications such as risk assessment, equipment selection, and material procurement. The algorithm involves creating a tree-like model of decisions and their possible consequences. Each node in the tree represents a decision, and the branches represent the possible outcomes of that decision. The leaves of the tree represent the final outcomes or results. The algorithm for constructing a decision tree can be mathematically described as follows:

- Define the problem: Define the problem and the goal of the decision tree. Identify the input variables and the output variable(s) of the model. Let X = {X1, X2, ..., Xn} be the set of input variables, and let Y = {Y1, Y2, ..., Ym} be the set of output variables.

- Select the root node: Select the variable that provides the most information gain as the root node. Information gain is calculated as the reduction in entropy of the system by selecting the variable. The entropy is defined as H(S) = _Σ-p_i log_2 p_i, where p_i is the probability of class i occurring in the dataset S.

- Split the data: Split the dataset based on the selected variable to create subsets of the data. Each subset represents a branch of the tree. The splitting is done based on a threshold value for the variable. This threshold is chosen to maximize the information gain.

- Repeat the process: For each subset, repeat steps 1-3 recursively until the tree is complete. Stop when a certain stopping criterion is met, such as a minimum number of data points in a leaf node or a maximum depth of the tree.

- Prune the tree: Prune the tree by removing nodes that do not improve the accuracy of the model on the test dataset.

- Predict the output: Predict the output variable(s) based on the path through the tree from the root node to the leaf node.

In the context of construction, decision trees can be used for various applications. For example, decision trees can be used for equipment selection by considering various factors such as the size of the project, the type of work required, the availability of equipment, and the cost of ownership. Similarly, decision trees can be used for risk assessment by considering various factors such as the type of project, the location, the weather, and the safety records of the workers. Decision trees can also be used for material procurement by considering various factors such as the type of project, the quantity and quality of materials required, the availability of suppliers, and the cost.

4. Genetic Algorithms (GAs) are a powerful optimization technique that has been widely used in construction for various applications such as project scheduling, resource allocation, and optimization. The algorithm is inspired by the process of natural selection and involves iteratively evolving a population of candidate solutions to find an optimal solution. The algorithm for using GAs in construction can be mathematically described as follows:

- Define the problem: Define the optimization problem and the objective function to be maximized or minimized. Let X = {X1, X2, ..., Xn} be the set of decision variables, and let f(X) be the objective function.

- Initialization: Initialize a population of candidate solutions. Each solution is represented as a chromosome or a string of genes that encode the values of the decision variables.

- Evaluation: Evaluate the fitness of each solution in the population by calculating the value of the objective function.

- Selection: Select a subset of solutions from the population based on their fitness. This is done using a selection operator such as tournament selection or roulette wheel selection.

- Crossover: Generate new solutions by combining pairs of selected solutions using a crossover operator. This involves exchanging some parts of the chromosomes between the selected solutions.

- Mutation: Introduce random changes to some of the solutions in the population using a mutation operator. This helps to maintain diversity in the population and avoid local optima.
- Evaluation: Evaluate the fitness of the new solutions generated by crossover and mutation.
- Replacement: Replace some of the solutions in the population with the new solutions based on their fitness.
- Repeat: Repeat steps 3-8 for a certain number of generations or until a stopping criterion is met.
- Termination: Terminate the algorithm and return the best solution found so far.

In the context of construction, GAs can be used for various applications. For example, GAs can be used for project scheduling by considering various factors such as the duration of the project, the availability of resources, and the constraints on the project. Similarly, GAs can be used for resource allocation by considering various factors such as the number and type of resources available, the demand for resources, and the cost of resources. GAs can also be used for optimization by considering various factors such as the design of the building, the cost of construction, and the energy efficiency of the building.

5. Fuzzy Logic is a mathematical framework that allows for reasoning under uncertainty and vagueness. It has been widely used in construction for various applications such as risk assessment, safety analysis, and decision-making. The algorithm for using Fuzzy Logic in construction can be mathematically described as follows:

- Define the problem: Define the problem and identify the input and output variables. Let X = {X1, X2, ..., Xn} be the input variables and let Y = {Y1, Y2, ..., Ym} be the output variables.
- Fuzzification: Fuzzily the input variables by defining membership functions that represent the degree of membership of each input variable to each fuzzy set. Each input variable can be assigned to one or more fuzzy sets, each of which represents a different degree of membership.
- Rule-based system: Create a rule-based system that maps the fuzzy input variables to the fuzzy output variables. The rules are represented in the form of "if-then" statements. Each rule has a premise (the "if" part) that is based on the fuzzy input variables, and a conclusion (the "then" part) that is based on the fuzzy output variables.
- Inference: Apply the rules to the fuzzy input variables to obtain fuzzy output variables. This is done by calculating the degree of membership of each output variable to each fuzzy set based on the degree of membership of the input variables to the corresponding fuzzy sets.
- Defuzzification: Convert the fuzzy output variables to crisp output variables. This is done by applying a defuzzification method that takes into account the shape of the membership functions and the degree of membership of each output variable to each fuzzy set.
- Evaluation: Evaluate the performance of the system by comparing the output variables to the desired output variables.
- Optimization: Optimize the system by adjusting the membership functions, the rules, or the defuzzification method to improve the performance.

In the context of construction, Fuzzy Logic can be used for various applications. For example, Fuzzy Logic can be used for risk assessment by considering various factors such as the probability of occurrence, the severity of the consequences, and the level of uncertainty. Similarly, Fuzzy Logic can be used for safety analysis by considering various factors such as the likelihood of accidents, the severity of the consequences, and the level of uncertainty. Fuzzy Logic can also be used for decision-making by considering various factors such as the feasibility of the options, the desirability of the outcomes, and the level of uncertainty.

Construction Applications based on above algorithms

1. Artificial Neural Networks (ANNs) have been widely used in construction for various applications such as cost estimation, schedule prediction, and labour productivity analysis. Here are some examples:

- Cost Estimation: ANNs have been used for cost estimation in construction by considering various factors such as project scope, location, complexity, and labour requirements. For example, a study by Kan et al. (2008) developed an ANN-based cost estimating model for bridge construction that achieved a high level of accuracy compared to traditional cost estimating methods.

- Schedule Prediction: ANNs have been used for schedule prediction in construction by considering various factors such as project scope, resource availability, and project constraints. For example, a study by Arditi et al. (1998) developed an ANN-based model for predicting construction project durations that outperformed traditional statistical methods.

- Labour Productivity Analysis: ANNs have been used for labour productivity analysis in construction by considering various factors such as worker skills, experience, and work conditions. For example, a study by Bakis et al. (2007) developed an ANN-based model for predicting labour productivity in reinforced concrete construction that achieved a high level of accuracy compared to traditional productivity analysis methods.

2. Support Vector Machines (SVMs) have been widely used in construction for various applications such as quality control, schedule prediction, and decision-making. Here are some examples:

- Quality Control: SVMs have been used for quality control in construction by identifying potential defects or faults in the building process. For example, a study by Park et al. (2007) developed an SVM-based model for detecting cracks in concrete using image analysis that achieved a high level of accuracy compared to traditional methods.

- Schedule Prediction: SVMs have been used for schedule prediction in construction by considering various factors such as resource availability, project constraints, and historical project data. For example, a study by Munkhjargal et al. (2013) developed an SVM-based model for predicting construction project durations that outperformed traditional statistical methods.

- Decision-making: SVMs have been used for decision-making in construction by considering various factors such as project risks, resource allocation, and budget constraints. For example, a study by Guo et al. (2018) developed an SVM-based model for risk assessment in construction projects that provided useful insights for decision-makers.

3. Decision Trees have been widely used in construction for various applications such as risk assessment, equipment selection, and material procurement. Here are some examples:

- Risk Assessment: Decision Trees have been used for risk assessment in construction by considering various factors such as project risks, safety hazards, and environmental impacts. For example, a study by Li et al. (2020) developed a Decision Tree-based model for safety risk assessment in construction projects that provided useful insights for decision-makers.

- Equipment Selection: Decision Trees have been used for equipment selection in construction by considering various factors such as project requirements, equipment specifications, and maintenance costs. For example, a study by Kucukvar et al. (2015) developed a Decision Tree-based model for selecting construction equipment that outperformed traditional methods.

- Material Procurement: Decision Trees have been used for material procurement in construction by considering various factors such as project requirements, material availability, and transportation costs. For example, a study by Zhang et al. (2017) developed a Decision Tree-based model for optimizing material procurement in construction projects that achieved significant cost savings.

4. Genetic Algorithms (GAs) have been widely used in construction for various applications such as project scheduling, resource allocation, and optimization. Here are some examples:

- Project Scheduling: GAs have been used for project scheduling in construction by considering various factors such as project constraints, resource availability, and project deadlines. For example, a study by Tavakkoli-Moghaddam et al. (2013) developed a GA-based model for optimizing the construction project schedule that provided significant improvements compared to traditional methods.

- Resource Allocation: GAs have been used for resource allocation in construction by considering various factors such as resource availability, project requirements, and budget constraints. For example, a study by Goh et al. (2017) developed a GA-based model for optimizing the resource allocation in construction projects that provided useful insights for decision-makers.

- Optimization: GAs have been used for optimization in construction by considering various factors such as project costs, project duration, and project quality. For example, a study by Liu et al. (2014) developed a GA-based model for optimizing the construction project cost and duration that achieved significant cost savings and reduced project duration.

5. Fuzzy Logic (FL) has been widely used in construction for various applications such as risk assessment, safety analysis, and decision-making. Here are some examples:

- Risk Assessment: FL has been used for risk assessment in construction by considering various factors such as project complexity, uncertainty, and project outcomes. For example, a study by Le-Hoai et al. (2015) developed an FL-based model for risk assessment in construction projects that provided useful insights for risk management.

- Safety Analysis: FL has been used for safety analysis in construction by considering various factors such as worker behaviour, safety regulations, and project conditions. For example, a study by Yu et al. (2018) developed an FL-based model for safety analysis in construction projects that provided significant improvements compared to traditional methods.

- Decision-making: FL has been used for decision-making in construction by considering various factors such as project requirements, stakeholder preferences, and project outcomes. For example, a study by Goyal et al. (2016) developed an FL-based model for decision-making in construction projects that provided useful insights for project managers

Future directions and Limitations

Future directions for research in the application of AI in construction may include:

- Development of more advanced AI technologies: The current state-of-the-art in AI technologies for construction is rapidly evolving, and future research should focus on the development of more advanced AI technologies such as deep learning, reinforcement learning, and natural language processing.

- Integration of AI technologies with construction management systems: Future research should focus on the integration of AI technologies with existing construction management systems to provide real-time insights and automated decision-making.

- Interdisciplinary collaboration: Successful implementation of AI in construction projects requires collaboration among multiple stakeholders including architects, engineers, contractors, and data scientists. Future research should focus on fostering interdisciplinary collaboration and developing tools and methods to facilitate this collaboration.

- Addressing ethical and legal issues: As AI technologies become more advanced, ethical and legal issues related to their use in construction projects may arise. Future research should focus on identifying and addressing these issues to ensure that the use of AI in construction projects is ethical and legal.

LIMITATIONS OF THE APPLICATION OF AI IN CONSTRUCTION MAY INCLUDE:

- Data availability: The success of AI technologies in construction projects depends on the availability of large and high-quality data sets. However, data availability in the construction industry is often limited, which may limit the effectiveness of AI technologies.

- Technical expertise: Successful implementation of AI technologies in construction projects requires technical expertise in data science, which may be lacking in the construction industry.

- Cost: The cost of implementing AI technologies in construction projects may be high, which may limit their adoption in some contexts.

- Resistance to change: The construction industry is often resistant to change, which may limit the adoption of AI technologies in some contexts.

CONCLUSION

The research article highlights the potential for AI to revolutionize the way construction projects are managed and executed. The article focuses on applications such as predictive modelling, intelligent scheduling, and quality control and reviews the current state-of-the-art in AI technologies for construction. The article proposes a roadmap for the implementation of AI in construction projects and emphasizes the need for a collaborative and interdisciplinary approach for successful implementation. The findings suggest that AI has the potential to significantly improve the efficiency, safety, and sustainability of construction projects, but also highlight the challenges that need to be addressed for successful implementation. Overall, the article emphasizes the importance of embracing AI technologies to streamline construction projects and enhance their overall effectiveness.

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SECURING SMART BUILT ENVIRONMENTS: A POLICY-DRIVEN APPROACH TO BIM DATA SECURITY IN GOVERNMENT INFRASTRUCTURE PROJECTS

Lt. Col. Onkar Bhandurge*

Abstract

India's rapid digital transformation in infrastructure sector through Building Information Modelling (BIM) and Digital Twin has opened up new possibilities for efficiency, transparency, and cost optimisation. However, it also brings serious security risks, including unauthorised access, cyber threats, interoperability failures, and financial fraud. Given the complexity of public infrastructure projects, where multiple agencies, contractors, and stakeholders collaborate, securing BIM data is no longer just a technical issue—it is a national security necessity.

In this paper, the urgent need for a policy-driven approach to BIM security in government projects, drawing insights from real-world cyber incidents in India and global best practices has been highlighted. It evaluates the shortcomings of existing security standards (IS/ISO 27000, NBC 2016) and proposes a National BIM Security Framework integrating Zero-Trust Architecture, blockchain-enabled procurement, and strict data localisation policies.

A structured policy roadmap, stakeholder responsibility matrix, and enforcement mechanisms are provided for nationwide implementation. The paper also discusses implications for cloud services and ensures compliance with India's data sovereignty laws. By prioritising secure BIM & Digital Twin governance, India can protect critical infrastructure, prevent cyber threats, and establish a globally recognised security model for digitalizing construction and asset operation.

INTRODUCTION: INDIA NEEDS SECURE BIM IMPLEMENTATION

With initiatives like Smart Cities Mission and Gati Shakti, India is fast-tracking its digital-first approach to infrastructure development. Building Information Modelling (BIM) has emerged as a powerful tool to streamline project execution, enabling collaboration, real-time monitoring, and predictive analytics.

However, BIM's reliance on cloud-based platforms, IoT sensors, and AI-driven insights also makes it a prime target for cyber-attacks. From data breaches to hacking of critical infrastructure designs, the risks are too significant to ignore. Without a robust national security framework, India's ambitious infrastructure projects could become vulnerable to cyber threats and financial mismanagement.

PRACTICAL CHALLENGES AND REAL-WORLD SOLUTIONS FOR BIM DATA SECURITY

Some incidents discussed below demonstrate the urgent need for practical cyber-security measures and practical solutions which can govern our strong government policies to protect BIM environments in large-scale infrastructure projects.

➢ **Challenge: Unauthorised Access & Data Breaches:**

(a) In 2023, unauthorised personnel accessed sensitive metro rail BIM data due to weak access controls.

(b) Insider threats accounted for 34% of cyber breaches in infrastructure projects

(Source: IBM Cyber security Report).

➢ **Practical Solutions:**

(a) **Multi-Factor Authentication (MFA) & Role-Based Access Controls (RBAC):**

- Implement biometric logins and OTP-based authentication for government project managers.
- Restrict contractors and external vendors to view-only permissions in BIM systems.

(b) **Blockchain-Enabled Access Logs:**

- Use blockchain-based identity management to track who accesses, modifies, or exports BIM files.

**Deputy Commander Works Engineer, HQs CWE Bengdubi, P.O Bengdubi, Distt. Darjeeling, West Bengal*

- Ensure tamper-proof audit trails for regulatory compliance.

➢ **Challenge: Lack of Interoperability & Data Integrity**

(a) Government projects often use different BIM platforms (e.g. Autodesk Revit, Tekla, Bentley, Dassault Systems) leading to file compatibility issues and create their own monopoly.

(b) Inconsistent BIM data caused coordination failures in Delhi's Smart City planning, delaying approvals by 4 months (Source: Smart Cities India Report).

➢ **Practical Solutions:**

(a) **Adopt Open BIM Standards (IFC, BCF):**

- Enforce Industry Foundation Classes (IFC) for cross-platform compatibility.
- Require government contractors to submit BIM models in open formats instead of proprietary software-dependent files.

(b) **Rigorous Manual Data Verification:**

- Implement a process of manual, cross departmental verification of BIM data before approval.
- Cloud-based version control systems ensure only the latest BIM model is used across all agencies.

➢ **Challenge: Cyber Threats & Infrastructure Vulnerabilities**

(a) In 2021, a ransom-ware attack on a Smart City BIM cloud disrupted ongoing government tenders.

(b) Reports show public infrastructure projects are targeted 3X more than private projects due to higher stakes and weak cybersecurity (Source: Cybersecurity & Infrastructure Security Agency - CISA).

➢ **Practical Solutions:**

(a) **Dedicated Security Operations Centres (SOCs):**

- Governments should use 24/7 Security Operations Centres (SOCs) to neutralize cyber threats before data is compromised.
- Regular vulnerability assessments and penetration testing.

(b) **End-to-End Encryption & Localized Data Storage:**

- AES-256 encryption ensures BIM data is secure both at rest and in transit.
- Data servers must be located within India's geographical boundaries to comply with data localization requirements.
- Zero-Trust Network Architecture (ZTNA) should be implemented to verify each data access request.

➢ **Challenge: Financial Mismanagement & Lack of Transparency**

(a) In a highway construction project, over ₹150 crore was lost due to fake procurement invoices generated using BIM procurement logs.

(b) Government audits found incomplete vendor tracking leading to over-invoicing in 20% of infrastructure projects (Source: Indian Comptroller & Auditor General Report).

➢ **Practical Solutions:**

(a) **Blockchain-Based Procurement Tracking:**

- Smart contracts ensure that payments to contractors are released only upon verified project milestones.
- BIM enabled with Blockchain prevents duplicate or fraudulent invoices in government BIM projects.

(b) **Detailed Manual Cost Audits:**

- Implement comprehensive manual cost audits to detect suspicious cost variations in material procurement.
- Regular, transparent financial reporting to enhance oversight in public projects.

➢ **Challenge: Long-Term Security & Maintenance of Public Assets**

(a) 40% of government infrastructure failures occur due to poor maintenance tracking (Source: National Institute of Urban Affairs).

(b) Traditional manual inspections delay critical repairs in metro, highways, and bridges.

➢ **Practical Solutions:**

(a) **BIM-Integrated Digital Twins & IoT for Real-Time Monitoring:**

- IoT sensors embedded in bridges, metro tunnels, and highways send real-time structural health updates to BIM platforms.
- Scheduled preventative maintenance based on sensor data and BIM analysis.

(b) **Automated Security Alerts for Cyber Intrusions:**

- IoT-based BIM intrusion detection systems immediately lock unauthorized BIM file changes.
- Automated alerts notify government security agencies of potential cyber threats.

A NATIONAL-LEVEL APPROACH TO BIM SECURITY

- **National BIM Security Framework:** To counter these challenges, a National BIM Security Framework elaborate in Fig.1 below is essential, with key policies focusing on:

a) Legal Compliance – Aligning BIM security with IT Act, 2000, and the Personal Data Protection Bill.

b) Zero-Trust Security – Enforcing identity verification, access control, and continuous monitoring.

c) BIM and Blockchain-Based Procurement – Preventing fraudulent transactions and financial mismanagement.

d) Data Localisation – Storing BIM data within India for legal and security compliance.

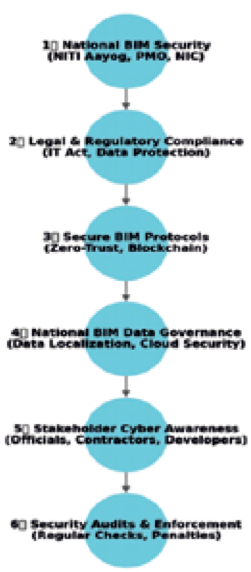

Fig. 1 : National BIM Security Framework-Policy Roadmap

e) Stakeholder Training – Mandatory BIM cyber security education for government officials, contractors, and vendors.

- **Stakeholder Responsibilities in BIM Security:** A clear governance structure defining responsibilities of key government agencies, contractors, and regulatory bodies is essential for effective implementation.

Stakeholder	Responsibility
NITI Aayog & PMO	Policy formulation, National BIM Security Framework approval
All Ministries & Gati Shakti	Implementation of BIM security in Smart Cities &Infrastructure projects
CERT-In & NIC	Cyber security monitoring, threat response, and IT infrastructure
Contractors & Vendors	Compliance with BIM security protocols, blockchain-based procurement
State Governments & ULBs	Enforce cyber security measures at state and local levels
Regulatory Bodies (BIS, CAG)	Audits, security compliance enforcement, reporting irregularities
Infrastructure Developers	Adopt and integrate BIM security standards in ongoing projects

ENSURING DATA LOCALISATION FOR BIM SECURITY

- **Data Localisation**

Data localisation refers to the requirement that certain categories of BIM data must be stored and processed within India's borders, ensuring greater security, regulatory oversight, and national control over infrastructure-related information.

- **Data Must Stay in India**

With rising cyber threats and concerns over foreign access, the government is focusing on data localisation—keeping sensitive project data within the country. By enforcing strict storage and processing rules, we can safeguard its digital infrastructure, strengthen regulatory control, and retain full ownership of its strategic public assets.

- **Mandatory Local Storage (Cannot Leave India)**

a) Infrastructure blueprints and designs

b) Procurement and financial records

c) Government-access logs and security reports

- **Limited Cross-Border Access (Can Be Processed Abroad, But Must Be Replicated in India)**

a) Non-sensitive architectural models

b) International project collaboration data

- **No Localisation Required**

a) Publicly available BIM training materials

b) Open-source templates

- **Impact on Cloud-Based BIM Services:**

a) Foreign cloud providers (AWS, Google Cloud) must establish data centres in India.

b) Cross-border BIM data transfers require government approval.

c) Government projects must use Indian cloud providers for sensitive data.

- **Recommended Indian Cloud & Data Storage Providers:**

a) **NIC Data Centres (National Informatics Centre) –** Government-approved storage for public projects.

b) **C-DAC (Centre for Development of Advanced Computing) –** Secure cloud services for government agencies.

c) **Private Players –** like Tata Communications, Sify Technologies, CtrlS Datacentres – Reliable Indian cloud storage providers.

ZERO-TRUST BIM ACCESS MODEL

A Zero-Trust Security Model (explained in Fig. 2 below) ensures that every access request is verified, regardless of location.

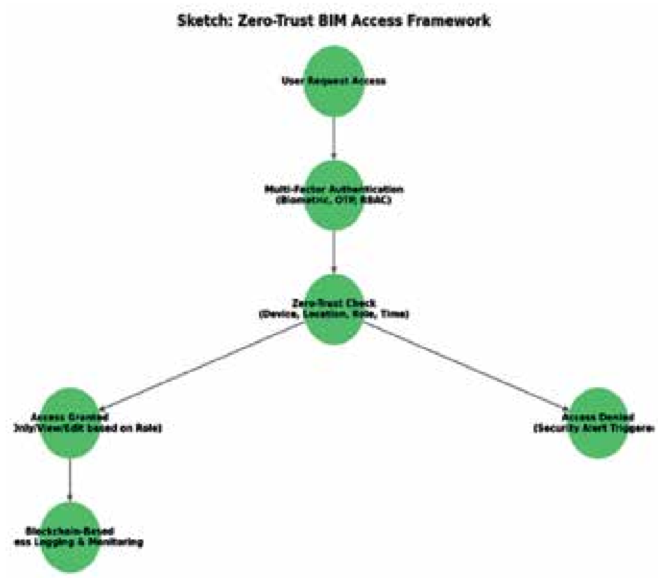

Fig. 2: Zero-Trust BIM Access Framework

IMPLEMENTATIONPLAN&COMPLIANCE

Phase	Key Actions
Phase 1 (Initial Year)	Pilot Projects in Smart Cities (Metro Cities)
Phase 2 (Next 2 Years)	Nationwide Stakeholder Training & Legal Compliance Updates
Phase 3 (Post 3 Years)	Full-Scale Implementation & Security Audit Enforcement

CONCLUSION

A Secure Digital Future for India. For BIM to successfully transform India's infrastructure, security cannot be an afterthought. By implementing following measures, we can protect its infrastructure projects from cyber threats and establish a globally recognised BIM security model.

a) Enforce the National BIM Security Frame-work.

b) Mandate : Zero-Trust Cyber security Policies.

c) Adopt Blockchain-Based Procurement for Transparency.

d) Ensure Data Localisation to Safeguard National Infrastructure.

e) Provide Stakeholder Training & Awareness Programmes.

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TRANSFORMING INDIA BY INFRASTRUCTURE AND URBAN DEVELOPMENT

A.K. Jain*

Abstract

India is to become world's third largest economy in 2027, for which the development of modern infrastructure and sustainable urbanisation would be the backbone. In this task PRAGATI platform provides an innovative and coordinating model for bridging the implementation gap, while accelerating development, ensuring accountability and effective resource utilisation. This can also leverage and change the current of urban development and infrastructure management paradigm.

The rapid and empathic infrastructure development in India, such as Z Morh tunnel at Sonamarg (J & K), inaugurated by Prime Minister Narendra Modi on 13th January 2025 and several challenging mega projects, viz. Chenab Railway Bridge in Jammu and Kashmir, Bagibeel bridge in Assam and 21.5 km long Mumbai Trans Harbour Link (Atal Setu) are taking the country towards progress and prosperity. J.P. Morgan predicts that India will become the world's third largest economy by 2027. This would be largely driven by the infrastructure development and sustainable urbanisation. According to the Reserve Bank of India for every rupee spent on infrastructure, there is 2.5 to 3.5 times gain in the GDP. According to the 2024-25 Economic Survey the government expenditure on major infrastructure sectors has grown at 38.8% during 2020-24. Under the PMAY-U, 89 million houses have been completed during 2015-24. Metro Rail Network has expanded by 1010 kilometres with another 980 kilometres under construction. The Smart Cities Mission has completed 7,479projects worth Rs. 1.50 lakh crore.

The PM Gati Shakti Master Plan focuses on next generation infrastructure for seamless and sustainable connectivity for the movement of people, goods and services. It leverages new technologies and geo informatics in planning, breaking the silos of departmentalisation to achieve synergy in project management. The geo-spatial planning tools optimise infrastructure design and reduce their environmental impact. Parivesh platform has streamlined environmental clearances, reducing approval time from 600 days to 70-75 days.

The timely implementation of the infrastructure projects had been made possible by breakthrough digital technologies, like the PRAGATI, and Whole of Government Platform.

**Former Commissioner (Plg.) DDA, New Delhi*

Fig. 1: Z-Morh Tunnel, Sonamarg, Jammu and Kashmir, inaugurated by Prime Minister Narendra Modi on 13th January 2025

Source: India Today, 13th January 2025

Fig. 2: Chenab Railway Bridge, Jammu and Kashmir

Source: Economic Times, 14th August 2022

Fig. 3: Bagibeel Bridge in Assam

Source: Incredible India

Fig. 4: Mumbai Trans-Harbour Link (Atal Setu) inaugurated by the Prime Minister Narendra Modi on 12th January 2024

Source: MMRDA, 2024

The PRAGATI (Pro- Active Governance and Timely Implementation) Platform, launched in 2015 by the Prime Minister, has helped completion of more than 340 major infrastructure projects, together with effective resource utilisation, environmental sustainability and ensuring accountability.

The Whole of Government Platform enables easier collaborations across departments for seamless implementation of the plans. It comprises over 1200 GIS based data layers from Central Government Departments and 755 from the States/Union Territories, covering data of land, soil, geology, water bodies, forests, mines, revenue maps and administrative boundaries. This helps to plan the projects with the ecological and environmental impact safeguards. The National Master Plan provides a micro- view by on-field surveys as well as macro- view from drones. It facilitates meticulous planning of infrastructure services, transport corridors and facilities (Figs. 5 & 6).

Area Development Approach creates convergence of various infrastructure services, workspaces and social amenities such as education and hospitals, parks, art and cultural spaces, etc. A digital common platform enables better synchronisation, co-ordination and cost and time management. Citizen engagement becomes easier and viable by virtual town halls, and online consultation over plans and programmes of development.

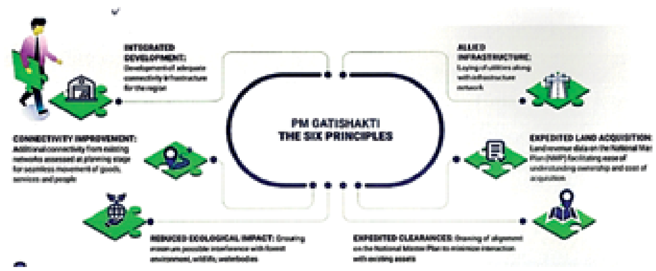

Fig. 5: The six principles of PM Gati Shakti Master Plan

Source: Ministry of Commerce and Industry, GOI 2023

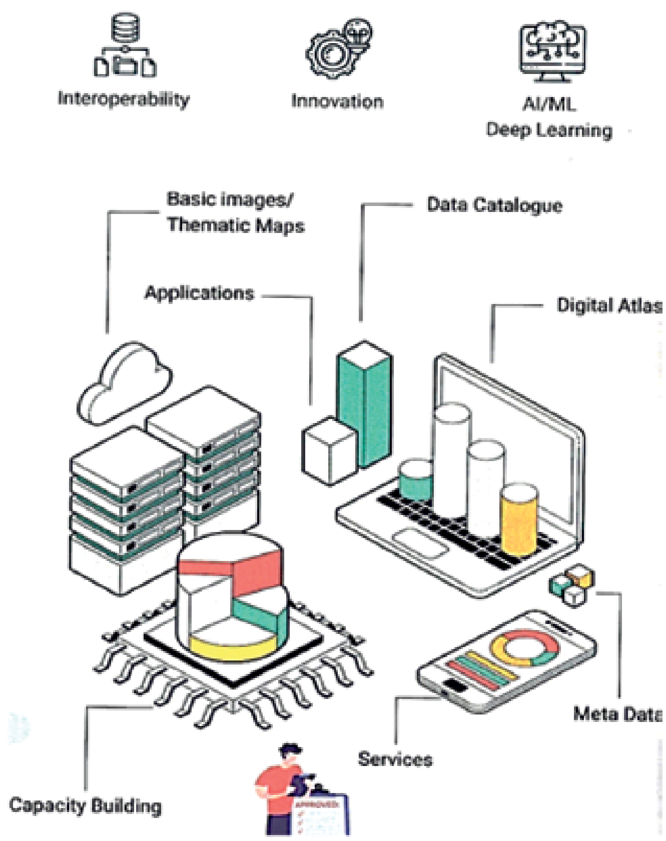

Fig. 6: Emerging Technologies for PM Gati Shakti Master Plan

Source: Ministry of Commerce and Industry, GOI 2023

URBAN CHALLENGES

In 2047, India's urban population is projected to increase from the current 500 million to about 820 million. This means that during next 22 years, Indian cities need to build as many buildings and infrastructure services as they currently have. Building greenfield cities and retrofitting the brown fields would be like building an entire country once again. This can be an opportunity to change the ways of planning and building which are more resilient and sustainable and address the sustainability and climate challenges.

Air quality in urban areas has deteriorated due to use of fossil fuels, dust and emissions. Water bodies and rivers are polluted together with shortage of water supply, sanitation, and sewerage. Transport gridlocks, accidents and lack of parking spaces are the order of the day. The cities are desperately suffering from the issues of drainage, floods, sanitation, disasters, housing shortage, crimes and social and gender inequity.

More than half of the city remains unplanned with slums and unauthorised colonies. More than 80% of the workforce is in the informal sector, with precarious jobs, health, education and food security. Urban areas consume more than two-thirds of energy and generate over 60% of greenhouse gas emission. They often experience 3.50 C higher temperature than surrounding rural areas due to the urban heat island effect, loss of blue and green spaces.

In the book 'Age of the City' (2023), Professor Ian Goldin and Tom Lee Devlin, recommend that for creating resilient cities, abandon the car-based sprawl, which is a colossal waste of resources and a social and environmental failure. Cars pollute the air, generate heat, take up too much space, and 95% of time remain in parking spaces. Instead plan and provide mass transit, bicycle and walking. Embrace the 15 minutes city, the way Paris has done, improving and emphasising its walk ability quotient. Carlos Moreno in his book '15-Minute City: A Solution for Saving Our Time and Our Planet' (2024) suggests adopting bio-morphic urbanism and ecosystems that are rooted to a place. Protecting green spaces and water bodies can be like the difference between life and death in a climate crisis scenario, where cities are becoming heat traps of concrete, steel and glass. Urban planning can mandate the coexistence of nature through green roofs, permeable pavements, renewable energy, carbon neutral materials and ventilation.

This means redefining the urban planning process and replacing the prescriptive Master Plan by Strategic Spatial Development Plan for 5 years, with a focus on participatory, local planning and collective vision. As such, the Spatial Development Plan needs to focus on balancing the four Es: i.e. economy, engagement, equality and environment. This need rewriting the script of urban planning by innovative data driven paradigms for a sustainable, inclusive and resilient urban development (Fig.7).

Fig. 7: Key Drivers for Digitisation and Data Driven Planning for Sustainable, Inclusive and Resilient Infrastructure and Development

Source: NIUA (2023)

As such, the Spatial Development Plan converges strategic and interlinked layers of sectoral planning:

- Sustainability Plan
- Climate Resilience Plan
- Heat Mitigation Plan
- Air Pollution Control Plan
- Comprehensive Mobility Plan, TOD, Transport Nodes Redevelopment Plans
- Heritage Conservation Plans
- Social Development, Recreation, Health, Education and Amenities Plans
- Land Management Plan
- Water Management Plan
- Energy Management Plan
- Sanitation Plan
- Drainage Plan
- Housing, Slums/Informal Settlements and Market Regularisation, Regeneration, Redevelopment and Upgradation Plans
- Action Plan and programme (timelines, accountability, institutional capacity building, governance, finances and legal regulatory framework)
- Financing and Investment Plan

Unified Planning and Building Regulations need to be radically reformed to open the cities towards the objectives of creation of jobs, entrepreneurship and productivity. The PRAGATI and Whole of Government Platforms are the crying need of the hour to streamline the planning, implementation and regulatory processes.

TOWARDS A CIRCULATORY URBAN SYSTEM

To align with the Sustainable Development Goals of making cities and communities inclusive, safe, resilient and sustainable, and combating climate change, it is necessary to shift from linear, unsustainable urban growth to a circular, eco-system (Fig 8).

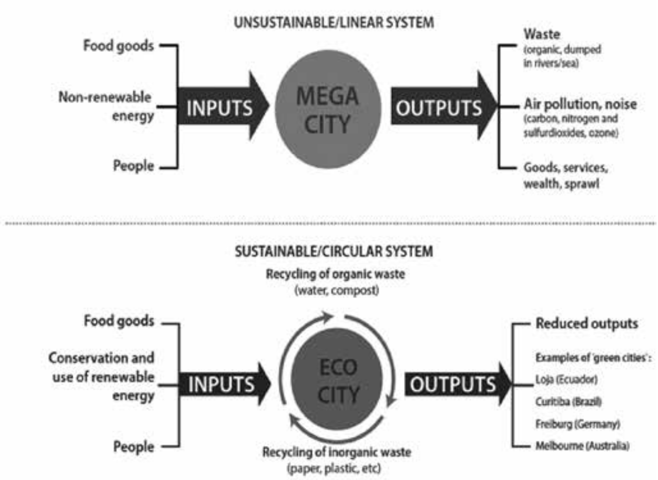

Fig. 8: City as a System

Source:UNESCO & MGIEP (2017) Textbooks for Sustainable Development, A Guide to Embedding, UNESCO and Mahatma Gandhi Institute of Education, Peace and Sustainability, New Delhi

Fig. 9: The cornerstone of a climate resilient and green habitat is by Integrating of the Ecology, Services and Networks, Transport, Built Environment and Heritage

Source: DUAC/Amit Ghoshal (2015) Punjabi Bagh Project, DUAC, New Delhi

The cornerstone of making a circular, and sustainable eco-city is to adopt an integrated approach towards ecology, transport, built environment, and services networks and the conservation of the heritage and natural resources – greenery, water, air, sewerage, solid waste management, and energy (Fig. 9). Carbon neutral buildings, energy and transport minimising the use of fossil fuels and lifecycle approach make the built environment sustainable and energy efficient (Fig. 10). The basic concept of recycling and conservation of energy and water involves adoption of renewable and trigeneration energy systems, sponge parks and pavements that absorb rainwater, dual piping for recycled wastewater, water saving toilets and taps, and satellite controlled micro-irrigation.

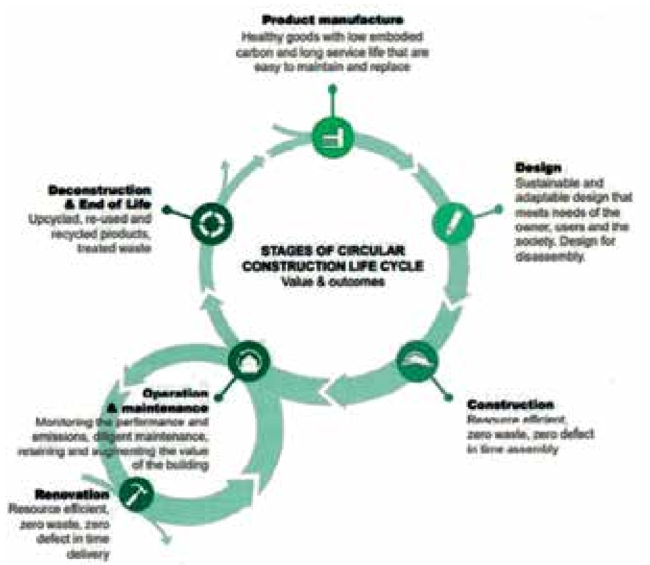

Fig. 10: Circular Life Cycle Construction

Source: Ninni Westerholm (2021) UNEP, Nairobi

Strategy of 5 Rs of waste management demands doing away with the landfills, but resort to three bin recycling with separate bins for trash, recyclables and compost, enzyme based STP, bio-remedial treatment, sludge gas/energy recovery, vermi-culture, fossilization and composting options (Fig. 11). Swales, porous paving, bio-drainage and storm surge gates in river, drains and canals and zero run off drainage, conserve water and save human settlements from floods. Passive climate design, rooftop solar panels and district cooling generate electricity and reduce city's heat build-up (Fig. 12). Rooftop vegetation, ventilation, insulation and super-insulated glazing can enhance the building's thermal performance. Air tunnels with cool air draughts in subterranean clay pipes can save on air-conditioning. These help in reducing the ecological footprints, formation of heat islands and pollution.

Energy Conservation Building Code (2017) provides useful guidelines for energy efficient building design.

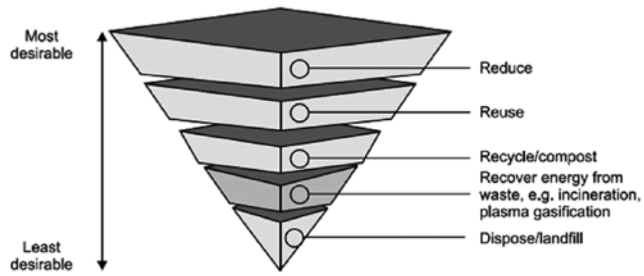

Fig. 11: Strategy of 5 Rs for Waste Management: Reduce, Reuse, Recycle, Restore and Recover

Source: Jain A.K. (2023) Climate Resilient, Green and Low Carbon Built Environment, Springer Nature, Singapore

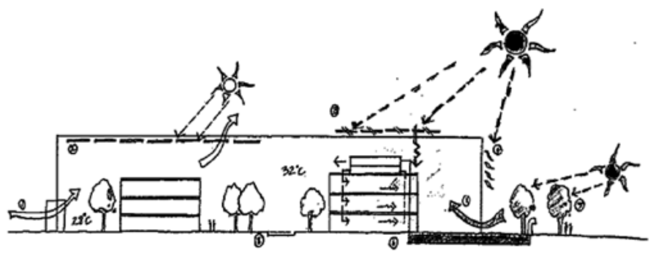

Fig. 12: Design of Research Centre in Wageningen, Netherlands (Behmisch, Behmisch& Partners) features the Sun, Photovoltaic, Courtyard, Skylight and Atrium

Source: Muller Dominique (2004) Sustainable Architecture and Urbanism, Birkhauser, Basel

Decentralised Wastewater Treatment Systems (DEWATS), bio swales and revival of water bodies are important tools for sustainable water and drainage management (Figs. 13 & 14).The lakes, water bodies and riverfront can be rejuvenated and landscaped by recycled, carbon neutral C and D waste, planting and water recycling strategies (Fig. 15).

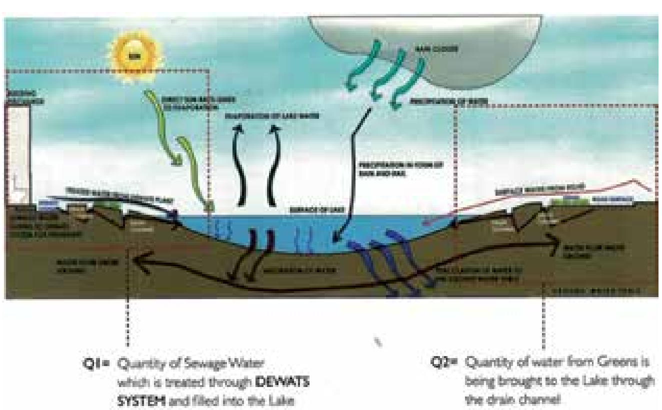

Fig. 13: DEWATS for Stormwater Harvesting and Conservation of Water Bodies

Source: DUAC/Rahoul B Singh (2014) Hari Nagar Greens, DUAC, New Delhi

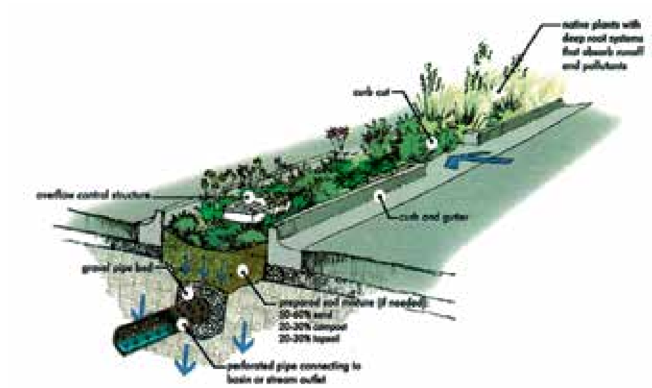

Fig. 14: A Bioswale for Sustainable Urban Drainage

Source:http://thewhiteriveralliance.org/eaglecreek// involved/images/bioswale%20enlargement.jpg

Fig. 15: Carbon Neutral Materials, Planting and Water Recycling Strategies at Ellinikon Park (Foster and Partners)

Source: Jeann Gonchar, Drawing it Down, Houston Memorial Park , USA, Architecture Record Sept. 2024.

The Lifestyle for the Environment Mission: A low carbon life style embedded in social behaviour can

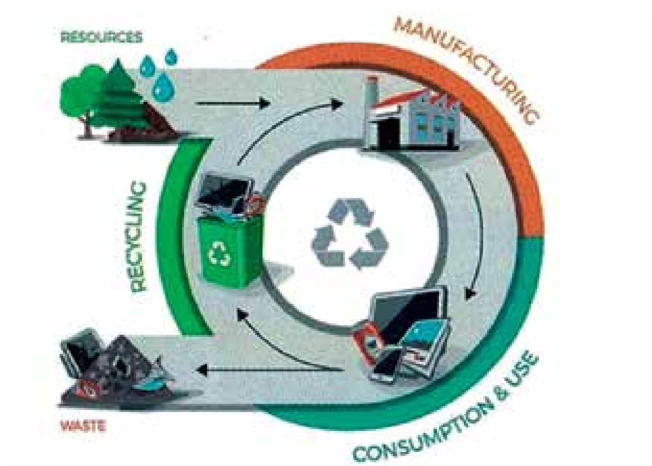

Fig. 16: Circular Systems are Restorative, Regenerative and aim at minimising wastes

Source: Khan, Khalil Uttah (2022) Wastewater Reuse, Linear Economy to Circular Economy, Shashwat, TERI, New Delhi drastically minimize the use of natural resources, and emission of wastes and pollution. Creating sustainable lifestyle requires a change in social norms and the ways of living based on the principles of organicity, non-accumulation (aparigraha), minimalism and slowing down. It is about caring, sharing, recycling, reuse, repairing and retrofitting for a balanced natural environment. This means adoption of circular systems, which are restorative, regenerative and minimise wastes (Fig. 16).

URBAN INFRASTRUCTURE DEVELOPMENT FUND AND GREEN SOCIAL AND SUSTAINABILITY BONDS

To ensure urban system to be innovative financing blended Green, Social and Sustainability (GSS) Bonds can be a viable option. The Urban Infrastructure Development Fund, incentivises the cities to improve their finances, make them ready for municipal bonds, and tap the market capital. This would also help in creating a business-like work culture and a spirit of competitiveness among the local bodies. The endeavour is to make the municipalities credit-worthy and enable them to float the bonds. This would require that the price of the services is recovered. Ahmedabad Municipal Corporation and Ghaziabad Municipal Corporation have floated green municipal bonds.

Indian Cities can also implement a basket of other financing options, such as public private partnerships, borrowing and Value Capture Finance (VCF). The McKinsey report estimates that nearly 45% of the resource requirement can be met through various land and asset monetization strategies, such as development charges, impact fees, building fees, Land value Tax, Capital Gain Tax, Tax Increment Financing and sale of Floor Area Ratio (F.A.R) or air rights. The National Monetisation Pipeline and Infrastructure Investment Trust (InvITs) being anchored for redevelopment of railway stations, Railway Corridors, Gati Shakti Units and Transit Oriented Development can also be adapted for urban development.

CONCLUSION

India often grapples with implementation gap due to which the development of urban projects and infrastructure suffers. Recent innovations and digital transformation by the PRAGATI and Whole of Government Platforms can be adopted for urban planning and infrastructure development. The current practice of 20-year Master Planning needs to be replaced by 5 years Strategic Development Plan based on biomorphic urbanisation and sustainable ecosystems, which are climate resilient, green and circular. Innovative, Green, Social and Sustainable Bonds can blend with the current options of urban financing.

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SUSTAINABILITY INNOVATIONS IN BUILT ENVIRONMENT

Usha Batra*

Abstract

Global climate talks began in 1991, but GHG emissions and global temperature have been rising faster than ever. The world experienced a new global record of unprecedented heat for continuous 14 months from June 2023-July 2024 when earth's average temperature reached or exceeded 1.5 degree C whereas as per Paris agreement - an international treaty to limit global warming and climate change, adopted in 2015 , the world had to pursue efforts to limit the temperature increase to 1.5° C above pre-industrial levels.

During 2024, COP29 held in Baku, Azarbaijan , a new climate finance agreement was to come up to match the scale of our global challenge , but unfortunately it was agreed to provide only $1.3 trillion annually by 2030, and only $300 billion annually by 2035 from developed to developing world which was quite insufficient. It means that the poorest countries will keep bearing the cost of adapting to a crisis they did not cause, making it difficult for the developing world to achieve the ambition on climate action.

As climate change intensifies, the architecture and construction sectors pivot toward eco-friendly practices with emphasis on reducing energy consumption, minimizing waste, and utilizing sustainable materials ensuring minimal environmental impact. Innovations in the field of Sustainable Architecture to reduce energy, water and waste and improve IAQ, construction technologies to improve efficiency, reduce costs, and enhance project management and innovative materials to reduce carbon emissions and cost have been discussed in the paper.

INTRODUCTION

Climate change is a global challenge and requires collective global action to avert and minimize the impacts of climate change. International efforts to address climate change are guided by the United Nations Framework Convention on Climate Change (UNFCCC) and its two instruments, namely the Kyoto Protocol and the Paris Agreement. The whole world is threatened by climate change and already experiencing its effects. As Climate change is international phenomenon, we all need to act together to stop it now.

India has set an ambitious goal to achieve 500GW of non-fossil fuel electricity capacity by 2030 which now has been extended to 2031-2032. Additionally, country is continuously refining its policies to reduce coal dependence and transition to cleaner energy resources.

India has shown impressive achievements to what it committed in 2015, as shown in the table below.

As per REN21, Globally, India stands 4th in Renewable energy Installed capacity, 4th in wind power capacity and 5th in Solar Power capacity. 143.64GW Renewable energy capacity has been installed as on 31.03.24 making an increase of around 4.0 times from 2014-2024 and Solar has increased 29.01 times from 2014-2024.

NDC (2015)	Target (2030)	Achievement
Non-fossil fuel based electric installed capacity	40% cumulative	43.8% (August 2023). Target achieved 9 years ahead of committed time
Reduce emissions intensity of GDP	33-35% over 2005 levels	Reduced by 33 per cent between 2005 and 2019
Additional carbon sink	2.5-3.0 billion tons	1.97 billion tons (2021)

Sector-wise Cumulative Achievements as on 31.03.24 are given below :-

Sector	Cumulative Installed Capacity (GW)
Solar Power	81.81
Wind Power	45.89
Bio Energy	10.94
Small Hydro	5.00
Total	143.64

However, India being most populous country, uses only 6% of the world's primary energy. To make it

*Former SDG, CPWD

a developed country, India's energy consumption will increase manifold. This demand needs to be carefully planned / controlled as shown in the Smart energy pyramid through energy conservation, energy efficiency and lastly through renewable energy which serves the dual purpose of fulfilling the demand and simultaneously reducing the global warming.

Smart Energy Pyramid

ENERGY AND BUILT ENVIRONMENT

The buildings, roads and transportation sector of the built environment is responsible for significant use of energy about 62% and a major source of green house gas emissions about 55%. Further this sector is growing and will continue growing at a rapid rate and hence will continue to consume more and more energy. As such, innovations in the fields of sustainable architecture (green / energy efficient buildings) ,construction technologies and innovative materials will gain importance.

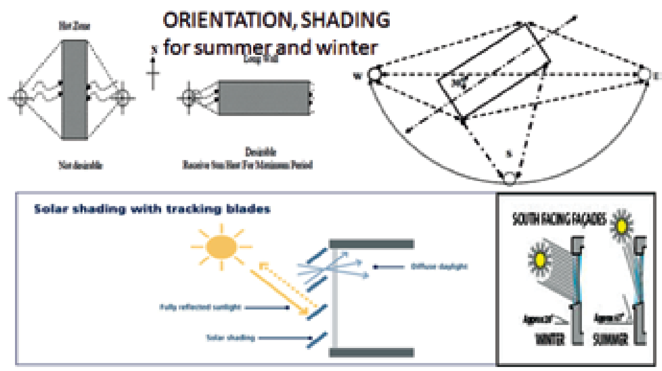
SUSTAINABLE ARCHITECTURE

Since building sector accounts for significant global energy consumption, sustainable architecture can play a key role in energy efficiency as green / energy efficient buildings reduce energy consumption, minimize waste, improve IAQ ensuring minimal environmental impact. Building envelope being the main cover protecting the building plays the most important role in energy efficiency.

As per report of CII, green buildings save energy to the extent of 40-50% and water to the extent of 20-30%. Envelope alone can contribute to 50% of this, meaning thereby that Energy saving potential of Energy efficient envelope alone is to the extent of 20-25% and is the permanent source of saving not requiring any performance check thereby reducing the demand for air conditioning which is major source of energy consumption in buildings. Sustainable/ energy efficient buildings will contribute towards cutting down energy and water consumption to less than half of the conventional buildings, and may completely eliminate the construction and operational waste through recycling.

Good envelope design envisages:

- Appropriate orientation (to reduce heat gain in summer and increase in winter) with respect to sun and wind direction & shape of the building (less perimeter to reduce exposure)



- Appropriate window to wall ratio (WWR) for light & ventilation i.e. design that increases daylight to reduce the need for daytime lighting.
- Shading devices to allow the desirable sun and cut-off the non- desirable sun , besides shading of walls and roof which improve air quality, provide insulation, and reduce the urban heat island effect and enhance harmony between nature and urban living.
- Natural ventilation for good indoor air quality and reduce energy consumption and reducing HVAC load
- Use of landscape elements in altering the micro-climate, providing buffer for heat, sun and airflow .
- Water conservation features like rainwater harvesting, grey water recycling, and low-flow fixtures to reduce water usage.
- Use of energy efficient lighting and equipment in buildings.
- Maintaining the temperature of Air conditioning as 24-26 instead of 18-20.

Further improvement in energy efficiency beyond good envelope design can be achieved by improving thermal performance of the envelope using thermal insulation as per ECBC norms for various climates.

As per research paper Published in International Journal of Environmental Science and Technology -volume 14, NOV 2017 , optimum level of insulation has been found to be 30% above U-values prescribed by Energy Conservation Building Code 2007.

Energy Conservation Building Co 2017 prescribes 3 levels of energy efficiency:

(a) Energy Conservation Building Code Compliant Building (ECBC Building)

(b) Energy Conservation Building Code Plus Building (ECBC+ Building)

(c) Super Energy Conservation Building Code Building (Super ECBC Building)

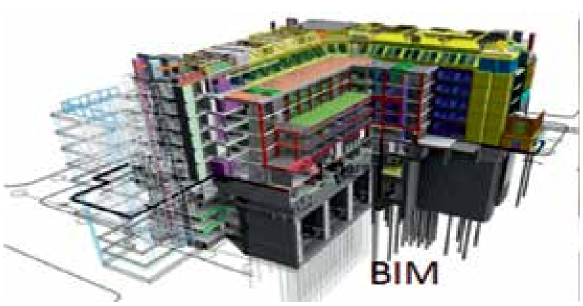
Thus energy efficient buildings are to be planned through good envelop design principles, reducing the demand of conventional energy which is further reduced through thermal insulation of the envelop and still further by use of renewable energy through Construction of net zero buildings that generate as much energy as they consume and energy plus buildings that generate more energy than they consume.

INNOVATIVE TECHNIQUES IN CONSTRUCTION

Innovative techniques in construction include digital technologies that improve efficiency, safety, reduce costs, and enhance effectiveness of project management .They include Building Information Modeling (BIM), Virtual Design and Construction (VDC), IoT, Modular Construction, Prefab construction, robotics, Artificial intelligence (AI), 3D printing etc.

Building Information Modeling (BIM)

Building Information Modeling / BIM is a holistic way of assimilating and managing all the information



related to a building asset. Cloud-based BIM models collate all the information that the stakeholders of the project will ever need, into a single model that can be accessed from anywhere and actions like viewing, editing, etc can be performed with ease.

BIM was extensively used in the creation of the Shanghai Tower, owing to its status as one of the tallest and greenest skyscrapers in the world. More than 30 consulting firms , dozens of subcontractors and project teams were involved. They utilized BIM to achieve the intense coordination required to see the project to fruition. In India, many highrise and complicated structures use BIM nowadays. CPWD has also made it mandatory for multi-storeyed buildings and projects costing above 30 crores.

Virtual Design and Construction (VDC)

VDC is a construction management technology that helps reduce the overall risk on a project by eliminating potential problems that would have occurred without the foresight that it offers. It is also known for optimizing processes, minimizing waste and project cost.

Internet of Things (IoT)

IoT devices help control, monitor and track various aspects of construction and building management thereby increasing efficiency and safety of work force. Monitors and sensors placed on-site help managers and supervisors to monitor and record site activities such as progress, quality and safety during construction. Sensors are placed on safety vests, belts and hard hats to enhance safety by warning them of hazardous material in their vicinity or their presence in an accident-prone zone. RFID tagged equipment and material can be tracked closely to prevent pilferage and wastage.

RC Modular Construction

Prefab RC structural members and 3D modular construction are gaining importance due to the growing space constraints and reducing time scales available for construction. RC elements are produced in controlled factory environments which enhance the quality and minimize errors, including finishes, provisions for electrical and plumbing works. This saves lot of time apart from correctly assembling the elements and sealing the joints. BMTPC has taken up a light house with 3D modular construction having more than 1000 dwelling units in Ranchi in which units like toilet, kitchen and rooms have been casted at yard, transported and assembled at site. DDA has constructed large number of flats in Delhi with pre- cast RC structural members.

Prefabricated Steel Framework/ off site construction

Steel elements – columns, girders, beams, flooring deck sheets, roofing sheets, staircases, etc are manufactured in factories, transported and assembled on site. Further Pre-engineered buildings are largely taken up in the country as the construction is faster, efficient, and sustainable, reducing time, cost, waste and improving safety and takingcare of shortage of skilled labour.

Artificial Intelligence (AI), Virtual Reality (VR) and Augmented Reality (AR)

AI-powered systems is used to convert large quantities of data into meaningful 3D models, maps, blueprints, etc. AI-powered virtual assistants taking advantage of machine learning can be used to check quality or deficiencies in construction.

Virtual Reality (VR) allows interacting digitally or virtually in a shared landscape. It brings together people who are sitting in different parts of the world into a common model/walkthrough of a project in real-time. It allows specialists and consultants to offer their recommendations to achieve project-specific goals.

The power of AR is magical as you can see your project come alive on-site even before it is built using special wearable glasses, helmets or even using your phone's camera. Now AR can make real-time changes (like during concept presentations and meetings) and these changes will reflect on the 3D image you see.

3D Printing

3D printing is like a house which can be constructed through a robotic printer as per design and requirement. This technology has already been used

to create various construction projects, including houses, bridges, and even skyscrapers including in India . L & T has taken up a project for Ministry of Defence, thus not just individual elements like walls, slabs, beams and columns, but entire buildings can be 3D printed too. Its speed, quality and waste reduction compensates for the high pre-production cost, including the cost of the 3D printer itself.

Construction Robotics, Drones and UAVs

Robots are being used in risky execution of construction, maintenance and high rise structures helping in risk reduction, improving quality, minimizing errors and faster execution. Robotics can automate repetitive and dangerous tasks reducing number of accidents on construction sites, with high quality results as they are not susceptible to mistakes, e.g. bricklaying, material handling and transportation, deconstruction and welding etc. GPS-enabled drones that can perform surveys,

monitor progress in high-risk areas such as mines, tunnels, etc.

Living Building Materials (LBM)

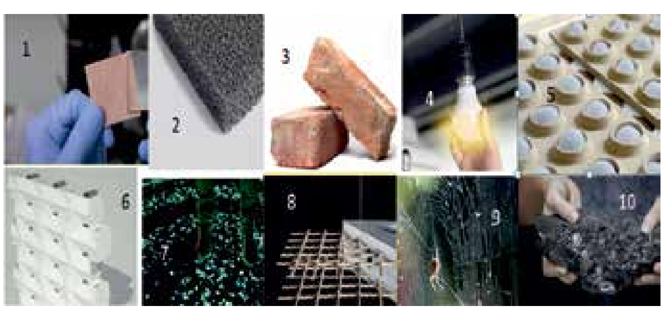
These materials are formulated taking inspiration from nature. LBM can be any form of bacteria or fungi which has sufficient strength to be used as a building material but will have the resilience of a living system too. Cyanobacteria and mushrooms containing mycelium are the ones that are showing encouraging results. These materials are allowed to react naturally with other materials to develop strength and regenerative properties which makes them truly sustainable. They can even be formed into building blocks (bricks) .

Their ability to absorb CO2 and reduce pollution in the surrounding is another notable characteristic. With its self-healing capabilities, great acoustic and insulation properties, and low to zero maintenance cost, LBM is going to be the future of construction materials.

INNOVATIVE BUILDING MATERIALS

Construction innovations that contribute to sustainability by reducing carbon foot print and cost are;-

1. **Transparent Wood ;-** Wood can be treated into a material that is capable of holding the same properties as glass or plastic. The material is transparent, sturdy as well as being able to store heat. This is a much more sustainable option than plastic or glass as well as weighing a lot less.



2. **Aluminum foam;-** Aluminum foam is created through injecting aluminum into oxygen. Aluminum is lightweight and nonflammable, a material that can be easily recycled and reused. Over 50% of aluminum foam is created from recycled aluminum.

3. **Cigarette Butt Bricks ;-** There are over 1.2 million cigarette butts dumped and thrown every year, ending up in landfills or littered here and there. Cigarette butts are now being mixed into the construction of bricks which lessens the amount of energy needed to bake them.

4. **LED and OLED ;-** LED lighting is especially effective within household light bulbs, uses little energy saving money. It also takes the demand off the energy grid. These ligh tbulbs last 40 times longer than traditional ones decreasing required disposal.

5. **Hydrogel ;-** Hydrogel can be combined with ceramics for use in construction. This material is capable of absorbing 500 times its own weight in water for cooling purposes. And thereby is capable of cooling interiors by up to 6 degrees saving not only in construction but in energy also as less air conditioning is needed in the buildings.

6. **Breathe blocks ;-** These blocks are concrete combined with plastic and have hollow insides to allow airflow within buildings. Breathe blocks have been designed to absorb pollution and are capable of removing 30% of fine particles and 100% of coarse particles. They can improve air quality in countries with higher pollution.

7. **Super-Hydrophobic Cement ;-** This material is created by modifying the structure of cement. It is also known as luminescent cement as it reflects and absorbs light which could make it a new stainable alternative to street lighting. Its durability makes it almost free of repairs and can last up to 100 years.

8. **Bamboo reinforced Concrete ;-** Bamboo reinforced concrete has been created to be a more sustainable option to steel reinforced concrete which is used in most buildings and construction. This is a more sustainable option as steel is costly and imported „ whereas most countries are growing bamboo.

9. **Synthetic spider silk ;-** Spider silk is one of the strongest natural materials. With the help

of 3D printing, scientists have been able to create synthetic silk which is made from room temperature water, silica and cellulose. It is used as an alternative to nylon and other strong textiles. Usage of synthetic silk could reduce the CO2 within the textile industry.

10. **Plasma rocks ;-** Plasma rock is a new material that has been recently created. It is made from reused materials found within coastal landfills which are created because of plasma gasification which happens when the extreme heat of underground landfills combines the waste into one. Plasma rock is non-toxic, durable, and puts landfill waste to use. This would reduce landfill mass and decrease the amount of harmful materials entering the ocean.

Apart from this, design and execution of buildings requires reuse and recycling of materials and reduction of waste to promote sustainability in construction Industry. Techniques like deconstruction need to be adopted for reuse and renovation of old structures to conserve resources, reduce waste and preserve the environment.

CONCLUSION

- Climate change is a global challenge and requires collective global action to avert and minimize impacts of climate change.
- India has set an ambitious goal to achieve 500GW of non-fossil fuel electricity capacity by 2030 now extended to 2031-2032 and has shown impressive achievements to what it committed in 2015.
- As climate change intensifies, innovations in the fields of sustainable architecture, innovative construction technologies and innovative materials gain importance.
- Good envelope design , thermal insulation and use of renewable energy contribute massively to energy efficiency.
- Innovative construction technologies improve efficiency,safety, reduce costs, and enhance effectiveness of project management and Innovative materials reduce carbon emissios and cost of project.
- Use of sustainable architecture, construction technologies and innovative materials will substantially contribute to energy-efficiency and reduction in greenhouse gas emission.

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CULTURAL SUSTAINABILITY IN BUILT ENVIRONMENT: LESSONS FROM GOND HOUSES IN MANDLA, M.P.

Ar. Alankar Jharia*

Abstract

Cultural sustainability in India's built environment emphasizes the integration of traditional cultural wisdom with modern technology to create inclusive, resilient, and environmentally conscious spaces. This paper investigates the intersection of cultural heritage and sustainability within the built environment, using the Gond houses in Mandla, Madhya Pradesh, India, as a compelling case study. In an era of rapid globalization and homogenized architectural practices, it is critical to examine how traditional building methods and cultural values can inform sustainable development. Traditional Indian architecture inherently embodies sustainability principles by reflecting a profound understanding of local climates, readily available resources, and deeply ingrained cultural values (Study of Sustainability Practices Ingrained in Indian Culture). Vernacular architecture, particularly evident in the design and construction of Gond houses, leverages locally sourced materials and passive design strategies to minimize energy consumption and maximize thermal comfort. This research delves into the specific architectural features and cultural significance of Gond houses, analyzing how these dwellings contribute to environmental, social, and economic sustainability within the Mandla region. The study examines the use of locally sourced materials like mud and bamboo, the implementation of passive cooling techniques such as thick walls and strategic orientation, and the integration of community spaces that foster social cohesion. Furthermore, it investigates how the construction and maintenance of Gond houses support local economies and preserve traditional skills and knowledge. In contrast to contemporary architectural trends that often prioritize energy-intensive materials and disregard local contexts, this paper argues for a renewed focus on integrating traditional wisdom with modern innovations. It highlights the importance of cultural identity in shaping sustainable design practices and fostering a sense of place and belonging. By analyzing the architectural and cultural elements of Gond houses, this research seeks to identify key lessons and best practices for creating a built environment that is not only environmentally responsible but also culturally vibrant and socially inclusive. Ultimately, this study advocates for a holistic approach to sustainable development that recognizes the interconnectedness of culture, environment, and economy. It proposes that by learning from and adapting traditional architectural practices, such as those exemplified by the Gond houses in Mandla, we can pave the way toward a more resilient, equitable, and culturally sensitive future for the built environment in India and beyond.

INTRODUCTION

Culture has deep ties with the built environment in India, where cities and villages often feature culturally significant public spaces. Traditional Indian architectural practices reflect an inherent dedication to sustainability. India's diverse climate and rich cultural heritage create a unique setting for exploring sustainable architectural practices. Indigenous cultures and identities often emerge from a response to nature and climate. Traditional Indian architecture, such as the clever use of courtyards and verandas, utilizes natural elements like sunlight, airflow, and thermal mass to maintain comfortable spaces and manage the climate. Traditional construction methods and landscape design concepts offer potential for use, and traditional ideology to respect natural resources may remain unchanged with development. Cultural sustainability in India's built environment integrates traditional cultural wisdom with modern technology to create inclusive, resilient, and environmentally conscious spaces. India's diverse climate and rich cultural heritage offer a unique context for sustainable architectural practices.

Globalization and changing aspirations have contributed to a decline in culturally expressive built environments, as modern buildings increasingly favour energy-intensive designs that disregard local climates and cultural contexts (Edwards & Turrent, 2000; Steele, 2005). This shift is driven by a desire to adopt architectural styles associated with modernity, often leading to the displacement of traditional designs and materials (Knox &Marston,

**Ph.D. Scholar, Department of Architecture and Planning, National Institute of Technology, Raipur (C.G.),*

2016). The adoption of global architectural styles and trends can overshadow traditional designs, resulting in a loss of cultural identity and a homogenization of the architectural landscape (Relph, 1976). This can lead to cities around the world looking increasingly similar, losing their unique character and sense of place. Furthermore, the increased use of reinforced concrete, steel, and glass in construction replaces traditional materials like timber and adobe, impacting local architectural traditions (Vale, 2008). While globalization brings innovation, it also poses challenges to preserving local architectural identity. This transformation is further influenced by the globalization of consumer culture, which may lead to a demand for standardized and generic designs, further eroding culturally expressive built environments (Watson, 2006).

A shift towards decarbonization, democratization, and digitalization is essential to transform India's built environment by blending traditional wisdom with modern innovations. The purpose of the study is to demonstrate how integrating cultural identity into contemporary architecture can revitalize local crafts and ecosystems, ensuring constructions are environmentally sustainable, culturally relevant, and socially inclusive.

According to the 2011 Census of India, Scheduled Tribes (STs) constitute 8.6% of the nation's total population25. Madhya Pradesh has the largest ST population in India, with over 1.6 crore individuals comprising more than 21% of the state's total population which makes this study area more important. Approximately 15% of all tribal households in India, totalling 3,122,061 dwellings, are in Madhya Pradesh. Within the Mandla district, STs account for 57.23% of the total population, with 511,798 ST individuals out of a total of 894,236 residents (Census, 2011).

METHODOLOGY

Study area

Madhya Pradesh is in the central part of India. As indicated by the two colors on the map shown in Fig. 1, it may be divided into two types of climatic divisions: composite zone and hot-dry climate.

For the study of gond houses Mandla is choosen as it constitutes the maximum number of Gond tribes in the composite climate of Madhya Pradesh. In this study three villages namely Bichuwa, Salaiya and Umaria are chosen for the further investigation which are 13 kms, 22 kms and 32 kms respectively from Mandla. Criteria for selection of the samples is given elsewhere (Jharia & Sanyal, 2024).

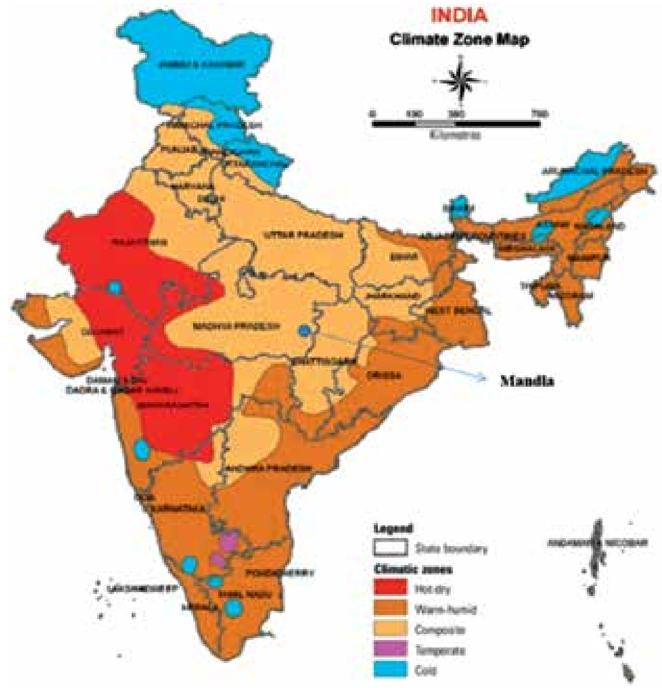
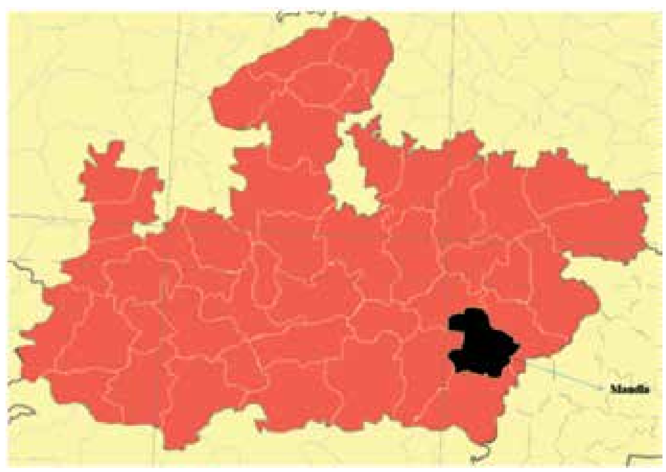


Fig.1. Climatic zone classification as per National Building Code 2016 and Madhya Pradesh and Mandla location in the classification

Source: National Building Code, 2016



Location of Mandla district on Madhya Pradesh map

CASE STUDY

Three different typologies were observed. As in Traditional houses there are two types; one is Mud wall another one is brick wall with mud mortar. Third one in Contemporary house is brick wall with cement mortar. Roofs in Traditional house are made up of burnt clay roof tiles while Contemporary houses are having RCC slab. The thickness of mud walls varies from 350 mm to 450 mm while of Brick wall with mud mortar are 230 mm-300 mm. Contemporary houses having brick walls with cement mortar is 230 mm (external wall) and flat reinforced cement concrete (R.C.C.) roof 100-115 mm were found.A comprehensive overview of Mandla's traditional and contemporary shelters and their typical layout may be found elsewhere (Jharia & Sanyal, 2024).

Traditional Dwellings

Traditional Indian architecture demonstrates an understanding of local climates, resources, and cultural values, providing valuable lessons for contemporary sustainable design. Vernacular architecture uses locally available materials and passive design strategies to ensure thermal comfort and minimize energy consumption.

The walls are made of enormous clay lumps or massive sun-dried bricks as shown in fig. 2,3 &4. Some people even utilise tiles to cover the roofs of their homes. Burned tiles and bricks are often purchased from professional bricklayers (kumar), as the Gondwere previously reluctant to building a kiln and baking bricks. Their deep reverence for Mother Earth (Dharti mate) forbade them from burning clay in a kiln. There is more combined storage capacity in the top level than for any other purposes. During hot summers, the plants on the rooftops, as well as the top storage unit, help to keep the temperature within the home cool.

At the bottom of the structure, which is the base of the house and acts as a strong foundation holding the entire structure together as shown in fig 5. This base is slightly projected towards the outside and is pasted with cow dung. It also serves as a seating area for the locals outside their house during their evening stories where the elders from the neighbourhood get together for their daily dose of socialising, while smoking the local flavoured beedi (tobacco rolled in tendu leaves) and unwinding in each other's company.

Fig. 2: Clay tiles used for roofing

Fig.3: Walls made of sun dried bricks with mud

Source: Author

Fig. 4: Traditional Dwelling

Fig.5: Sitting Platform outside the houses

Source: Author

Contemporary Dwellings

Modern buildings often prioritize energy-intensive materials and designs that disregard local climates and cultural contexts, leading to increased energy consumption and environmental damage. Integrating cultural identity into contemporary architecture can revitalize local crafts and ecosystems. Incorporating artisans and their traditional skills into the design process allows buildings to reflect regional cultural values, promote economic opportunities, and preserve cultural heritage.

Contemporary shelter is frequently seen as the example of an internationalism, which eradicates local traditions and transforms the globe into a faceless urban sprawl (Huppauf & Umbach, 2005). The present day houses in Mandla uses 230 mm thick burnt brick external wall,115 mm thick internal wall in burnt clay bricks and 100–150 mm thick reinforced cement concrete roof as shown in Fig. 6.

Fig, 6: Contemporary Dwelling

Source: Author

The temperature was recorded and hourly data was gathered using data loggers to analyze daily fluctuations within each home. As illustrated in Fig. 7, the data loggers were placed at a height between 1000 and 1200 mm, positioned centrally within the space. This height was determined based on the average seated human height of 1.0 m (Das, 2006). Data loggers were installed in the center of each room and set to continuously collect data for three days, operating around the clock. The average for one day was then calculated from the three days of data. Data was automatically collected at one-hour intervals (every 60 minutes). Additionally, the hourly data collected for each room was averaged to produce a single dataset for each house, which was then compared to the average outdoor temperature recorded during the measurement week.

ANALYSIS OF RESULT

Peak winter recorded average temperature in week from 11th December 2022 to 17th December 2022

The graph (Fig. 8) below illustrates the average temperatures recorded over a week during the coldest period of the year, from December 11 to December 17. The temperatures from the three sample houses are represented by three different colored graphs. The blue graph shows the variations in average outdoor temperature during this timeframe. Notably, the traditional brick and mortar home demonstrates superior performance in winter, with temperatures recorded as much as 4-5 degrees Celsius higher than those of the contemporary home and the traditional house with mud walls.

Fig. 7: Location of sensors in the selected houses

Source : Author

Peak summer recorded average temperature in week from 20th May 2023 to 27th May 2023

The graph (Fig. 9) below shows the average temperatures recorded over a week during the hottest period of the year, spanning from May 20 to May 27, 2023. The three colored graphs illustrate the average temperatures of the three sample huts, while the blue graph indicates the fluctuations in the average outdoor temperature during this timeframe. Additionally, the mud house is represented by a graph that highlights its consistent temperature range.

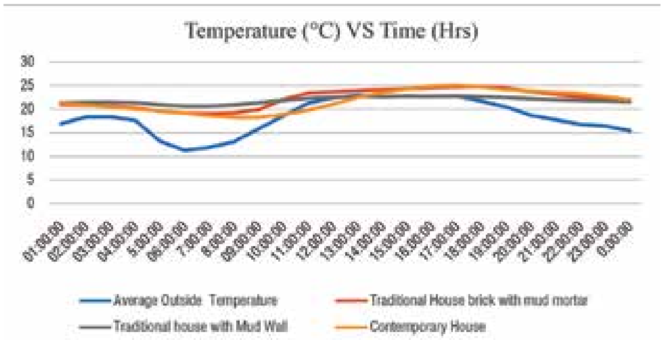


Fig.8: Outside and Inside Temperature variation over 24-hour cycle in peak of winter

Source : Author

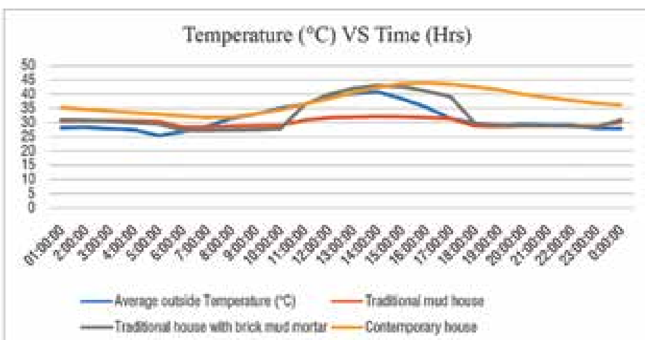
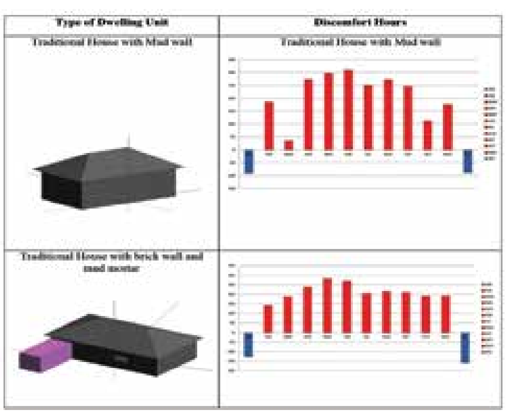


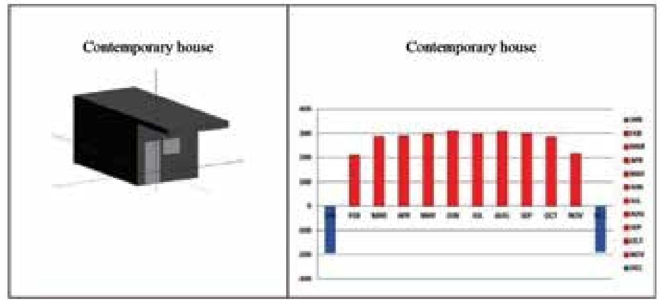
Fig 9: Outside and Inside Temperature variation over 24-hour cycle in peak of summer.

Source: Author

Table 1 : Showing the discomfort hours.

Source : Author





DISCUSSION

The research indicates a significant contrast between traditional and contemporary dwellings in India, particularly in their approach to sustainability and cultural integration. Traditional Indian architecture, exemplified by vernacular structures, showcases a deep understanding of and harmony with local climates, resources, and cultural values. These dwellings prioritize the use of locally available materials such as clay, sun-dried bricks, and timber, coupled with passive design strategies like courtyards and roof planting, to ensure thermal comfort and minimize energy consumption. This approach not only reduces the environmental impact of construction but also promotes regional architectural styles that are adapted to the specific climatic conditions of the area.

The case study revealed that the traditional house with mud walls exhibits superior thermal performance during the winter months. Data was gathered through computer simulations software Design Builder using ASHRAE 2020 to calculate discomfort hours throughout the year with the U-value of the mud was determined to be 1.3 Watt/sq.m Kelvin. Temperature Readings obtained from software were calibrated original temperature values. It was observed that the high thermal capacity of mud walls, measuring 350 mm in thickness for internal walls and 450 mm for external walls, significantly contributes to maintaining optimal temperatures even when outdoor temperatures drop at night. After sunset, when heat sources are no longer present, materials with high thermal mass effectively store solar energy that has entered the space through openings, helping to retain warmth during the winter.

Table 1 presents a comparison of three selected houses. The Contemporary house, constructed with brick, cement mortar, and an RCC slab, experiences the highest number of discomfort hours due to excessive heat, followed by the Traditional house made of brick with mud mortar. In contrast, the Traditional house with mud walls has the fewest discomfort hours related to excessive heat. The analyzed data indicates that the Traditional house with mud walls experiences a total of 2334 discomfort hours throughout the year. Additionally, the internal temperatures of this dwelling remained consistent during 24-hour measurements. While outdoor temperatures fluctuate significantly throughout the day, the temperatures recorded within the mud dwellings show minimal variation, resulting in an almost straight-line graph as depicted in Fig. 8.

During peak winter, the thermal behaviour of the mud-walled house is advantageous at night; as outside temperatures drop, the recorded indoor temperatures remain higher than those in the other two types of dwellings due to the thermal lag properties of the mud walls. The excellent thermal characteristics of mud allow for effective thermal time-lag within these dwellings, helping to maintain higher nighttime temperatures compared to the cold outdoor conditions. The other dwellings, specifically the Traditional house with brick mortar and the Contemporary house, recorded 2420 and 3175 discomfort hours respectively. Notably, the Traditional house with brick mortar outperformed the Contemporary house made from brick and cement mortar in terms of discomfort hours and temperature variation between indoors and outdoors over a 24-hour cycle during peak winter.

In contrast, contemporary dwellings often prioritize energy-intensive materials such as reinforced cement concrete and designs that disregard local climates and cultural contexts. This leads to increased energy consumption for heating, cooling, and environmental damage. The shift towards internationalism in modern architecture has resulted in the eradication of local traditions, transforming the landscape into a faceless urban sprawl. The current study also highlights the cultural and social functions of traditional dwellings, such as the projected base plastered with cow dung serving as a seating area for community socializing. This integration of social spaces within the architectural design fosters community living and preserves cultural heritage, aspects often lacking in contemporary designs.

CONCLUSION

To effectively integrate traditional architectural practices into modern urban planning and housing policies in India, several strategic measures can be implemented. First, sustainable building regulations should be established to encourage the use of locally sourced, eco-friendly materials like mud, clay, bamboo, and stone, which have lower environmental impacts compared to energy-intensive industrial materials. Incorporating vernacular design principles into urban planning is equally important. These principles, such as passive cooling systems, natural ventilation, and climate-responsive layouts, should be prioritized in new developments to enhance sustainability and adapt to local climatic conditions. Supporting local artisans is another critical step. Policies should include programs that engage artisans in construction projects, allowing them to apply their traditional skills while preserving cultural heritage and stimulating local economies. Additionally, raising awareness about the benefits of traditional architecture is essential. Educational campaigns targeted at architects, builders, and the public can help foster appreciation for vernacular practices, while academic institutions should integrate courses on traditional architecture into their curricula to train future professionals.

Financial incentives can further promote these practices by reducing the cost burden associated with sustainable construction. Subsidies or tax breaks for projects that successfully incorporate vernacular elements can encourage wider adoption. Water conservation techniques from traditional architecture, such as rainwater harvesting systems and step wells, should also be integrated into housing policies to address water sustainability challenges. Community participation in the planning process is vital to ensure that new developments respect cultural values and historical significance. Engaging local communities can lead to more culturally sensitive urban environments that reflect regional identities. Investment in research and development is another key area for progress. Funding studies that explore the integration of traditional architectural wisdom with modern technology can yield innovative solutions that balance cultural integrity with contemporary needs. Lastly, resilience planning should focus on leveraging traditional practices that have historically adapted well to local climates such as thick mud walls for insulation to mitigate climate change impacts.

By implementing these measures, urban planning and housing policies can create a harmonious blend of tradition and modernity. This approach not only fosters sustainable development but also revitalizes local crafts, ecosystems, and cultural identities. Ultimately, bridging the gap between traditional wisdom and modern technology is essential for building resilient, environmentally friendly, and culturally vibrant communities across India.

To adapt vernacular architecture principles for large-scale urban housing projects, a multi-faceted approach is essential, focusing on material scalability, climate-responsive design, regulatory frameworks, and socio-cultural integration. Vernacular materials such as mud, bamboo, and stone can be re-engineered for urban density through hybrid systems that combine traditional materials with modern reinforcements, as well as through modular construction techniques that allow for prefabrication. Climate-responsive designs can be enhanced by integrating vertical greening and optimizing thermal mass with compressed earth blocks to maintain energy efficiency. Policy reforms are crucial; zoning incentives can encourage the use of local materials while heritage-conscious codes can permit traditional techniques in urban settings. Engaging communities in participatory design processes ensures that new developments reflect local cultural identities while maintaining modern functionality. Challenges such as material standardization and technological gaps can be mitigated through regional material hubs and training programs for architects in vernacular-digital hybrids. Successful case studies like the Asian Games Village in Delhi illustrate the potential of scaling vernacular architecture by using local materials and passive cooling strategies, ultimately fostering resilient, culturally vibrant urban environments that bridge tradition and modernity.

While the paper critiques contemporary architecture for overlooking cultural sustainability, a critical gap lies in addressing how traditional methods can be practically adapted to meet modern demands for structural durability, cost-effectiveness, and regulatory compliance. To bridge this, hybrid construction techniques could merge vernacular principles with contemporary engineering. For instance, stabilized mud blocks reinforced with low-carbon cement or bamboo composites treated for fire resistance can enhance durability while retaining thermal benefits. Cost challenges could be mitigated through localized supply chains for traditional materials (e.g., establishing regional earth-brick manufacturing hubs) and policy incentives like subsidies for eco-friendly materials. Regulatory frameworks must evolve to certify vernacular techniquessuch as adapting India's National Building Code to include seismic-resistant rammed earth or load-bearing mud walls, as seen in Colombia's NSR-10 Earth Construction Code. Case studies like the Auroville Earth Institute demonstrate how compressed stabilised earth blocks (CSEB) meet ISO standards for strength and affordability, while projects like InFILL House in Nepal show how traditional materials can comply with urban safety norms through modular design

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SUSTAINABILITY IN BUILT ENVIRONMENT

R. Srinivas* And Radhika Sarda**

Abstract

The construction sector significantly impacts India's economy, contributing approximately 8% to GDP while employing millions and driving industrial growth. However, it is a leading contributor to global CO2 emissions, resource depletion, and biodiversity loss. The built environment system is responsible for 40% of global CO2 emissions, 40% of global resource use and 40% of global waste streams. It is also one of the four value chains - along with food, energy, and fashion - responsible for approximately 90% of nature and biodiversity loss worldwide. In 2023, India, contributed 8% of global fossil carbon dioxide emissions. A rising population, a rapidly urbanizing and growing economy, have all contributed to emissions in India soaring in recent decades. Since 70% of global carbon emissions are from urban areas, this rapid pace is expected to house 50% of its population in urban areas by 2051, exuberating challenges in infrastructure, sustainability, and urban governance.

Accordingly, the paper broadly attempts to highlight the emerging scenario in built environment and suggest measures to facilitate that the built environment system plays its part in halting and reversing nature loss by 2030 - the mission the core of the Global Biodiversity Framework.

INTRODUCTION

In India, rapid urbanization is poised to reshape cities, with the urban population expected to reach 50% by 2051. Moreover, the total number of metropolitan (million plus) cities would be 75 and total number of the urban centres would be more than 10,000. This rapid growth presents immense challenges in housing, infrastructure, and sustainability, especially as 70% of India's 2030 infrastructure remains unbuilt. With construction contributing 22% of India's carbon emissions, the sector must adopt innovative, low-carbon practices to mitigate environmental impacts while driving economic growth.

This paper explores the intersection of urbanization and sustainability in India's construction sector. It evaluates emerging trends, challenges, and opportunities, offering actionable recommendations to achieve a balance between development and environmental stewardship. This study aims to chart a sustainable pathway for the built environment, aligning with India's net-zero commitments and global climate goals.

*Urban Planning Expert, ADB Transit oriented Development Cell, Institute of Urban Transport & Ministry of Housing and Urban Affairs

**Young Professional, States and Managing Urbanization Vertical, NITI Aayog*

ROLE OF CONSTRUCTION SECTOR AND ENVIRONMENTAL IMPLICATIONS

The built environment contributes significantly to global carbon emissions, with construction activities accounting for 11% of emissions and operational emissions from buildings contributing 28%. Together, these two components represent 39% of global energy-related CO2 emissions. In India, the construction sector accounts for 8% of emissions, while operational emissions from buildings add another 22%, reflecting the sector's dual impact on embodied and operational carbon (Fig.1).

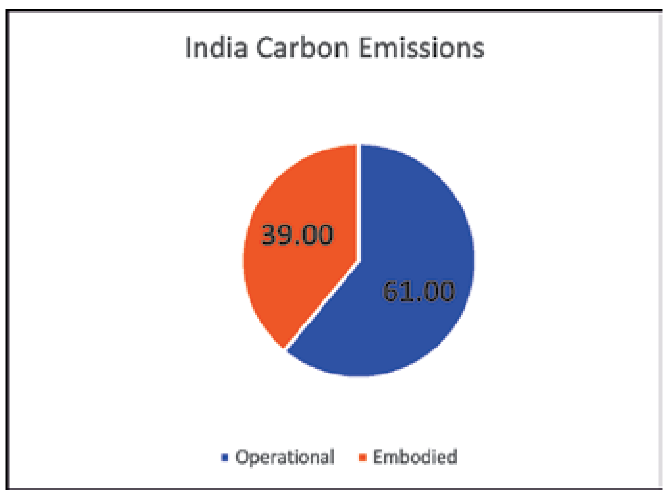


Fig. 1: India's Carbon Emissions 2023

Source: Compiled from various sources by the authors

With a disproportionate impact of operational emissions in the Indian context, Indian Building sector is currently accounting for 22% of emissions. The 2030 projected India's urban infrastructure remains unbuilt and unmaintained. This thus, presents a dual challenge of meeting housing demand while minimizing carbon emissions. The Table 1 below provides a comparative breakdown of global versus Indian emissions and building stock requirements.

Table 1: Table showing comparative global and Indian building stock and carbon emissions projections

Year	Region	Building Stock (billion m2)	Estimated CO2 emissions (million tons)
2030	Global	~120	~13000
	India	~40	~2000
2040	Global	~130	~10,500
	India	~50	~2500
2060	Global	~140	~8000
	India	~60	~3000

Source: Compiled from various sources by the authors

According to the above table, India's building stock is predicted to increase by 5.7 billion square meters by 2030, 21.5 billion square meters by 2040, and 45 billion square meters by 2060. As a result, the nation's building space is expected to more than double over the next 20 years, with 70% of the new construction taking place in urban regions.The building sector is likely to provide an enormous opportunity for reducing Green House Gas (GHG) emissions as it also drives sustainability in the numerous allied industries upstream and downstream of the value chain.

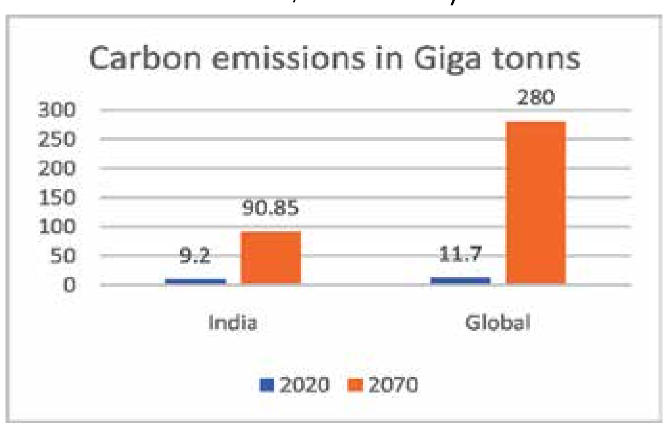
The built environment is growing in a sustainable manner, and the real estate industry is making more and more progress in this direction. India has pledged to reduce its carbon intensity by 45% by 2030 compared to 2005 levels, and the Indian real estate industry must actively contribute to the country's goal of decreasing predicted CO2 emissions by one billion tonnes by that time. As they continue to expand their real estate footprint, real estate developers are taking steps to reduce carbon and other harmful emissions, supporting the continued efforts in this area. As developers become more aware of how the built environment affects the ecosystem around them, they are incorporating sustainability into their operations and construction methods. Developers, occupiers, investors, and society at large all benefit from achieving ecologically sustainable expansion while creating exceptional tenant experiences.

Sustainability has come into the mainstream in the overall real estate ecosystem and the relevance of green buildings is only increasing. Especially, Delhi NCR's commercial office real estate inventory constitutes 45 – 50% share of green buildings (with varied certifications). Many developers are adopting initiatives including water harvesting, solar energy, trash composting, sustainable design, conserving natural resources, utilizing greener construction technologies, and optimizing water usage. Cities must be receptive, innovative, and productive in order to promote sustainable growth and guarantee a higher standard of life, as they will account for a significant portion of the GDP by 2050.

India has a unique opportunity to provide thermally comfortable and zero-carbon buildings and, in doing so, give scale to manufacturing low-carbon materials, adopting sustainable design and construction practices, and creating and sustaining a market for innovative technologies. This represents a historic opportunity to illustrate resilient, prosperous development that is decoupled from carbon. A whole systems approach can provide enormous opportunities to lower embodied carbon emissions and reduce operational consumption while simultaneously increasing clean energy usage and improving the standard of living.

DELIBERATIONS AT UN CLIMATE CHANGE CONFERENCE: INDIA'S STAND

India's commitment at the UN Climate Change Conference 2021 to achieve net-zero emissions by 2070 aligns with transformative global goals. Significant decarbonization of the built environment, which accounts for around 40% of global energy-related GHG emissions, is necessary to achieve this.



Source: Compiled from various sources by the authors

Building technologies can produce rapid climate gains, while other energy sectors, like centralized renewables, might need major infrastructure transformation and investment. This is a historic opportunity in India, where half of the buildings, including residential buildings, that will be standing in 2050 have not yet been constructed. Once constructed, they will last for 50–100 years. It is also a contrast to decarbonizing sectors such as transport where the assets are short lived. The built environment thereby lends itself to democratization and faster adoption as one of the most cost effective and deep carbon abatement wedges while being the human theatre for wellness and health.

TRANSFORMATION OF CONSTRUCTION SECTOR

Currently, the construction industry is at a turning point where it is necessary to improve and rebuild the construction process with more sustainable and effective business procedures. For the sector to finish projects on schedule and within budget, it must be flexible enough to react to events and innovate more quickly than in the past.

The construction industry is undergoing a rapid transformation driven by cutting-edge technologies, sustainable practices, and innovative infrastructure solutions. As one of the fastest-growing sectors globally, the future of construction in India looks promising, with a focus on smarter, more efficient, and eco-friendly development. The key trends and innovations shaping this dynamic industry on many fronts. In addition to having a significant impact on construction, the inherent changes occurring throughout the entire construction value chain will also have a significant impact on society, as well as the individuals who will use infrastructure and live in buildings. From the actual production of higher-quality assets to their operation and maintenance, as well as the potential for the creation of data-driven decision systems, this evolution will have an impact on several scales.

Smart Infrastructure

India's urbanization is at an all-time high, and smart cities are the future. The government's Smart Cities Mission is driving innovation by integrating technology with urban planning. Smart infrastructure uses IoT (Internet of Things), AI (Artificial Intelligence), and big data to optimize resource management, reduce energy consumption, and enhance urban living standards. For example, smart buildings now feature automation systems for lighting, security, and climate control, creating safer, more efficient spaces for residents and businesses alike.

Sustainable and Green Construction Practices

Although the construction sector contributes significantly to environmental deterioration, sustainability is currently a top concern. Green building techniques are now becoming a norm with use of water-saving devices, solar energy, and energy-efficient materials. Construction projects are becoming more environmentally friendly and lowering their carbon footprint thanks to certifications like LEED (Leadership in Energy and Environmental Design).

For example, Delhi NCR has pioneered green construction, with 45%-50% of its commercial real estate certified as green buildings. Similarly, the Surat Smart City project integrates solar energy and water recycling systems.

Materials innovation is also playing a significant role in sustainable construction. New alternatives like recycled steel, self-healing concrete, and even 3D-printed materials are gaining traction, promising to lower environmental impact while maintaining structural integrity.

With almost 40% of carbon emissions attributable to the built environment, it is imperative that construction industry continues to play its part in addressing the fight to save the planet. Sustainability and innovation therefore go hand in hand, and how the cities create a greener and more energy efficient buildings – before it is too late.

This involves reducing the quantity of the waste produced while simultaneously accelerating the use of upcoming materials, such as concrete made without cement. By 2040, over two-thirds of the current global building area that exists today will still be there. It would be challenging to meet the Paris Agreement's 1.5°C target if existing structures were not widely decarbonized worldwide. These buildings would still be releasing CO_2 emissions in 2040.

India set a goal to achieve net zero emissions by 2070 at the UN Climate Change Conference in 2021. India plans to reduce its projected carbon emissions by 1 billion tones. By 2050, the built environment should have zero net emissions achieved through:

- Innovative, robust, low-embodied materials and assemblies that use aggressive conventional and unconventional high-performance measures that are compatible with circularity and planetary ecosystem services;

- Integrating affordable distributed energy resources with building-to-grid community scale integration to harness demand flexibility and offer reliable, equitable energy access;
- Low-carbon, region-specific, long-lasting, and disaster-resilient building typologies built and operated with cost-effective, integrated passive and active resource efficient technologies.

Equitable access to well-being for a resilient built environment, which encompasses mobility, biodiversity, renewable energy, water, and sanitation, as well as open spaces by ensuring:

- Resilience to combat warming and pollution levels and provide equitable access to a clean, remedial, health-promoting built environment;
- Technologies and attitudes that support a culture of resource conservation and environmental vigor restoration;
- Knowledge management via curriculums for integrated living environments that teach architecture, engineering, science, and sustainability at the educational, vocational, and workforce levels.
- Secure, scalable technologies that allow the built environment to function dynamically

Throughout the building life-cycle, digital tools and modelling frameworks such as energy modelling, digital supply chains, benchmarking, and circularity can be accomplished by

- Information and resource management systems that offer scientific foundations and data analysis for the operation of conventional, passive, and active systems at the building, community, and regional/national levels;
- Cost-effective, widely available, cyber-secure, sensors, and controllers that integrate buildings with (micro) grids.
- Key strategies, technologies and tools for building net zero communities.

Design, implement, and run a community with a net zero carbon footprint. This can result in widespread investment and policy adoption, as well as the development of human capital and an affordable, scalable technology suite. Radical transformation towards achieving equitable wellness and planetary resilience by 2050 intensity its economy by 45% by 2030. In order to approach this , it is believed to surpass this target and critical to transform the built environment that constitutes nearly 40% of global energy-related GHG emissions. While other energy sectors such as centralized renewables may require significant infrastructure change and investment, building technologies can create quick climate wins. This is a historic chance in India, where half of the homes and buildings that will be standing in 2050 have not yet been constructed but will do so within 50 to 100 years. Additionally, it contrasts with decarbonizing industries like transportation, where the benefits are fleeting.

As the human theatre for wellness and health, the built environment thus facilitates democratization and quicker adoption as one of the most profound and economical carbon abatement wedges.

Modular and Prefabricated Construction

The adoption of modular construction has reduced project timelines by 30%-50% while minimizing construction waste by 60%. Prefabricated housing is particularly effective in disaster-prone areas, as seen in Kerala's flood recovery efforts. This method is particularly useful in affordable housing, hospitals, and commercial complexes where quick turnaround is essential. Modular construction is also a sustainable solution, as it minimizes the use of raw materials and reduces the energy consumption involved in traditional construction methods. It is an approach that is gaining popularity for its ability to deliver high-quality structures in record time.

Sweden has been a pioneer in modular housing, cutting project timelines by 50% and reducing waste by 60% through factory-assembled modules. Prefabrication is also widely used in disaster recovery, such as in post-tsunami housing in Japan.

Advanced Construction Materials and Techniques

Innovations in materials science are creating stronger, more resilient buildings. Innovative materials such as graphene and self-healing concrete offer enhanced durability and sustainability. For example, graphene concrete can reduce cement use by 20%, lowering embodied carbon. These advancements help increase the lifespan of structures, reducing the need for constant repairs and replacements.

Table 2: Table showing a comparison between traditional and advanced construction materials

S.No.	Criteria	Traditional Materials	Advanced Materials
1	Embodied Carbon	Generally high (e.g., concrete)	Often lower; geopolymer concrete reduces carbon significantly
2	Durability	Good but susceptible to weathering	Enhanced durability; resistant to wear
3	Cost	Lower initial costs	Higher upfront costs; potential long-term savings
4	Sustainability	Limited recyclability	More sustainable; often recyclable and uses waste materials
5	Design Flexibility	Limited design options	High flexibility; allows complex designs
6	Installation	Requires skilled labor	May need specialized techniques but can reduce construction time

Source: Compiled from various sources by the authors

Robotics and automation are also making their mark on construction. From autonomous machinery capable of handling repetitive tasks to drones surveying construction sites, these technologies are improving efficiency, safety, and precision.

Sustainable Urbanization and Affordable Housing

With India's urban population expected to grow significantly in the coming years, affordable housing and sustainable urbanization will be critical areas of focus. For example, under the Pradhan Mantri Awas Yojana (PMAY), 11.2 million houses have been sanctioned, with 65% completed by 2023. Sustainable urbanization efforts could save 40% in energy usage through mixed-use developments. At the same time, sustainable urban development involves creating communities that are not only economically viable but also environmentally friendly. Long commutes are becoming less necessary as mixed-use complexes that incorporate residential, business, and recreational areas become more prevalent, promoting greener lifestyles.

A FUTURE BUILT ON INNOVATION

As the construction industry moves toward a future of smart infrastructure, sustainable practices, and ground-breaking technologies, the opportunities for growth and innovation are immense. For industry players, staying ahead of these trends is critical. Builders, contractors, and developers must embrace these advancements to remain competitive in a rapidly evolving landscape.The construction sector is essential to reducing the effects of climate change as the world struggles with it. The critical need to reduce CO2 emissions is addressed with Zero Net Carbon (ZNC) buildings, which emerge as a ray of hope. ZNC buildings, which are characterized as extremely energy-efficient structures that obtain their operational energy from renewable sources, mark a significant advancement in sustainability.

Sustainable Practices

There is a growing emphasis on sustainable practices within the construction industry, as companies recognize their responsibility to the environment and future generations. Embracing these innovations not only enhances the brand image but can also lead to significant cost savings in the long run.

a) Green Building Materials

Building materials that are sustainable can greatly reduce the project's ecological footprint. These materials include recycled, reclaimed, or rapidly renewable resources, which not only minimize waste but also often outperform conventional materials in energy efficiency and durability.

b) Energy-Efficient Design

On the other hand, energy-efficient design plays a crucial role in sustainable construction. By optimizing layouts, integrating passive solar heating, and selecting energy-efficient windows and insulation, one can significantly reduce energy consumption, leading to lower utility bills and less environmental impact.

A building's energy efficiency is further increased by integrating renewable energy sources like wind turbines and solar panels. Not only does this lower the reliance on fossil fuels, but it also aligns with goals for sustainability, creating a positive impact for future generations. The Edge in Amsterdam is a globally recognized NZEB, using renewable energy, advanced insulation, and energy-efficient designs to operate entirely on renewable sources.

c) Waste Reduction Techniques

Any effort made to implement waste reduction techniques can lead to substantial benefits. By actively minimizing waste through recycling and reusing materials on-site, not only save on disposal costs, but also contribute to a more sustainable future.

Plus, using tools like waste tracking systems can vastly improve the project management. By understanding the waste patterns, one can identify areas for improvement and make more informed decisions, ultimately enhancing both productivity and commitment to sustainability.

The European Union is a leader in adopting circular construction practices, mandating the reuse, and recycling of construction waste to minimize landfill contributions.

d) Workforce Innovations

Now, as the construction industry continues to evolve, workforce innovations play a crucial role in shaping a more efficient and skilled workforce. By adopting new technologies and methods, one can not only enhance productivity but also create a safer and more cohesive working environment.

e) Training and Skill Development

Any progressive construction company recognizes the importance of ongoing training and skill development. Embracing modern learning methodologies, one can ensure that the team is equipped with the latest techniques and provides a safer work environment. Whether through virtual training programs or onsite workshops, investing in the workforce's growth is imperative.

f) Automation and Robotics

Development in automation and robotics in construction is transforming the way projects are executed. By integrating these advanced technologies, can greatly enhance efficiency and reduce the risk of human error. This shift not only streamlines operations but also positions at the forefront of an industry rapidly moving towards high-tech solutions.

Singapore's Smart City Initiatives incorporate IoT (Internet of Things) and AI (Artificial Intelligence) to optimize resource consumption, improve energy efficiency, and enhance urban liveability. Smart buildings feature automated systems for lighting, climate control, and security, reducing operational energy use by up to 25%.

- **Safety Standards and Compliance**

Changes in safety standards and compliance requirements push to adopt stricter protocols. Regulations are increasingly emphasizing worker safety and site management, making it crucial for prioritizing training and resources that ensure full compliance and mitigate risks.

- **Incentives for Sustainable Practices**

With a global push towards sustainability, many governments are now offering incentives for adopting green building practices. These incentives can substantially reduce overall project costs and encourage to implement energy-efficient materials and methods.

Another key aspect of these incentives is that they often come in the form of tax credits, grants, or reduced permit fees. By leveraging these benefits can enhance the project's financial feasibility while contributing to a healthier environment. Embracing sustainable practices not only benefits the modern construction landscape.

- **Future National Building Code**

With the ongoing evolution of urban living and environmental preservation, the updated National Building Code should mandate at least 50% renewable energy integration and 30% water reuse in all urban developments by 2035 There will be a need to prepare for regulations that demand higher standards for energy efficiency and material sourcing.

Incentives for adhering to these future building codes may include reduced insurance premiums or expedited permit processes, which can significantly benefit the projects. Staying ahead of these changes means that one can adapt quickly, ensuring construction work complies with upcoming regulations.

CONCLUSION

India's construction industry, projected to grow by $1 trillion by 2030, must prioritize smart, resilient, and sustainable practices. This can be achieved through strong policy frameworks, capacity-building initiatives, and leveraging cutting-edge technologies. In 2024, the construction industry will demonstrate a dynamic environment driven by substantial investments in the energy and infrastructure sectors, technology innovation, and sustainable construction methods. Key factors influencing this growth include modern construction methods, legislative support for innovation, and the widespread adoption of construction software.

Advancements in construction technology are driving global growth, with the market projected to expand by $8 trillion by 2030. Smarter, more effective procedures are made possible by tools like AI, IoT, and BIM. Driven by technology-driven innovation and sustainability initiatives, construction output is predicted to increase by 85% to $15.5 trillion by 2030, with China, the United States, and India leading this surge.

From the beginning to the end of a project, construction technology and software are integrated. Digital technologies are being used more and more by construction organizations for project management tasks like planning, scheduling, estimating, and design. In an ever-expanding construction business, these advances enable experts to meet the needs of complicated building projects, improve productivity, and foster collaboration.

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TECHNOLOGICAL INTERVENTIONS IN MASS HOUSING CASE STUDY: LIGHT HOUSE PROJECT, CHENNAI

Dr. Pawan Kumar* And Meenal Jyotika**

Abstract

Technological interventions in mass housing may have two folds: firstly, it fulfills the needs of updated technology such as 3D printing, modular construction, prefabricated construction, etc for mass construction of housing units at safe, speedy and economical levels to supply housing stocks to the mass. Secondly, it provides digital property (housing) walk-through (in visualizing, understanding, purchasing, etc.), computation design, online/app-based solutions (to maintain the housing stocks in an efficient manner), etc. Light House Projects (LHPs) under PMAY-U are model housing projects built with alternate technologies suitable to geo-climatic and geo-hazards conditions of the regions. Precast concrete technology used in the Light House Project of Chennai is fully mechanized and produced in controlled factory environments and therefore the quality of precast elements is superior which enhances durability and safety of the structures. It is high time to do experiments on materials & technology and syndicate these learning experiences and outcomes with architects, engineers, town planners, interior designers and other allied professionals which may be lighthouse for augmentation of housing stocks for the society.

INTRODUCTION

In the housing sector, technological interventions are required not only for constructions of houses at larger scale but management of housing projects from conception stage to completion stage. Presently, the online housing market has user friendly technology driven interventions which provide information related to housing projects from pre-construction stage to post-construction stage, occupancy of houses to management of housing (property) assets, demolition to disposal of houses, etc. In fact, technological interventions at various stages of lifecycle of housing projects are vital.

Technological interventions are critical in the construction phase of large housing stocks. The conventional process of construction has its own limitations particularly for large-scale mass housing projects. It may lead to excessive delays, cost overruns, large quantities of construction waste, suboptimal quality of housing units, etc. Therefore, updated technological interventions are required which provide enhancement over conventional construction by mechanizing various parts of the construction process. The mechanized system has manifold advantages which may increase quantity & enhance quality of construction, optimize the use of resources, reduce the quantity of construction waste generation & carbon footprint, etc. Hence, technological interventions in mass housing projects are always useful and cost effective.

**Town and Country Planning Organization, New Delhi.*

***DevOps Engineer, Cloud202 Technology Solutions Pvt. Ltd., New Delhi.*

TECHNOLOGICAL INTERVENTIONS IN MASS HOUSING

The concept of mass housing refers to large-scale housing developments which are built to accommodate masses and common people. It involves the construction of a greater number of standardized residential units in less time to supply more housing stocks. It meets the demand for housing which may be purchased by the common people. Therefore, mass housing is often associated with low-cost housing. In other words, mass housing may be referred to large-scale, standardized housing projects typically undertaken by governments and other agencies to provide housing at affordable prices to the common people. In today's context, successful launch of any housing project either by Government or private developers need proper interface with clients through technological interventions. Table 1 along with Fig. 1 describes some of the online and offline technological interventions in housing projects.

Table 1: On-line and Off-line Interventions in Housing Projects

S.N.	On-line and Off-line Interventions	Description	Remarks
i.	Online Housing (Property) Portal	Such portal provides basic useful information about the project, demand & supply scenario, no. of available dwelling units, cost, etc. Publication & display of such information is considered as transparent and authentic.	It promotes 'ease of doing businesses and 'ease of living' in the society.
ii.	Digital Property Walk-Through	Digital property walk-through is a virtual experience that allows users to explore a property distantly. It uses 360-degree camera to take a series of panoramic images and connect the same with smart phone app which automatically uploads the pictures and creates walk-through.	Clients can visualize layout, blueprint and ambience of the project without visiting the site.
iii.	Dedicated Customers Portal	Such portal is dedicated to the customers for making online payment, complaints and customer support. It allows seamless communication between agencies and customers.	It is technological interventions for problem solving in a time bound manner with transparency and accuracy.
iv.	Alternative Technologies	The Global Housing Technology Challenge (GHTC) program was launched in 2019 which had taken several initiatives to showcase innovative construction technologies for mass housing	Houses built with alternate technologies compared to conventional construction are swift, economical and better quality.
v.	Housing Management (online) Software	Housing Management Online Software, also known as "Property Management Software". It is a digital platform that allows concerned agencies and housing societies to streamline various issues such as tenant screening & verification, rent collection, request for additional services, etc.	Generally, it is used by estate managers to manage real estate, looking after housing societies, housing assets, etc.
vi.	App based Solutions	It is useful to streamline search and selection of properties/houses. Housing information such as no. of available units, floor plans, amenities, etc. can be accessed by buyers and renters. Further, applications for the same can be submitted through a dedicated mobile app.	It is a one stop solution to property and housing related information.

Source: collected from different sources and represents approximate information

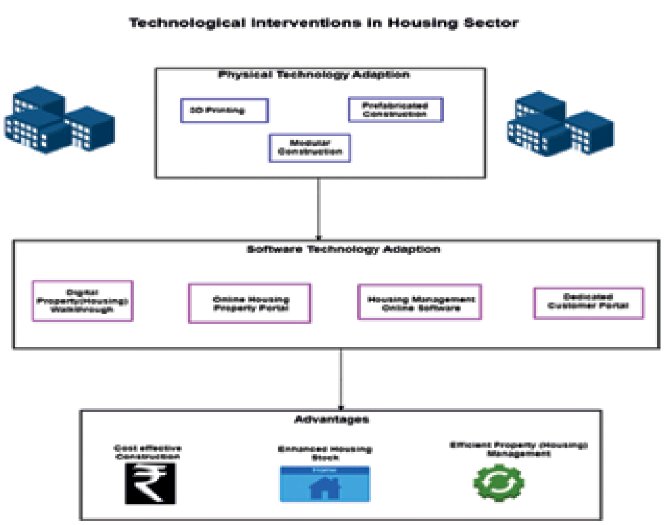

Fig. 1: Technological Interventions in Housing Sector

For the most part, the main purpose of technology interventions in mass housing is to get rapidity, quality and durability in construction with reduction in waste creation, energies and resources. The same can be achieved through:

Materials (i.e. precast concrete, etc.),

Formworks (i.e. modular formwork to cast columns, beams, floors, walls, etc.),

Panels (prefabricated panel/sandwich panel) and

Steel Structures.

Some of the technologies used in mass housing projects across the country are described in Table 2.

Table 2: Selected Examples of Technologies used in Mass Housing Projects

S.N.	Housing Technologies Used	Description	Example (s)
	Precast Concrete Construction System : 3D Precast Volumetric	3D precast volumetric construction uses prefabricated concrete modules to construct building components. It is also known as concrete modular construction. It can be used to build rooms, kitchens, bathrooms, toilets, stairs, and more.	Housing Project under Under Light House Project at Ranchi, 1008 housing units were developed using **3D modular precast concrete construction system.**
ii.	Precast Concrete Construction System: 3D Monolithic Volumetric	3D monolithic volumetric construction involves production of three-dimensional modular units in controlled factory conditions. Then modules are brought to sites either as a basic structure or with all internal & external finishes & services installed, and preferably ready for assembly.	A Housing Pilot project was undertaken by Tata Housing to display the feasibility of using 3D monolithic volumetric construction for residential buildings, particularly for mass housing projects. It is a five-storey building with 20 apartments which has been constructed using this technology.
iii.	Precast Concrete Construction System: Precast Components assembled at Sites	In Pre-cast concrete construction system, structural members such as pre-cast column, beam, precast concrete / light weight slab, AAC blocks/ infill concrete walls, etc. are casted in the factory and assembled at site. It may be considered as alternate to conventional RCC framed structure with bricks/blocks as infill walling material	CIDCO Mass Housing Project (12-storey building with 96 flats) at Navi Mumbai utilized precast technology. The project was commenced on April 4, 2022 and completed on July 9, 2022. It is an example of construction of safe and durable houses by using precast concrete system to fulfill urgent housing needs.
iv.	Prefabricated Sandwich Panel System	Prefabricated sandwich panel system is a construction method which uses factory-made panels instead of traditional brick and mortar for building walls, roofs, etc. The panels are made of two strong outer layers with an insulating core in between these two layers.	In LHP of Hosing at Indore, houses have been constructed using prefabricated sandwich panel system with pre-engineered steel structural system. In this system, EPS cement panels are manufactured at the factory in controlled condition. Panels are joined through tongue and groove joints together for construction of the building.
v.	Light Gauge Steel Framed Structures	Light gauge steel framing is one of the prefabricated building technologies which are more suitable for low-rise buildings up to G+ 3 storey particularly for residential and commercial purposes. It uses cold-form steel sections as structures which are formed in a cold state from galvanized steel sheets. Galvanizing helps in protection against corrosion in extreme environmental condition.	Light gauge steel framed structure with infill-concrete panel (LGSFS-ICP) technology has been used in Police Constable Quarters Building for Karnataka State Police Housing Corporation Ltd. at Bengaluru. Light Gauge Steel Frame System (LGSF) along with Pre-Engineered Steel Structural System is being used in Light House Project at Agartala.

Source: Compiled from Various Sources and represents approximate information

TECHNOLOGY SUB-MISSION UNDER PMAY (URBAN)

The Pradhan Mantri Awaas Yojana (Urban) was launched in June 2015 with an aim to provide affordable housing for all in urban areas. To meet the target for constructing houses, PMAY Mission has adopted "Technology-Sub Mission" for faster and cost-effective construction of houses as per geo-climatic and hazard conditions of the country. The Sub-mission works on the following aspects:

i. Design and Planning

ii. Innovative Technologies and Materials

iii. Green buildings using natural resources and

iv. Disaster Resistant Design and Construction.

Basically, housing is a process to provide shelter, basic services and amenities for indoor livable and outdoor healthy environment to the occupants. Affordable housing refers to housing units that are within financial means of the larger segment of society whose income is below the median household income. The technological advancement in the housing sector under PMAY (U) helps mass construction of housing stock at affordable costs. In other words, "Technology Sub-Mission under Pradhan Mantri Awas Yojana (Urban)" is a step ahead to fulfill the dreams of housing supply by using innovative emerging technologies.

LIGHT HOUSE PROJECTS UNDER PMAY (URBAN)

Light House Projects (LHPs) under PMAY-U are model housing projects with houses built with shortlisted alternate technologies suitable to geo-climatic and geo-hazards conditions of the regions. These demonstrate and deliver ready-to-live houses with speed, economy and with better quality of construction in a sustainable manner. In fact, Light House Projects are model housing projects with approx. 1,000 houses built with six alternate technologies.

In Light House Projects, the following six technologies have been utilized for mass housing in different regions of the country which are as follows:

Prefabricated Sandwich Panel System

Monolithic Concrete Construction using Tunnel Formwork

Precast Concrete Construction System

Precast Concrete Construction System (3D Volumetric)

Light Gauge Steel Structural System & Pre-engineered Steel Structural System

PVC Stay in Place Formwork System

Table 3 describes details of technologies used, status of the projects, number of houses constructed, etc. under Light House Projects.

Table 3: Housing Technology and other Details in Light House Projects (LHPs)

S.N.	Location of LHPs	No. of DUs	No. of Storey	Housing Technology used in Construction	Status
i.	Indore Madhya Pradesh)	1024	S+8	Prefabricated Sandwich Panel System	completed
ii.	Rajkot (Gujarat)	1144	S+13	Monolithic Concrete Construction System	completed
iii.	Chennai (Tamil Nadu)	1152	G+5	Precast Concrete Construction System-precast components assembled at site	completed
iv.	Ranchi (Jharkhand)	1008	G+8	Precast Concrete Construction System – 3D Volumetric	completed
v.	Agartala (Tripura)	1000	G+6		
vi.	Lucknow (Uttar Pradesh)	1040	S+13		

Source: LHPs Booklets

LIGHT HOUSE PROJECT (LHP) AT CHENNAI: A CASE STUDY

Light House Project at Chennai (Fig.2) was dedicated by the Hon'ble Prime Minister of India to the Nation on 26th May 2022. This LHP was constructed in a record time of 12 months despite COVID restrictions. The Pre-cast concrete system technologies from America and Finland have been used. Table 4 describes the various technologies used, project costs of LHP in the country.

Fig. 2: Light House Project, Chennai

Source: www.ghtc-india.gov.in

Table 4: Description of Technology and Country of Origin in Light House Projects

Location	Name of Technology	Country of Origin	No. of Houses	Project Cost (Cr.)
Chennai, Tamil Nadu	Precast Concrete Construction System - Precast Components Assembled at Site	Finland/USA	1,152	₹ 116.27
Rajkot, Gujarat	Monolithic Concrete Construction using Tunnel Formwork	France	1,144	₹ 118.90
Indore, Madhya Pradesh	Prefabricated Sandwich Panel System with Pre-engineered Steel Structural System	Japan	1,024	₹ 128.00
Lucknow, Uttar Pradesh	Stay In Place PVC Formwork with Pre-Engineered Steel Structural System	Canada	1,040	₹ 130.90
Ranchi, Jharkhand	Precast Concrete Construction System - 3D Volumetric	Germany	1,008	₹ 134.00
Agartala, Tripura	Light Gauge Steel Framed (LGSF) System with Pre-engineered Steel Structural System	New Zealand/Kenya	1,000	₹ 162.50
Total			6,368	₹ 790.57

Source: Light Hose Projects E-Newsletter Volume XL, June 2024

Table 5 describes a brief profile of the project in terms of plot area, built up area and carpet areas of dwelling unit, etc.

Table 5: Areas Details of Light House Project at Chennai

Location of Project	Nukkampal Road, Chennai, Tamil Nadu
No. of DUs	1,152 (G+5)
Plot area	29,222 sq.mt.
Carpet area of each DU	26.78 sq.mt.
Total built up area	43439.76 sq.mt.
Technology being used	Precast Concrete Construction System - 3S System
Other provisions	Anganwadi, shops, milk booth, library and ration shop

Source: LHP Report

Description of Precast Concrete Technology

Precast concrete is a construction product when concrete is poured and shaped in casting yards. After curing, the same is transported to the site for assembling. It needs a controlled course of action to ensure desired qualities without defects. In other words, precast components such as walls, slabs, staircases, columns, beams, planks, retaining walls, etc. are manufactured in casting yards in controlled conditions then the same is transported to site for assemble through jointing and grouting. Such technology is useful in the construction of both low-rise and high-rise buildings.

Construction Process of Precast Concrete Technology

Precast concrete is made of the following materials/ ingredients such as:

- cement (binding agent),
- aggregates(fine aggregates to fill voids between larger particles and coarse aggregates which improve strength to concrete & reduce shrinkage),
- water (for hydration of cement & lead to hardening of concrete mix), admixtures (retarding admixtures slow down setting time of the concrete which may be beneficial for casting process & transportation whereas accelerating admixtures speed up setting & hardening process of concrete in cold weather conditions),
- reinforcements (mesh/steel bars to enhance structural genuineness & resistance to tension forces), etc.

The proportions of these ingredients are determined and used as per required properties such as shapes, sizes, finishing, strength, durability, usages in different environmental conditions, etc. Table 6 describes various steps involved in making precast concrete.

Table 6: Steps involved in Production of Precast Concrete

S.N.	Steps	Description
i.	Concrete Mix Design	It is a process of selection of various ingredients and their quantities in desired proportion to create concrete with the preferred properties for different uses in both normal and specific environmental conditions.
ii.	Formwork/Mould Design	Mould is a type of tool used in product design to form and figure various components into different shapes and sizes. For designing of precast concrete elements, moulds or forms are created which are typically made of steel or fiberglass and the same can be reusable for multiple castings.
iii.	Batching	Batching concrete is a process of measuring and mixing the ingredients of concrete in the correct proportions. In fact, individual components of the concrete mix are specifically measured and mixed in a batching plant. It is required for consistency and quality of precast concrete.
iv.	Casting	The mixed concrete is poured into the moulds/form works to get the desired shape of precast elements. Reinforcements such as steel bars or mesh may be placed within the moulds to provide additional strength to the precast concrete.
v.	Curing	After casting, concrete go through a curing process in a controlled environmental conditions such as a curing chamber, water bath, etc. to maintain optimal conditions for hydration in precast plant which helps to develop its strength and durability.
vi.	De-moulding	Concrete has sufficiently cured then the precast elements are removed from the moulds/form works. The moulds/frameworks are cleaned and used for the subsequent casting.
vii.	Finishing	Additional finishing of precast elements may be required such as floating, staining, toweling, colour surface treatments, polishing, coatings, etc. to achieve the desired appearance and functionality. Finished precast elements may vary in weight and size and the same is transported from casting yards to the construction site for assembly and formation of the structure

The LHP in Chennai under PMAY-U is one of the projects which provided affordable, durable and environmentally friendly houses to the beneficiaries. It has been constructed by using precast concrete construction system at the site and completed within 12 months. A brief description of technology used is as follows:

- Pre-cast Concrete Structural System comprises of pre-cast column, beam, precast concrete / light weight slab, AAC blocks/ infill concrete walls. It is also known as 3S Prefab Technology where 3S stands for S-Strength, S-Safety, S-Speed, and Sustainability.
- All required precast components such as columns, beams, slabs, etc have been casted in castings yards.
- These components are shifted to the construction sites.
- Precast components erected one after the other for construction.
- Precast components have been connected through mechanical fasteners, embedded connectors, etc.
- Joints between precast components (i.e. beam-column, beam-slab, column-foundation, etc) have been 'cast in-situ' i.e. critical joint areas are poured with fresh concrete on-site to create a monolithic connection to form a single structural unit.
- Gaps between precast components have been filled up with grouts which help in structural integrity and weatherproofing.
- Sealing joints have been treated with appropriate sealant materials to prevent water infiltration and corrosion.
- Internal services have been implanted through precast components.

The Light House Project of Chennai with 1152 houses in G+ 5 storey along with all basic and social infrastructure facilities have been completed in partnership with the State Government of Tamil Nadu. The 1,152 houses at LHP Chennai are spread across 12 towers and 6 floors with basic infrastructure such as internal water supply, sewer lines, internal electrification, internal roads, lifts, LED Street lights, rainwater harvesting, etc. It also comprises of shops, milk booths, etc. for the ease of families living inside the premises. Presently, all houses have been occupied by the allotted beneficiaries.

DISCUSSION AND CONCLUDING REMARKS

The selection of technologies for various geo-locations and geo-climatic conditions to supply adequate housing to the lower and middle class segments of society through mass housing projects has its own significance and consequences. Therefore, technology interventions in the housing sector for mass construction and production of housing stocks are need of the hour. It is high time to encourage and promote experiments on materials & technology and syndicate these learning experiences and outcomes with for augmentation of housing stocks in the society.

Apart from construction, both supervision of housing stocks and management of estate assets require technological interventions at stakeholder levels such as builders, housing promoters, real estate managers, buyers, sellers, loan providing institutions, etc. and therefore it is important to appraise these technological performance and outcomes. Further, promotion 0f usages of these technologies in planning and designing of safe and sustainable houses at lager scale is required through government and private sector agencies.

Precast concrete technology used in Light House Project of Chennai is fully mechanized and produced in controlled factory environments and therefore the quality of precast elements is superior which enhances durability and safety of the structures. According to Building Materials and Technology Promotion Council (2018), it is stated that for monolithic concrete construction system using engineered formwork, at least 500 housing units may be required and, for precast, the required scale may be as high as 5000 housing units. Hence, this technology is significant for light house projects but the same may be more technical and economical viable if it is used for large scale mass housing projects.

After pandemic in 2020, real estate industry is moving towards digital realm which is becoming more popular and adaptive by the people. Computational design using algorithms and computer programming is a next-generation technology which can generate multiple design options swiftly and compare the same to identify the most efficient and cost-effective option. Further, it can also customize designs to meet the specific needs of mass housing in different climate regions as per topography, environment and disaster sensitivity. Contrarily, privacy and security are critical challenges in real estate technology, especially for smart home technologies. It needs to be addressed through legal provisions by the concerned agencies and create awareness among the clients through the building professionals.

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DEPLOYABLE SHELTERS AS A SCALABLE SOLUTION FOR POST-DISASTER MASS HOUSING

Simran Shaikh* And Dr. Debashis Sanyal**

Abstract

Natural disasters have become more frequent and severe due to climate change, resulting in large-scale displacement and housing crises worldwide. Traditional post-disaster housing solutions, including tents and makeshift shelters, often fail to provide sustainable and dignified living conditions. Deployable shelters offer a revolutionary alternative, combining rapid deployment, modularity, and sustainability. These shelters can be transported, assembled quickly, and scaled up to accommodate large populations, making them ideal for post-disaster scenarios. Advances in materials, prefabrication, and renewable energy integration further enhance their efficiency. This paper explores the significance of deployable shelters in the contemporary world, presents case studies demonstrating their effectiveness, and evaluates their potential as a long-term solution for mass housing in disaster-affected regions. By examining technological innovations and successful implementations, this study aims to highlight the critical role of deployable shelters in enhancing disaster resilience and response.

INTRODUCTION

Disasters such as earthquakes, hurricanes, and floods have devastating impacts on communities, displacing millions of people and creating an urgent need for immediate and effective housing solutions. Conventional emergency housing methods are often inadequate, failing to meet the demands of scalability, durability, and cost-effectiveness. Deployable shelters present an innovative solution, leveraging modular design, lightweight materials, and prefabrication techniques to create adaptable and resilient living spaces. Their ability to be rapidly deployed and reused makes them a sustainable choice in disaster management. This paper delves into the importance of deployable shelters in the context of increasing global disasters, discussing their technological advancements, practical applications, and suitability as scalable housing solutions. Through case studies and technological insights, this research highlights the potential of deployable shelters to bridge the gap between emergency relief and long-term rehabilitation, ensuring better living conditions and faster recovery for affected communities.

** Student, NIT Raipur*

*** Associate Professor, NIT, Raipur*

Fig. 1: Disaster affected community house (Temporary Housing in a Kathmandu Tent Camp.)

Source: Disaster Research Center, University of Delaware

DEPLOYABLE STRUCTURES

Deployable structures are dynamic and adaptable frameworks designed for easy transportation, rapid assembly, and efficient storage. These structures are widely used in architecture, disaster relief, military applications, and space exploration due to their ability to compactly fold and expand as needed. Their key characteristics include mobility, scalability, quick assembly, lightweight yet strong materials, and modularity, allowing multiple units to interconnect and form larger structures. Various mechanisms are used in deployable structures, including scissor-hinged systems, origami-inspired folding techniques, tensile and pneumatic structures, and expandable panel-based designs.

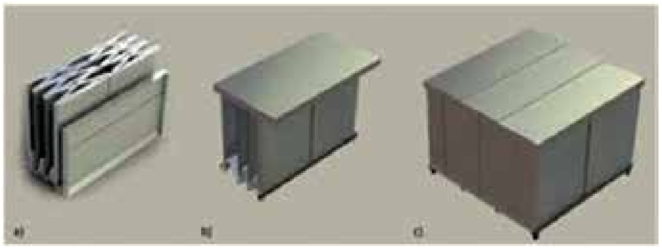

Fig. 2: Deployable Structure Mechanism

Source: TOSUN & MADEN, 2023 p.6

These structures find applications in disaster relief as emergency shelters, in the military for mobile command centers and medical units, in space missions for expandable habitats and solar arrays, and in events for temporary pavilions and retractable stadium roofs. Given your thesis focus on deployable shelters for earthquake-prone regions, integrating hybrid structures that combine origami and scissor-hinged mechanisms can enhance adaptability, efficiency, and rapid deployment in post-disaster scenarios.

Fig. 3: Deployable Structure Mechanism

Source:TOSUN & MADEN, 2023

OVERVIEW OF CHALLENGES IN POST-DISASTER HOUSING

Natural disasters such as earthquakes, hurricanes, and floods displace millions of people annually, creating an urgent need for immediate and effective housing solutions. Traditional emergency shelters often fail to provide adequate protection, comfort, and long-term usability. The immediate challenge for construction management following a catastrophic event is the quick reconstruction of destroyed homes and infrastructures (Exploring the Potential of Design for Manufacture and Assembly (DFMA) in Post Disaster Housing Solutions, n.d.). Limited resources, logistical challenges, and the lack of sustainable planning further complicate post-disaster recovery efforts. Additionally, the increasing frequency and severity of climate-induced disasters demand innovative and resilient solutions that can be rapidly deployed while ensuring safety and sustainability.. An example of this is when a home provided after a disaster is "downgraded" from the pre-disaster home e.g., from three bedrooms to two, thus impacting survivors' home value and generational wealth (Goentzel et al., n.d.).

CURRENT SITUATION IN INDIA

India is highly vulnerable to natural disasters such as earthquakes, floods, and cyclones, leading to massive displacement and housing shortages. poorly designed shelters can have adverse impacts on the health (Kuchai et al., 2024).The country experiences an annual average of over 2,000 deaths due to disasters (NDMA, 2018), with millions losing their homes. Traditional relief shelters, such as tarpaulin tents and temporary housing, often fail to provide long-term safety and sustainability. The government and NGOs have initiated various disaster response programs, but there remains a pressing need for innovative, rapid, and scalable housing solutions. Deployable shelters can play a crucial role in addressing these challenges, providing immediate relief while ensuring resilience in the face of future disasters.

IMPORTANCE OF DEPLOYABLE SHELTERS IN MASS HOUSING

Deployable shelters offer numerous advantages over traditional emergency housing:

- **Rapid Deployment:** They can be set up quickly, reducing response times in post-disaster situations.

- **Scalability:** Modular configurations allow shelters to be expanded based on needs.
- **Sustainability:** Many designs incorporate recyclable and environmentally friendly materials such as aluminum alloys, composite panels, and modular insulation systems, reducing environmental impact. For example, the Hex House by Architects for Society is a sustainable deployable shelter that uses recyclable materials and passive cooling strategies, minimizing its carbon footprint.
- **Durability:** Unlike tents, deployable shelters offer better insulation and structural integrity. For instance, Exo Housing by Reaction Housing is designed with a durable polymer shell that offers better protection and longevity compared to conventional tents.
- **Cost-Effectiveness:** In the long run, they provide a more economical solution due to reusability and adaptability. Their modular design allows for easy transportation and rapid assembly, reducing labour and logistics expenses.

Fig. 4: Post Disaster Housing Condition

Source: Better Shelter

Deployable shelters provide an effective solution for mass housing in disaster-hit areas due to their rapid deployment, ensuring immediate relief to affected populations. Their scalability allows flexible configurations to accommodate varying needs, while sustainability is achieved through eco-friendly materials and energy-efficient features. Unlike temporary tents, they offer durability, providing better insulation and structural integrity for long-term use. Additionally, their cost-effectiveness makes them a viable alternative, as they can be reused and adapted for multiple scenarios, reducing overall expenses. Having a home is a basic human need and is essential for the wellbeing of individuals, families, and communities (Müller & ElZomor, 2024).These advantages make deployable shelters a crucial component of disaster recovery and rehabilitation efforts.

PRINCIPALS OF DEPLOYABLE STRUCTURE

Deployable shelters are designed based on key engineering principles to ensure functionality and efficiency. Modularity allows individual units to be connected or expanded to create larger housing solutions based on the scale of displacement. Foldability and compactness facilitate easy transportation and storage, making deployment swift and efficient. The use of lightweight yet high-strength materials enhances portability without compromising durability. Lastly, their ease of assembly ensures quick setup with minimal tools and labour, making them an ideal solution for emergency scenarios.

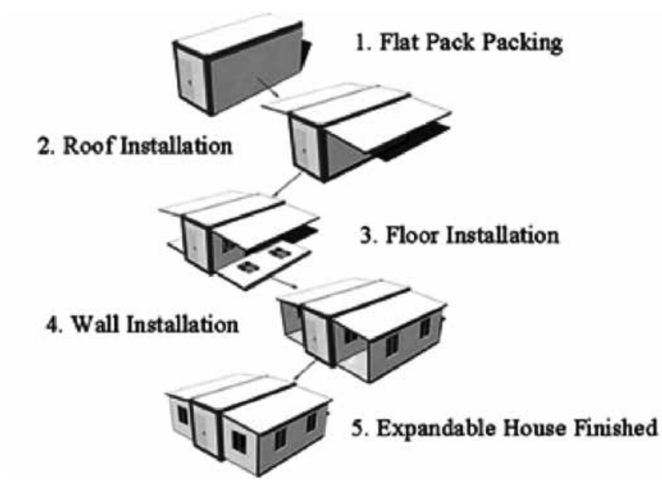

Fig. 5: Flat Pack Mechanism

Source :indiamart.com

- **Modularity:** Allows units to be combined for larger housing solutions.
- **Foldability & Compactness:** Ensures easy transportation and storage.
- **Lightweight & High Strength Materials:** Enhances portability without compromising durability.
- **Ease of Assembly:** Minimal tools and labour required for setup.

STRUCTURAL AND MATERIAL INNOVATION IN DEPLOYABLE STRUCTURES

Structural and material innovations play a crucial role in enhancing the efficiency and resilience of deployable shelters. Prefabrication and modular design significantly reduce setup time while ensuring structural integrity. The use of lightweight materials such as aluminium alloys, composites, and high-tensile fabrics enhances portability without compromising strength. Smart materials, including shape-memory alloys and self-healing polymers, improve durability and adaptability to environmental conditions. Furthermore, energy efficiency is integrated through renewable energy sources such as solar panels, wind turbines, and rainwater harvesting systems, making the shelters self-sufficient. Mobile nodes facilitate the deployment and redeployment of the network To withstand extreme conditions (A_survey_on_rapidly_deployable_solutions_for_post-Disaster_networks, n.d.) seismic and wind resistance is achieved through reinforced joints and flexible structures, ensuring longevity and safety in disaster-prone areas.

SUITABILITY OF DEPLOYABLE STRUCTURE FOR MASS HOUSING

Deployable shelters are particularly suited for mass housing in disaster-hit regions due to:

- **Adaptability to Various Climates:** Designs can be modified for different geographical locations.
- **Ease of Maintenance & Reusability:** Ensuring long-term functionality beyond emergency response.
- **Integration with Urban Planning:** Potential to serve as transitional housing before permanent reconstruction.

Transportation has also been a concern for earth-bound applications. Today there is also strong research being carried out on mobile and rapidly assembled structures, mostly made of lightweight deployable structures, for adaptable building layers and for mobile or temporary applications, such as emergency shelters for disaster relief or military operations.

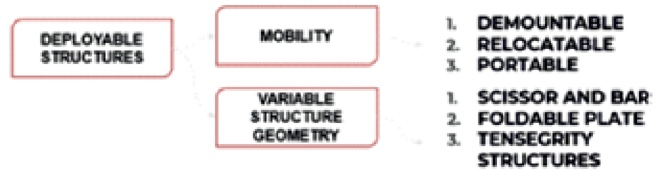

Fig. 6: Types of Deployable Structures

Source : Author

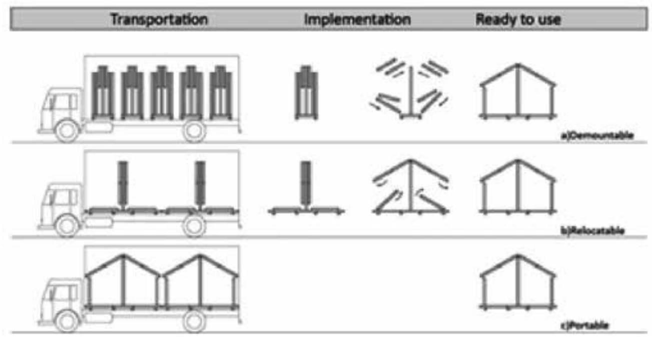

Fig. 7: Transportation of Structures

Source: TOSUN & MADEN, 2023

Deployable shelters are particularly suited for mass housing in disaster-hit regions due to their adaptability, ease of maintenance, and seamless integration with urban planning. Adaptability to various climates ensures that shelters can be customized for different geographical conditions, making them suitable for both extreme cold and hot environments. Ease of maintenance and reusability provides long-term value, as these shelters can be repurposed for future emergency responses. Additionally, their integration with urban planning allows them to serve as transitional housing, supporting communities during reconstruction phases while maintaining livable conditions.

CASE STYDY

1. **Relief Housing Units by better shelter.**

Fig.8: Exterior View of Shelter

Source : https://bettershelter.org

Fig. 9: Interior View of Structure

Source : https://bettershelter.org

Provided in Kerala, A resistant shelter that arrives with all parts in a flat pack and is easy to assemble for immediate safety and dignity in emergency response. All-in-a-box shelter Rapid distribution Assembled in a matter of hours Immediate safety and dignity in an emergency.

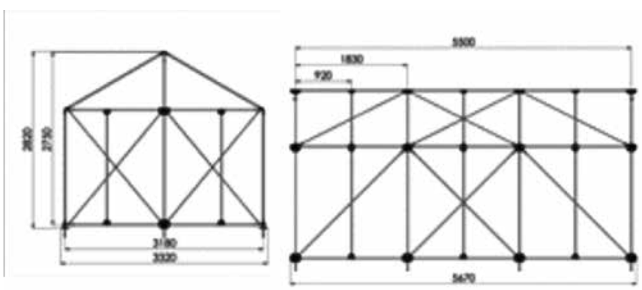

Fig. 10: Structural System of Shelter

Source :https://bettershelter.org

The frame is the unit's load-bearing structure. It is made from galvanized, high-strength steel and is modular, self-supported, and intended to be used with the unit's panels. Foundations, frames and columns are fastened together with connectors.

Better Shelter with Collaboration with IKEA has provided shelters in India.This design has been successfully implemented in Kerala, where disaster-resistant shelters were deployed in flood-prone regions. The flat pack nature of the shelter enabled quick transportation and rapid on-site setup, providing immediate relief to displaced communities. Given its adaptability and effectiveness, aligns with global emergency housing standards. Further Better Shelter offers a practical, scalable, and sustainable solution, its long-term viability in diverse climatic conditions should be further analyzed. Factors such as thermal insulation, ventilation, and resistance to extreme weather conditions should be carefully evaluated to ensure its suitability across different geographical regions.

2. Expandable Mobile shelters By DRDO

- **Development:** DRDO has created the Expandable Mobile Shelter (EMS) for enhanced working space while ensuring transportability.
- **Construction:** Made from aluminium with sandwich panel construction; resembles a conventional shelter when folded.
- **Versatility:** Can serve as mobile operation rooms, command posts, communication shelters, field offices, field hospitals, mobile repair facilities, and VIP caravans.
- **Space Efficiency:** Expands to three times its original size, providing a comfortable working environment in the field while reducing logistics needs.

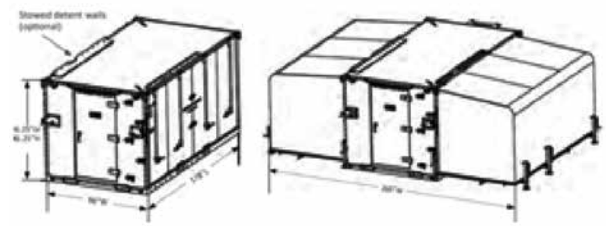

Fig. 11: Mechanism of Structure

Source : DRDO

Fig. 12 : Exterior View of Structure

Source : DRDO

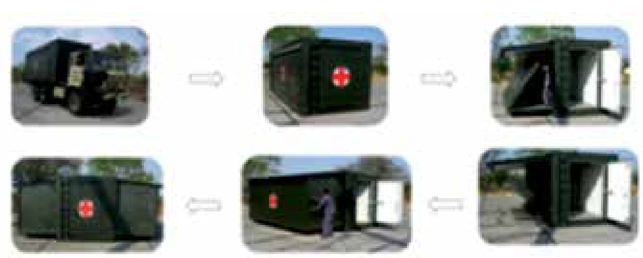

Fig. 13: Deployable Mechanism of Shelter

Source: DRDO

FINDINGS

Case Study	Deployment Mechanism	Findings
Relief Housing Units by Better Shelter	Flat-pack modular units with panelized construction	Flat-pack modular design allows compact transport and easy assembly. - Panelized system with insulation enhances thermal comfort. - Secure locking mechanism improves safety and structural integrity.
Expanded Military Shelter by DRDO	Scissor-hinged expandable system with rigid panels	Uses scissor-hinged expandable structures for rapid deployment. - Strong, durable materials (Aluminum alloy, composites) ensure longevity. - Automated expansion system speeds up deployment.

Source: author

Scalability & Modular Adaptability directly addresses the challenge of providing mass housing solutions in post-disaster scenarios. Deployable shelters offer a scalable approach to emergency housing by utilizing modular, prefabricated, and rapidly deployable units that can be expanded or reconfigured based on the number of displaced individuals. Their standardized components enable mass production, ensuring quick response times while maintaining structural efficiency. Additionally, these shelters can be pre-positioned in disaster-prone regions, reducing logistical challenges during emergencies. By integrating flexible design mechanisms, such as origami-based folding and scissor-hinged structures, deployable shelters optimize space utilization and adaptability in diverse terrains. This scalability not only improves resource efficiency and cost-effectiveness but also ensures that affected populations receive dignified, secure, and climate-responsive housing in the aftermath of a disaster.

CONCLUSION

Deployable shelters represent a breakthrough in post-disaster mass housing, offering an efficient, scalable, and sustainable alternative to traditional relief efforts. By incorporating advancements in materials, prefabrication, and modularity, these shelters can effectively bridge the gap between emergency response and long-term recovery. Their rapid deployment, cost-effectiveness, and adaptability make them essential for disaster-prone regions, ensuring that affected populations receive immediate and dignified housing. As technological innovations continue to evolve, deployable shelters can play a vital role in strengthening disaster resilience and supporting sustainable urban planning for future emergencies.

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MASS HOUSING RE-IMAGINED: HARNESSING TECHNOLOGY FOR EFFICIENT SOLUTIONS

Sristi Tokdar* And Dr. Debashis Sanyal**

Abstract

In response to rapid urbanization and the growing need for affordable housing, adopting technological innovations in mass housing will be crucial. This paper will explore how emerging technologies will revolutionize the design, construction, and management of large-scale housing projects, helping cities deliver cost-effective, high-quality solutions.

Key topics will include smart technologies like energy management systems and IoT devices, which will optimize energy use, reduce costs, and enhance living conditions. Case studies of successful projects will provide insights into best practices and challenges, highlighting the impact of these technologies on sustainability and housing quality.

The paper will also examine the socio-economic benefits of these advancements, such as reduced construction costs, faster timelines, and improved housing quality. These innovations will help create more resilient, inclusive communities, addressing housing shortages and promoting sustainable urban development.

INTRODUCTION

In cities around the world, the need for scalable and effective housing solutions has increased dramatically due to urban migration and population expansion. The need to handle expanding populations in a sustainable and economical way has caused metropolitan areas to grow quickly, which has necessitated a reassessment of conventional building techniques. Innovative technologies are taking the place of or complementing conventional methods, which are frequently limited by high costs, protracted construction periods, and negative environmental effects. Prefabrication methods, smart building systems and modular construction are only a few of the many technologies for these developments. There are distinct advantages to each of these technologies, including shorter building durations, low expenses, increased energy efficiency, and less trash production.

By using these innovative techniques, developers can produce housing solutions that support long-term sustainability in addition to meeting the urgent demands of metropolitan populations. Examining the many technical developments in mass housing, their useful applications, the advantages they offer to urban settings, and their potential to influence the direction of sustainable urban life are the main objectives of this article.

** Student, NIT Raipur*

*** Associate Professor, NIT, Raipur*

TECHNOLOGICAL INTERVENTIONS IN MASS HOUSING

Smart Building Technologies

- **Intelligent Energy Management Systems (EMS)**

Intelligent EMS are pivotal in creating energy-efficient mass housing. By using IoT devices to monitor and manage energy consumption, these systems enable

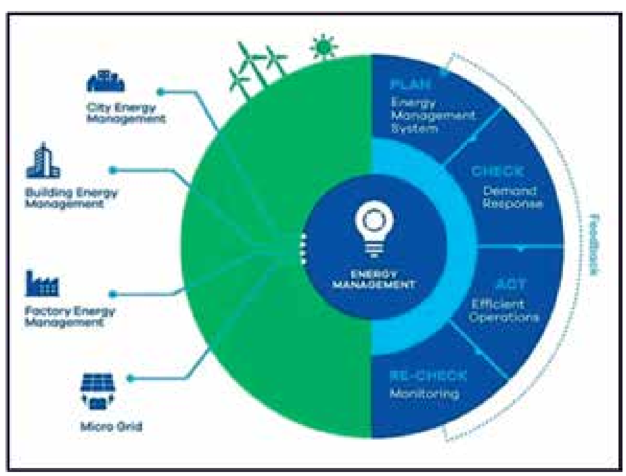

Fig. 1: Energy Management System[1]

real-time energy adjustments, reducing costs and environmental impact. For instance, in the "Masdar City" project in Abu Dhabi, EMS has reduced energy consumption by 40%, showcasing the potential for substantial energy savings. The integration of AI algorithms in EMS further enhances predictive analytics, enabling more accurate forecasting of energy needs and optimizing resource allocation.[1]

- **Internet of Things (IoT) Devices**

IoT devices are revolutionizing the way buildings interact with their environment and occupants. From smart sensors that monitor air quality and lighting to automated systems that adjust temperature and security settings, IoT technologies enhance the functionality and efficiency of mass housing. The "Songdo International Business District" in South Korea is a prime example, where IoT-enabled infrastructure supports smart waste management, traffic control, and energy use, improving overall urban efficiency and liveability.[8]

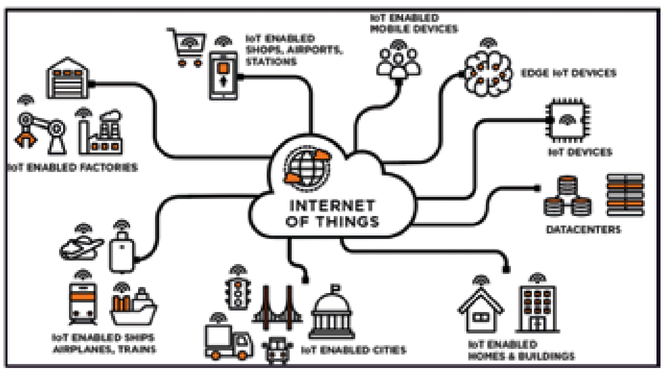

Fig. 2: Internet of Things [10]

Prefab and Modular Construction

Prefabrication and modular construction offer a solution to the challenges of traditional construction by significantly reducing build times and costs. These methods involve manufacturing building components off-site in controlled environments, ensuring higher precision and less material waste. The "Lego-style" modular construction of the "B2 Tower" in Brooklyn, New York, completed in just 19 days, highlights the speed and efficiency of this approach. Glass Fiber Reinforced Gypsum (GFRG) panel system, also known as the Stay-in-Place formwork system, is gaining traction in India as a sustainable and rapid construction technology for mass housing. Originally developed in Australia, GFRG panels are prefabricated, lightweight, and made from high-strength gypsum reinforced with glass fibers. These panels function as both structural and load-bearing elements, reducing the need for additional reinforcement. In India, the adoption of GFRG technology has been driven by the need for affordable and sustainable housing. The GFRG housing project in IIT Madras stands as a pioneering example, demonstrating that entire structures can be built within days using this technology. The Indian government has also promoted GFRG under initiatives like PMAY (Pradhan Mantri Awas Yojana) due to its cost-effectiveness, thermal efficiency, and minimal water usage during construction. Additionally, projects in Kerala and Tamil Nadu have showcased the ability of GFRG to withstand seismic and cyclone-prone conditions, making it a viable solution for disaster-resistant housing.

Furthermore, the adaptability of modular construction allows for customization to meet various architectural and cultural needs, enhancing the aesthetic and functional appeal of mass housing. [6]

Fig. 3: Prefab & Modular Construction [4]

Building Information Modelling (BIM)

BIM is transforming the planning and execution of mass housing projects by providing a comprehensive digital representation of the building process. This technology facilitates collaboration among architects, engineers, and contractors, ensuring that all aspects of the project are aligned.

BIM has gained significant momentum in India, particularly in large-scale infrastructure and smart city projects. One of the most prominent examples is the Mumbai Metro Line 3 (Colaba–Bandra–SEEPZ Corridor). This underground metro project extensively utilized BIM for design coordination, clash detection, and construction sequencing, ensuring efficiency in planning and execution.

BIM played a crucial role in resolving design conflicts between different disciplines, optimizing space utilization, and enhancing project management. With real-time data visualization, digital twin technology, and collaboration among multiple stakeholders, the implementation of BIM reduced construction errors, rework, and material wastage, thereby improving cost-effectiveness and sustainability.

Another notable example is Bangalore International Airport Terminal 2, which leveraged BIM for its entire lifecycle—from design to construction and facilities management. The adoption of BIM helped in sustainability planning, energy efficiency analysis, and seamless coordination among consultants, contractors, and engineers.

The "Rijksmuseum" renovation in Amsterdam leveraged BIM to coordinate complex restoration work, minimizing disruptions and ensuring high-quality outcomes. BIM's ability to simulate different construction scenarios and lifecycle costs makes it an indispensable tool for sustainable and efficient building practices.[9]

Fig. 4: Building Information Modeling [9]

Advanced Materials

The development and use of advanced materials are critical to improving the sustainability and performance of mass housing. Innovations such as graphene-enhanced concrete, graphene being a composed material of carbon atoms arranged in a honeycomb lattice pattern, nearly transparent with one atom thickness, when used in concrete, imparts strength about 200 times greater and makes the concrete six times lighter in comparison to conventional concrete, enabling to produce lightweight composite materials, which offers superior strength and durability, and aerogel insulation, which provides exceptional thermal performance, are redefining building standards. The use of phase-change materials (PCMs) in the "HIVE Project" in Barcelona demonstrates how advanced materials can regulate indoor temperatures, reducing reliance on heating and cooling systems and enhancing energy efficiency. (2)

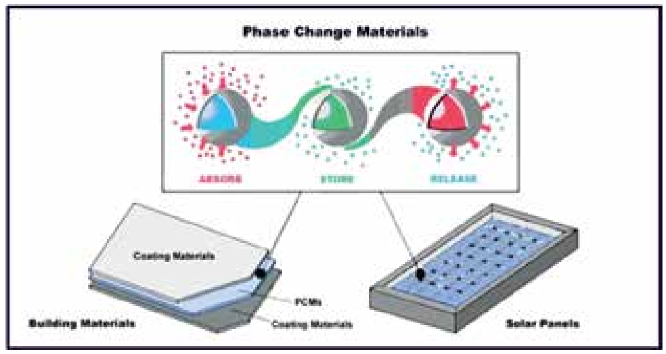

Fig. 5: Phase Changing Material (PCM) [2]

CASE STUDIES

Case I : Smart City Project, New Town, Kolkata

New Town, Kolkata, a planned satellite city, has emerged as a model of smart urban development in India. This project integrates technology and infrastructure to create a sustainable and efficient urban environment. The city's smart initiatives aim to enhance quality of life, reduce environmental impact, and promote economic growth.[5]

Fig. 6: New Town Smart City, Kolkata, India [5]

Technological Implementation

1. Smart Metering & Energy Monitoring

- Advanced Smart Meters: Residential units are equipped with IoT-enabled smart meters that track real-time consumption of electricity, water, and gas.
- Usage Insights & Alerts: Residents receive notifications on unusual consumption patterns, enabling proactive energy savings.
- Automated Billing & Dynamic Tariffs: The smart metering system allows for demand-based pricing, encouraging energy conservation during peak hours.

2. Passive Energy Efficiency Measures

A. Climate-Responsive Building Design

- Orientation Optimization: Buildings are strategically placed to minimize heat gain during summers and maximize natural daylight in winters.

- High-Performance Building Envelope:
  - Thermal insulation in walls and roofs to prevent heat transfer.
  - Cool Roof Coatings & Reflective Paints to reduce heat absorption and lower indoor cooling needs.
- Natural Ventilation & Cross-Airflow Design:
  - Strategic window placements and ventilators enhance airflow, reducing the need for artificial cooling.

B. Smart Shading & Day lighting

- External Shading Devices: Overhangs, louvers, and pergolas minimize direct solar heat gain.
- Double-Glazed & Low-E Glass Windows: Reduce indoor overheating while maintaining natural light.
- Daylight Optimization:
  - Light shelves and skylights maximize indoor illumination, reducing reliance on artificial lighting during the day.

3. Energy-Efficient Appliances & Smart Home Systems

- BEE 5-Star Rated Appliances: Refrigerators, air conditioners, and washing machines with high energy efficiency are promoted.
- Home Automation & IoT Integration:
  - Motion-Sensor-Based Lighting & Fans: Automatically turn off when a room is unoccupied.
  - Smart Thermostats & AC Control Systems: Adjust cooling based on occupancy and external weather conditions.
  - Automated Blinds & Curtains: Work in sync with temperature settings to reduce heat gain.

4. Renewable Energy Integration

- Solar Rooftop Installations:
  - Net metering allows households to feed excess solar energy into the grid, reducing electricity bills.
  - Government incentives encourage adoption, increasing rooftop solar installations across residential sectors.
- Solar Water Heating Systems:
  - Reduces dependence on electric water heaters, cutting down electricity consumption significantly.

5. Sustainable Water & Waste Management for Energy Conservation

- Rainwater Harvesting & Grey water Recycling: Reduces dependence on energy-intensive water supply systems.
- Decentralized Wastewater Treatment Plants (DEWATS): Minimize energy consumption in large-scale sewage treatment.
- Waste-to-Energy Initiatives: Organic waste from residential areas is processed to generate bio energy.

6. Energy-Efficient Public Infrastructure within Housing Clusters

- LED Streetlights with Smart Controls: Adaptive brightness based on occupancy and natural light conditions.
- EV Charging Infrastructure: Reduces reliance on fossil fuels and promotes clean mobility solutions.

Impact & Outcomes

- 15% average reduction in residential utility bills.
- 40% energy savings in public lighting.

Fig. 7: Vanke Zhejiang Residential Project [7]

- 20% water conservation due to smart monitoring.
- Increased reliance on solar energy, reducing grid dependency.

Case II : Prefabricated Housing in China

China's rapid urbanization has driven the need for efficient and scalable housing solutions. Prefabrication has been adopted extensively to meet this demand, with several large-scale projects demonstrating its potential.[7]

Technological Implementation

1. China Vanke Prefabrication Initiative: Vanke, one of China's largest property developers, has embraced prefabrication to construct residential buildings. Factory-produced modules are assembled on-site, significantly reducing construction time and labor costs. The "Zhejiang Residential Project" completed in 2019, utilized 90% prefabricated components, cutting build time by half compared to traditional methods.
2. Green Building Standards: Vanke integrates green building practices in its prefabricated projects, using recycled materials and energy-efficient designs. Solar panels and rainwater harvesting systems are standard in these developments, reducing environmental impact.

Impact on Housing

The prefabricated housing projects have improved affordability by lowering construction costs. The streamlined construction process ensures consistent quality and durability. Moreover, the modular nature allows for customization to meet varying residential needs, catering to different income groups.

Socio-Economic Benefits

Prefabrication has stimulated the local economy by creating a demand for skilled labor in manufacturing and assembly. The technology also addresses the housing shortage in urban areas, providing quick and efficient solutions for growing populations.

Case III : Passive House Projects in Germany

Germany has been at the forefront of energy-efficient housing, with the Passive House standard setting benchmarks for thermal performance and energy consumption. These projects emphasize reducing the ecological footprint while ensuring comfortable living environments.[3]

Fig. 8: Kranichstein Housing, Germany [3]

Technological Implementation

1. Energy-Efficient Design: Passive Houses use super-insulation, airtight construction, and heat recovery ventilation systems to minimize energy loss. High-performance windows and thermal bridge-free construction are essential features.
2. Renewable Energy Integration: Many Passive Houses incorporate solar panels and geothermal heating systems, further reducing reliance on non-renewable energy sources. The "Bahnstadt" district in Heidelberg, entirely built to Passive House standards, showcases the integration of renewable energy in urban housing.

Impact on Housing

The energy efficiency of Passive Houses results in significantly lower utility bills, with some homes achieving near-zero energy consumption. The comfort and air quality are superior due to controlled ventilation and stable indoor temperatures, enhancing resident well-being.

Socio-Economic Benefits

The adoption of Passive House standards has driven innovation in the construction industry, promoting the development of new materials and techniques. It has also led to the creation of specialized jobs in energy-efficient construction and retrofitting.

SOCIO-ECONOMIC IMPACTS

Cost Reductions

Technological advancements in mass housing result in significant cost savings. Prefabrication and modular construction reduce labor and material costs, while smart technologies lower operational expenses. For example, the "Lendlease" project in Australia reported a 25% reduction in overall costs due to the use of advanced construction techniques and energy-efficient systems. These savings make housing more affordable and accessible, particularly in regions with acute housing shortages.

Enhanced Construction Timelines

Innovations in construction technology dramatically reduce build times. The "Broad Sustainable Building" in China, a 57-story skyscraper constructed in just 19 days using modular techniques, exemplifies the potential for rapid urban development. This capability is crucial in responding to natural disasters or sudden population surges, where quick and efficient housing solutions are essential.

Improved Housing Quality

The use of technology in mass housing enhances build quality, ensuring that structures are more durable, energy-efficient, and comfortable. Smart building systems improve indoor environmental quality (IEQ) by monitoring and adjusting air quality, lighting, and temperature. The "Passive House" projects in Germany, which adhere to strict energy efficiency standards, have demonstrated significant improvements in occupant health and comfort.

Resilient and Inclusive Communities

Technological integration in mass housing fosters resilient and inclusive communities by improving access to essential services and enhancing social connectivity. The "Favela-Bairro" project in Brazil, which integrates smart infrastructure with social programs, has empowered residents and improved living conditions. These initiatives highlight the role of technology in promoting social equity and resilience in urban areas.

CHALLENGES AND FUTURE DIRECTIONS

Challenges in Technological Adoption for Mass Housing

Despite the numerous benefits, several challenges hinder the widespread adoption of technology in mass housing. These include high upfront costs, regulatory hurdles, and the need for skilled labor.

- **High Upfront Costs**

  The initial investment required for implementing advanced construction technologies such as smart systems can be prohibitively expensive, especially in regions where affordable housing is most needed.

- **Regulatory Hurdles**

  Outdated building codes and zoning laws can slow down the adoption of new technologies, requiring significant regulatory adjustments to accommodate innovative construction methods.

- **Skilled Labor Shortages**

  The integration of advanced technologies necessitates a skilled workforce capable of operating and maintaining these systems. The current skills gap poses a challenge in ensuring efficient project execution and long-term maintenance.

- **Data Security and Privacy Concerns**

  The increasing use of connected devices in smart housing systems raises potential risks related to data security and privacy. Ensuring robust cybersecurity measures is critical to protecting residents and maintaining trust in these technologies.

Future Directions in Mass Housing Technologies

The future of mass housing is being shaped by the integration of AI, machine learning, and sustainable technologies, which promise to revolutionize how housing is developed and maintained.

- **AI and Machine Learning in Housing Operations**

  AI-driven analytics and machine learning algorithms can optimize building operations, predict maintenance needs, and enhance energy management, making housing developments more efficient and cost-effective.

- **Decentralized Energy Systems**

  The development of microgrids and renewable energy sources like solar panels is set to enhance the resilience and sustainability of mass housing projects, reducing dependency on centralized power systems.

- **Sustainable and Biophilic Design**

  Incorporating biophilic design elements such as green roofs and vertical gardens will not only improve the living environment but also promote urban biodiversity, contributing to healthier and more sustainable urban areas.

- **Enhanced Urban Resilience**

  Future housing developments will focus on creating resilient communities that can adapt to environmental challenges and changes, ensuring long-term sustainability and improved quality of life for residents.

  By overcoming current challenges and embracing these forward-looking strategies, the mass housing sector can deliver scalable, efficient, and sustainable housing solutions to meet the needs of rapidly growing urban populations.(11) Ministry of Housing and Urban Affairs, Government of India has identified and constructed six Light house projects at various places in India with different technologies for mass housing under global housing technology challenge.(12)

CONCLUSION

Technological advancements are revolutionizing mass housing, offering scalable, efficient, and sustainable solutions to urbanization challenges. Innovations such as smart building systems, prefabrication, BIM, and advanced materials are transforming how housing is designed and constructed, leading to significant improvements in cost, time, and resource efficiency.

Smart technologies enable real-time monitoring, optimizing energy use, enhancing security, and improving building operations. Prefabrication and modular construction reduces time and costs, minimize waste, and allow for scalable, flexible designs. BIM enhances collaboration and resource management, streamlining project execution.

These technologies address immediate housing needs while fostering long-term sustainability and resilience. As the construction industry evolves, integrating these innovations will be crucial for creating inclusive, adaptable, and sustainable urban living environments.

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INNOVATIONS IN BUILDING CONSTRUCTION

Dr. K.M. Soni*

Abstract

Innovation is a key driver of progress in every sector so also in the construction industry. In construction industry, innovation is sought in various fields such as materials, methods, and processes to make the buildings efficient, sustainable and cost effective.

Innovation in construction techniques becomes essential for safety, sustainability, and speed. The use of off-site prefabricated and 3D modular and 3D printing construction is going to replace most of the traditional construction. Monolithic construction using innovative formwork and walling system will replace traditional steel and plywood formwork.

Sustainability is another key area of innovation as the construction has a significant impact on the environment. Use of more and more renewable energy sources, sustainable materials and methods involving low carbon or zero carbon emissions, creation of green infrastructure is essential.

Since both natural and manufactured materials are utilized in the construction, innovation is taken up on substituting natural materials with manufactured sustainable materials. Use of recycled construction and demolition (C&D) waste, stamped concrete, use of bamboo, pollution absorbing bricks, and stubble-based materials are innovated materials in new future.

Information technology and Artificial Intelligence (AI) will also enter into the construction sector. Use of drones, BIM, robots, and AI techniques will modernise project management for higher productivity and efficiency.

INNOVATIVE CONSTRUCTION TECHNIQUES

Innovative construction techniques for construction of mass housing include monolithic construction using new types of formworks such as jump formwork, aluminium formwork, and tunnel formwork, off-site construction using prefabricated structural components and 3D modular construction, light gauge steel framed system, sandwich panel system, stay in place formwork, and 3D printing construction techniques. Soni (2023) has described such techniques except 3D printing technique.

3D Printing Construction

3D printing technology has a robotic concrete printer operated through a computer aided design (CAD) that can construct a house as such suitable for individual houses and mass housing. Due to use of CAD, it enables the creation of complex designs and shapes with precision and efficiency, based on digital models. The technique has an edge as every individual has a dream of constructing the house as per his own design and wants to see it virtually before its construction for the modifications and construct exactly as per the choice at the earliest. 3D printing construction technique prints the house on site according to the digital model with the appropriate durable materials in very less time. The technique will ease the construction process with precision, reduce construction time, labour cost, and construct the house exactly as per the requirement which would be ready without any delay and cost overruns. 3D printed house would be like the one purchased from the catalogue but modified as per one's modifications.

*Former ADG, CPWD, New Delhi

3D printed houses are not now the dream as L&T has completed seven projects with a built-up area (BUA) of approximately 1.13 lakh sqft, including a 50,000 sqft building for the Ministry of Defence in Chandigarh. As per L&T, a villa project that would typically take 24 to 36 months can be completed in 12 months by using 3D printing technology, also reducing wastage and electricity consumption (Fig.1).

This technique is being currently used to construct low-rise buildings however in future higher-level buildings will also be feasible. Advantages of 3D printing technique are faster and precise construction, innovative and complex architecture with owner's own design choice and likely being cost effective.

Pre-fabricated (Offsite) Construction

Offsite construction makes the construction process more efficient, quality-driven and faster particularly

3D printing construction technology

LHP Chennai with pre fab components

LHP Ranchi with 3D modular components
LHP construction with LGFS infill walls

befitting for repetitive sections required for mass housing to take cost advantage of economy of scale. In future, even non-repetitive sections would be feasible with CAD. Offsite construction shifts most of the site activities to the factory and thus is faster and qualitative. Another reason of selection of pre-fab construction may be restriction of deployment of machinery either due to space or noise constraints or site restrictions due to air pollution. In future, offsite construction is likely to be taken up at large scale to prevent air and noise pollution at construction sites in brown field areas.

Pre-fab construction uses structural components like beams, slabs, columns, staircases, walls etc or 3D modules like kitchen, toilet, rooms assembled at site through cranes. In both the systems, casting od components is done in the factory or casting yard under controlled environment, transported to the site and placed at the required locations. For cost optimization, structural components are standardized. The system requires small cast in situ work, particularly at the connections. Advantage of the pre-fab construction is that the components can be casted in advance or simultaneously to the necessary design work and casting of the foundation. Since the concreting to be done at site is minimal, speed of work is very fast. Economy of scale and speed help in achieving cost economy of the project.

Prefab construction is taken up with steel, RCC and a combination of both. Ministry of Housing and Urban Affairs through BMTPC had taken up pre-fabricated concrete construction in the light house project (LHP) of Chennai for construction of 1152 houses in 12 towers of six floors and 3D volumetric construction for construction of Ranchi LHP having 1008 houses in 7 towers of 9 floors each.

Light Gauge Steel Framing (LGSF)system is another system made of thin gauge cold formed steel structural frame for pre-fabricated structure used in Agartala LHP for construction of 1000 houses in 7 towers of 7 floors each however only for infill walls. The components of the frame are fabricated in the factory, brought at site and erected on the foundation at the site. Once the walls are ready, they can be cladded with light-weight materials.

Innovative Formwork

To optimise the time and cost particularly for repetitive housing, innovation of formwork has been made. Innovative formwork includes aluminium formwork, and tunnel form work for monolithic construction.

- **Aluminium formwork**

Aluminium formwork made of high strength aluminium alloy is light weight, easy to lift and erect by an individual worker for monolithic concrete construction in which walls and slabs are cast monolithically. The formwork elements can be used for more than 250 repetitions.

The formwork panels are held in position by pin and wedge arrangement system requiring no bracing. The walls are held together with wall ties, while the decks are supported by beams and props. All panels are labelled for easy identification at site. The system consists of beam components, deck components, wall components and other components. The formwork is designed based on requirements of dwelling units of the project. The system usually follows a four to eight days cycle depending upon the project.

Advantages of monolithic construction using aluminium formwork is placement of the formwork does not require heavy machines/cranes resulting into speedy construction, is of good and consistent quality, has better seismic resistance and durability, and results into time saving and higher carpet area within the same plinth area due to less thickness of RCC walls. Limitations are that post construction changes are not feasible, has less insulation, requires all the services to be planned in advance which cannot be changed at a later date, and unsuitable for large modules. A lot of construction is being taken up in the country with such formwork in government and private sectors.

- **Tunnel formwork**

Another innovative formwork is tunnel formwork which comes in two half units of the form of inverted

"Ls" which on bolting together at the top form a tunnel. The inbuilt wheels and the jacks help the formwork move in and out of the position and are adjusted to the final height.

The formwork, made of steel is usable up to 500 times suiting to a variety of module sizes. The construction is faster with the tunnel formwork to the extent that

even a 24-hour construction cycle can be achieved. Advantages are of similar to aluminium formwork however finish with the tunnel formwork is very good and joints are less in number. Limitations are that such formwork requires use of cranes, the layout of building has to be in conformity to box type structure and one side walling generally front is left during monolithic casting for removal of formwork which is to be taken up with traditional construction.

INNOVATIVE WALLING SYSTEMS

Stay in Place formwork

The formwork system comprises of two light weight formwork panels on both the faces of the walls which may be of EPS boards, grids made of rib mesh, PVC panels, light weight metal etc., generally separated by stiffeners, with the steel reinforcement provided in the wall, in which concrete is poured in-situ. Since the formwork is not removed, it is known by different terms like stay in place formwork, sacrificial formwork, lost in place formwork etc. The construction is suitable for low rise structures as load bearing otherwise such a system is used for infill walls replacement of brick/block work in RCC framed or steel framed structures. Advantages are that the structure is light weight, energy efficient, faster, with easy handling of the panels.

Formwork with Sandwich Panel System

Sandwich panel system comprises two outward face sheets and a core material, out ward face sheets made of robust materials like metallic sheets or concrete and the core material, often a lightweight material like closed-cell foam or honeycomb cores, made of EPS, PUF, rock wool or similar materials. Sandwich panel construction is used for low rise structures or for infill walls in multi-storeyed construction. The sandwich panel system has been used for filler walls with steel framed structure in Indore LHP for construction of 1024houses in 8 towers of 8 floors.

DRONES AND ROBOTICS

Drones are being used for surveying, site inspections, and progress and construction monitoring. These are also used for quality and safety monitoring, providing real-time data and details in project management, and topographic mapping. In future, drones are going to be used more and more activities in construction sector. All major agencies and NHAI are using drones in their projects.

Use of robots is gaining popularity in civil engineering fields, particularly at sites involving risks such as railway tracks, underground structures, dams and tunnels, electric lines, nuclear structures, roads and buildings, sewer lines, and in demolition and rescue operations. They can also be used in crack sealing, pothole repairs, paint marking, resurfacing, and kerb and drain construction, welding, grinding, cleaning, plastering and painting, where such operations are difficult for human beings. In building construction and maintenance, robots have large applications, particularly in repetitive activities and dangerous conditions like external finishing in high rise buildings, bricklaying, steel columns welding, casting of prefabricated/precast modular members, pipe fitting, deep sewer line inspections, and cleaning. In nuclear installations, robots have large applications during operation and maintenance of nuclear facilities and laboratories, nuclear reactors, decommissioning and dismantling of nuclear reactors, and emergency conditions.

Advantages

i. Improvement in work quality, efficiency and productivity

ii. Consistency, accuracy and human safety

iii. Reduction of labour cost and time saving

INNOVATION IN GREEN MATERIALS AND GREEN CONSTRUCTION

Since construction sector consumes large natural resources and carbon emitting resources, zero net carbon buildings are being planned and constructed to reduce CO2 emissions to attain sustainability by way of providing natural ventilation, reflective surfaces, energy efficient electric fittings, low flow faucets, onsite energy production from renewable sources such as solar and wind, and by using low carbon emitting construction building materials and equipment. Many organizations are involved in auditing and rating the green buildings. Now, emphasis is being given to construct net zero carbon buildings.

Concept of green buildings was based on use of green material or green technique over non-green material or technique however due to more and more green materials and techniques being invented, the concept is now to be shifted on more greener materials and techniques. Finally, those green materials and green techniques are to be preferred over others which have zero carbon emissions or near zero carbon emissions during their production as well use.

ARTIFICIAL INTELLIGENCE–INNOVATION IN DIGITAL TRANSFORMATION

Artificial intelligence (AI) is going to enter almost in every field so also in construction sector. Some of the identified sub domains include resource optimization and waste utilization, estimation and scheduling, construction site analytics, supply chain management, HSE (Health, Safety and Environment) analysis, contract management, communication and voice user interfaces, quality and audit system, and construction of AI driven prefabricated offsite construction.

AI can help in analysing and selection of appropriate design, materials, and processes in short time based on their availability, optimum cost, recyclability, and sustainability. Use of advanced AI techniques with

BIM can also be used for many civil engineering applications. The cost of a project depends upon many factors like design, selection of materials, processes, specifications, and scope of work. Any change in the same changes the cost. Therefore, BIM and other AI based techniques will provide updated cost immediately on change of any of the parameter affecting the cost. During rescheduling of any activity or deviations during execution, AI based techniques can provide updated estimated cost immediately on real time basis. Even today, various models of BIM are available which integrate time, cost, sustainability, facility management, HSE (Health, Safety and Environment) and lean construction in the geometry. AI will also enable to select best suited materials and methods for preparing the cost estimates and will go on rescheduling time and costing automatically based on the automated inputs, and even helping in monitoring and decision-making process during execution by providing cost of variations. Deep learning techniques can also aid in better predictions of financial resources, energy efficiency, water and waste efficiencies and even carbon footprint updates. In case of off-site construction, AI will be more useful with regards to selection of the materials and processes, reuse and recovery, and waste-efficient procurement.

AI techniques will enable smart working and smart supervision at all the places simultaneously, integration of IoT sensors and other digital instruments and equipment resulting into quality, safety and higher productivity. A repository of design data, costing, specifications, contract data, accounts and financial resources, and thereafter generation, collection, storage and analysis of site data will provide deep insights for visualisation, monitoring and future modelling. Through AI techniques, a large volume of images, videos and other forms of data can be generated, compared, modelled, and used on construction sites and for future projects through the analysis being made from a faraway place in the office. AI techniques will thus optimise site performance in all key areas such as planning, design, safety, quality, schedule and cost.

AI will benefit SCM in timely placement of orders, timely transportation, working and replacement at site simultaneously with minimum storage for which data may already be available in the repository. In prefabricated construction, AI will further be very useful as this will integrate design of mix, materials, sustainability, machinery requirement, processes, quality, HSE, storage of raw materials and finished products, their transportation and assembly at site, IoT-based real-time monitoring, risk involved, and cost implication for better decisions.

Safety during construction and maintenance of high-rise structures and skyscrapers due to requirement of working at heights may essentially require use of AI based technologies in future and robots may gradually take over risky construction and maintenance in such conditions. Similarly, environment affected due pollution of air, water and noise has to be monitored strictly as per the legal requirements. Use of advanced data analytics techniques of AI can predict its levels through which preventive measures can be taken. Data from different digital technologies like IoT sensors, UAV, CCTVs, digital photos, videos, plant and equipment and other IoT based devices at site can also be linked to control room, located at a desired place.

At present, with manual control, it is difficult as a contract involves bulky and multiple conditions, even duplicity of items and conditions. Sometimes, various sub-contracts are also included where co-ordination and time management become major issue leading to litigation costs, claims, project delay and loss of reputation as present contracts are heavily dependent upon on human intelligence, efforts and interpretation. Automation of the contract management system with AI will help in augmentation of the efforts and memory of contract managers for curtailing such mistakes and risks. Another challenge in the contract management is measurements of thousands of items in a complex and high-rise construction project involving multiple services and new and innovative materials whose specifications are to be referred each time. In such cases, AI tools and techniques will help in contract management and better implementation. Further, AI will help to retrieve the data and information which can also be linked to the quality standards, acceptance criteria and resulting cost adjustments.

Thus, AI will help in productivity enhancement, efficiency, quality improvement, creative, efficient planning and design, progress monitoring, safety and contract management.

INNOVATION IN BUILDING MATERIALS

Recycled C&D Waste Materials

Recycling Construction and Demolition (C&D) waste materials is now common in many Indian cities which produce recycled sand, recycled aggregates (RA), recycled concrete aggregates (RCA) and filter press material from mix of soil, brick masonry and cement concrete waste. Though BIS restricts the use of recycled products in limited way, in future recycled sand and RCA are going to find place in almost all types of RCC works and RA in various applications of road works like GSB and low-grade concreting. It is also likely that recycled sand finds place in part replacement of cement during its manufacturing process.

Recycled Sand

Recycled Concrete Aggregates (RCA)

Recycled Aggregates (RA)

Filter Press Material

Stamped Concrete

Stamped textured or imprint concrete is being used in the country in flooring, replacing tiles and other materials. It is a decorative concrete, used in flooring from which large number of finishes can be achieved in desired colours with the surface resembling bricks, stones, tiles or wood. The process includes preparation of sub-grade, placing of forms, providing reinforcement for stability, placing the concrete, screeding and finishing the concrete, applying colour and lastly, stamping the concrete using desired moulds. Thus, stamped concrete can be used for functional and aesthetic purposes, saving the natural stone.

Stamped Concrete

Bamboo in Structural Elements

Seasoned and well-treated bamboo is going to make an entry in built environment as the reinforcement, particularly low-rise buildings as it has adequate strength, is nature friendly and energy efficient material. Researchers have already started work on using group of bamboos as beams and also as a reinforcement in RCC work.

Pollution Absorbing Bricks

Pollution absorbing bricks contain a special coating helping to neutralize air pollutants, transforming smog into harmless compounds through a photo catalytic process, thus, helpful in use as cladding material or exposed brickwork in smog intensive cities.

Use of Bamboo

Stubble Ash in Concrete and Cement

In future, research may also be carried out for using stubble ash in mixing cement and concrete to improve concrete strength and other properties of concrete like rice husk.

CONCLUSION

Innovation in civil engineering has become a necessity as time has become an important component of the project management. Therefore, innovative techniques reducing the construction time will gain importance, particularly those being energy efficient and sustainable. Energy efficient and sustainable offsite construction techniques will be used more in future. Some of the futuristic potential technologies are 3D printing technology, 3 D modular construction, pre-fab concrete construction, modular walling materials, robotics and AI driven project monitoring and execution tools. Need will also be felt to integrate these trends of innovations with capacity building.

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PRECAST CONCRETE FOR SUSTAINABILITY: A GLOBAL SOLUTION FOR BUILDINGS & INFRASTRUCTURE

Vinay Gupta*

Abstract

Precast Concrete has been found to be extremely useful product, as it provides a perfect combination of speed, quality, durability and aesthetics. Be it a building or a bridge or, for that matter, any structure. While buildings were known to incorporate elements like pre-tensioned hollow core slab units, RCC Double-T units, Inverted Channel units, etcetera, bridges make much more intensive use of precast concrete for superstructures, sometimes even piers of bridges. Even elevated metro stations use precast RCC or Pre-stressed concrete for concourse slabs, platform slabs, track supporting slabs, cross-heads, etcetera. Similarly, underground metro stations use precast concrete for OT Ducts, platform slabs, etcetera. Precast Pre-stressed roof trusses were, perhaps, used for the first time in India for a factory building. In bridges life seems impossible without precast concrete. A public structure like a flyover or a bridge needs to be completed at the fastest pace possible, because the running traffic can not be made to suffer for long. Precast segmental Bangalore Elevated Expressway has entailed a speed of 2 ½ days per span of superstructure with each launching girder. It becomes equally important to manufacture precast concrete segments in the pre-casting yard. For this purpose, Long Line method and Short Bench method of pre-casting are usually employed. However, precast segmental construction requires a lot of care in the construction process.

INTRODUCTION

India is going through a phase of rapid development, wherein the industrial as well as construction of infrastructure projects such as roads and metro structures has picked up pace in many cities. India has been able to produce excellent examples of industrial structures, corporate buildings, residential buildings, bridges, flyovers, elevated viaducts, metro structures, etc. India has taken a giant leap in the field of structural engineering over the past 15-20 years. Such structures demand a speedy construction to minimise the traffic disturbance being located in urban habitat. Precast concrete being reasonably cheap and versatile material, is found to be the most appropriate choice of the engineers. Samtel Color Ltd has made an extensive use of Precast PSC roof trusses for a factory building, making it possible to construct 25,000 Sqm factory in mere one year. Use of pre-casting has also been made for façade elements of multi-storeyed Infosys parking building at Bangalore. Similarly, precast pretensioned hollow core slabs are in vogue in many residential buildings. Precast PSC (pretensioned and post-tensioned) have been successfully employed for construction of many elevated metro stations, especially over the running road.

**Managing Director, Tandon Consultants Pvt. Ltd. New Delhi.*

USE OF PRE-CASTING IN BUILDINGS

Factory Building

When an entrepreneur is planning to manufacture something new, he needs to bring the product into the market soon to have edge over others. Also, he starts earning early. Hence, for an electronic factory of Samtel Colour Ltd for manufacturing of TV colour picture tubes the author designed a concrete factory building. One may wonder why concrete, why not steel shed. An electronics factory building requires air-conditioned areas and dust control such as class 10000, class 1000, etc. Even though the initial cost of the precast concrete factory building was more compared to a similar steel shed, the life cycle cost of concrete was lesser due reduction in air-conditioning load. In order to complete it in a time equivalent to a steel building, roof was designed to be in precast post tensioned concrete trusses of 25m span spaced at 10m with precast inverted C-shaped RCC roof units. This resulted into a total construction time of mere 11 months for the 25000 Sqm building, figures 1 & 2. Being in concrete the building is more durable. The higher earthquake force due to a larger inertial mass was taken care of by providing elastomeric bearings between 10m high columns and the PSA roof trussed. This provision reduced the seismic force to nearly half.

Fig. 1: PSC roof trusses of Samtel Color Ltd Factory Building

Fig.2: Elastomeric Bearings between Roof Trusses and Columns to reduce Seismic Force

FAÇADE OF A MULTI-STORIED PARKING BUILDING

It has been reported that multi-storied parking building of Infosys has been provide with fancy façade with the elements made out of precast concrete elements with an excellent aesthetics, Figures 3 & 4.

Fig.3: Façade of multi-level car parking building: aesthetics possible only in precast

Fig. 4: Another view of facade of multi-level car parking building

PRECAST ELEVATED STATIONS FOR METRO

An example, where pre-casting has been used to a large extent is of several stations of Delhi Metro, figures 5 & 6. Here, the transverse beams at concourse level are made into Precast Post-Tensioned concrete L-beams (2 parallel beams at each pier location). These beams receive Precast-Pretensioned Concrete Double-T units (topped with Cast-in-Situ RCC) to act as slab & beam in longitudinal direction. Such Double-Tee units were also used at platform level. Even the Cross-head (pier cap) is made out of Precast Post-Tensioned Concrete, connected to the central row of piers with the help of vertical pre-stressing cables. In order to keep the weight of precast Cross-Head low for lifting ease, it was divided into two parallel units. In these stations, except for foundations and sub-structures almost everything is made in precast concrete. The structural concept resulted into speedy construction and highly reduced distribution to the running traffic during construction.

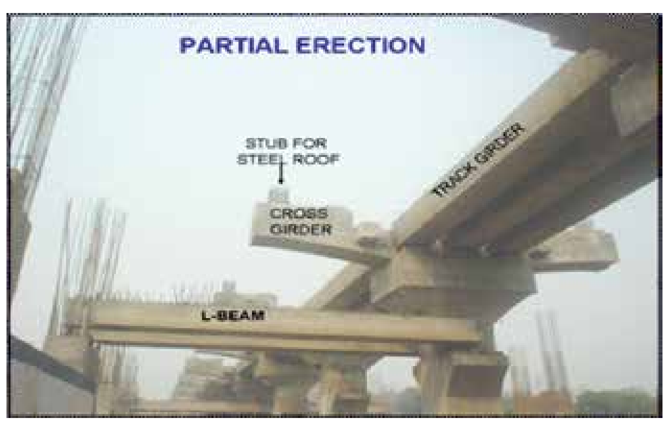

Fig:5. Construction of Precast Stations

Fig. 6: Precast Stations of Delhi Metro

OTHER TYPES OF PRECAST MEMBERS IN VOGUE

Precast Pre-tensioned Hollow Core concrete units of slabs are quite in vogue for larger spans and repetitive use in multi-storeyed buildings. These units can be precast much faster than other types of precast structures, because in pre-tensioning Long-line method of casting and pre-stressing is used wherein a row of 8 to 10 slab units are cast & pre-stressed in a long line operation. In order to facilitate pre-tensioning the pre-stressing strands are stressed using strong abutments on both sides before pouring the concrete. Once the concrete attains requisite strength, the pre-stressing force is transferred to the concrete slab. Such precast units require suitable jointing mechanism at supporting beam locations, figures 7 & 8. Similarly, precast pre-tensioned railway sleepers are manufactured for speed & quality.

Fig.7: A view of precast pre-tensioned hollow core concrete slab units

Fig.8: Abutments for stressing of pre-tensioning of strands

USE OF PRE-CASTING IN BRIDGES

There are several methods of constructing precast segmental concrete bridges. Some of them are as follows:

CONSTRUCTION USING OVERHEAD LAUNCHING GIRDER

Simply supported span made continuous

Bangalore International Airport (BIAL) Flyover is midway through the construction. It has two nos 4 lane each carriageway superstructures. Each one is constructed as simply supported 40m span (temporarily resting on steel stools) made continuous 320m long to rest over Spherical Bearings. Apart from shorter cables, it also has 4 nos 320m long cables of 27K15 size. Every span has two cast-in-situ stitch segments. Fig. 9 & 10 depict the construction using overhead Launching Girder (LG). Overhead LG usually entails higher speed of construction.

Fig.9: Steel supports for temporarily simply supported spans of bial flyover

Fig. 10: Construction of 320m long 8 span continuous bial flyover using overhead LG

AESTHETICS IN PRECAST SUPERSTRUCTURE

In the project of Wazirabad Approaches to the Signature Bridge in Delhi, comprising 4 span continuous precast segmental integral modules. These spans are constructed as simply supported spans on temporary steel supports, later made continuous integral through cast-in-situ concrete stitch, figure 11. Since, the end supports attract larger longitudinal movements due to temperature, creep & shrinkage, these have been provided with 600mm wide integral end piers with heavy reinforcement. All such piers incorporate SCC poured in single stage into the full height shuttering. The outer precast element has been shaped in such a way that it is narrower & thicker on the lower side and wider & thinner on the upper in order to provide an unique aesthetics to the superstructure.

Where it is not feasible to achieve concrete compaction through needle vibrator due to narrow concrete section and/ or congested reinforcement, solution lies in incorporating Self Compacting Concrete (SCC). Essentially, SCC incorporates larger percentage of fines and super-plasticisers. In order to maintain cohesivity of the mix, viscosity modifying agent (VMA) is added. As a result, we get slump / spread of 600 mm+, making it possible for the concrete to flow by itself and have self-compacting properties.

Fig. 11: Approaches to Signature Bridge, Delhi

USE OF PRECAST CONCRETE STRUTS WITH PRECAST SEGMENTS

Figures 12, 13 & 14 depict a high speed of construction of 57km long elevated viaduct of Bangna Bangpli Bangpakong Expressway (BBBE) in Thailand. Both up and down carriageways requiring 27m wide single box girder superstructure has been launched using specially designed Under Slung Launching Truss. The superstructure comprises Dry Jointed Precast Segmental Superstructure employing External Pre-stressing. The system entails a very high speed of construction. Even the elevated Toll Plazas have made use of up 6 nos. parallel precast segmental box girders for width up to 80m. The use of internal precast concrete struts makes it feasible to provide single cell box making the construction easier.

Fig. 12: BBB Expressway, Bangkok

Fig.13: BBBE: launching of 27m wide segments

Fig. 14: Precast Segmental Structure of Elevated Toll Plaza

CONSTRUCTION USING UNDERSLUNG LAUNCHER GIRDER FOR PRECAST SUPERSTRUCTURE

Another system is the type shown in figures 15 & 16, which uses a self-launching type under slung launching girder. (approximately 2 ¼ span length) as used for Delhi-Noida bridge, wherein 13 spans of 42.5m each, making a continuous superstructure of approximately 550m were constructed. Here, the segments were fed through a 64 wheel low bedded trailer plying over the previously constructed deck. These are picked up by a cantilevering portal in order to place it on trolleys resting over the under slung launching girder. This type of system may be faster but it is suited to straight or near straight spans only.

Fig.15: Self launching type under slung launching truss

Fig. 16: Handling of segments on under slung launching truss

USE OF ARTICULATED UNDERSLUNG LAUNCHING GIRDER FOR CURVED SPANS

Another interesting system of under slung launching girder uses mid span articulation to negotiate the plan curvatures, as depicted in Figures 17 & 18. This system has been successfully used for 26 km long LRT System 2 in Kuala Lumpur, Malaysia over 10 years ago, wherein Dry Jointed Precast Segmental Superstructure using External Prestressing was used.

Fig.17: Articulated under slung launching girder

Fig. 18: Handling of segments : LRT Kuala Lumpur

PRECAST CONSTRUCTION USING GROUND SUPPORTED STAGING

Under slung assembly system of assembling and pre-stressing the segments has been used in several important bridges and flyovers. In this arrangement the assembly truss is located below the segments, wherein the segments may either be supported through the flange (cantilevering deck slab) or through the soffit slab. Former being more often employed, has the advantage that larger vertical clearance below the assembly truss for the traffic movement during construction is available. But, it entails a larger barricading width. It is worthwhile to mention here that the cantilever slab would require extra bottom reinforcement in order to be able to carry the segment weight.

This type of Under slung Launching Truss system is suited to sharp plan curvatures, where long straight launching truss cannot negotiate the curves, due to the transverse offset, that is created between the arc of the bridge centre line and chord line of the launching truss. In this system, short span straight segments of steel girders / trusses of 6m to 8m are placed over steel trestles resting over temporary spread footings at ground level. These straight girder segments negotiate the curvatures with kinks at their junctions. Over these girders, a set of jacks and trolley for manoeuvring the segments longitudinally, transversely and vertically, including the movement for dry matching is provided, figures 19 & 20.

Fig. 19: Under slung launching truss with straight segments

Fig. 20: Supporting system of precast segments

This type of under slung system is slow but, it makes it feasible to construct segmental superstructures in as sharp as 70m radius of plan curvatures. However, a caution is made to ensure that nobody disturbs the supports of the temporary steel trestles supporting the underslung launching trusses. In this system, the precast segments can either be fed from the forward end, which takes more time to slide the segments back or from sides, if space is available, entailing a faster construction. In another system of feeding of segments, overhead Goliath Crane is provided, which makes it faster to move the segments

PART SPAN PRECAST CONSTRUCTION FOR SPEED OF 8 SPAN CONTINUOUS SUPERSTRUCTURE

Superstructure of the elevated viaduct comprises 30 nos. of 262 m long continuous superstructure modules, resting over POT bearings over the respective pier caps, figure 21. Analysis & design of superstructure had to account for the stages of construction decided for the superstructure. Hence, it became prudent to discuss with contractors as to the construction methodology. There were mainly two ways of constructing continuous superstructure. One was to construct simply supported spans resting over pier caps including pre-stressing of individual spans. Thereafter casting the stitch segment over the pier and stressing integration cables. This option would cause larger sagging bending moments during construction, usually leading to uneconomical structure. The other option was to construct 1¼ span, then ¾ & ¼ span and so on and ¾ span at the end. Thus construct the eight spans in eight stages and prestress selected top and bottom cables at each stage. This option was found to be more efficient and was chosen for the project.

Shape of the 16 m wide box girder was chosen to be a 2 cell box in order to avoid second operation of transverse pre-stressing of deck slab, figure 22. The box cross section was suitably shaped for an acceptable architectural form simultaneously giving due regard to structural behaviour. Speed of superstructure construction, this way, turned out to be about 3 ½ days per span per LG. The segments were provided with high strength rubber liner in order to achieve enhanced aesthetics. Drainage water pipe was passed through the pier diaphragm at transverse centre of the box girder, for enhanced aesthetics. For pre-casting of segments, Short Bench method was used, figure 22. Each pre-casting bed gave a time cycle of 1 ½ days per segment per bed.

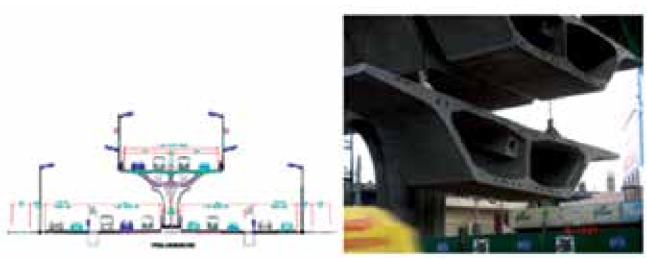

Fig. 21: GAD of Bangalore-Hosur Elevated Expressway

Fig. 22: Outer shutter during precasting

The overall operation of LG comprises the following: (i) placement of a bracket and pier frame on the forward side pier and supporting the LG on the same, figure 23. (ii) Lifting and placing of respective pier segment over temporary hydraulic-screw locked jacks over the forward pier cap. (iii) Placement the LG over this pier segment, figure 24. The pier frame becomes redundant at this stage and can be taken to the next pier. (iv) Erect the segments of the respective ¾+¼ span.

After this operation, Epoxy Bonding Agent is applied to the segments one after the other and temporary pre-stressing of 0.3 MPa imported in the same sequence. Once the entire span length is applied with Epoxy Bonding Agent and temporary pre-stressing applied, the permanent pre-stressing is applied and temporary pre-stress demobilized. At this stage, the LG is ready to move for the next span launching.

Fig. 23: Launching Operation

Fig. 24: Pier Frame & Bracket

PRECAST SEGMENTAL CANTILEVER CONSTRUCTION

At times special considerations are required where long span special crossings have to be constructed, such as the ones over roads and over the existing Railway tracks. In the case of Commonwealth Games related project of Barapulla elevated viaduct, 3 to 5 span continuous superstructure modules with up to 84m main span, integral with piers were devised. Integral structure not only helped in avoiding maintenance demanding bearings and expansion joints, it also reduced the requirement of large pier caps and temporary supports to stabilize the cantilevers during construction. The segmental cantilever construction was facilitated using specially designed and fabricated segment launcher, capable of lifting and moving with 100T segment, figure 25. In order to reduce the locked in forces due to creep, shrinkage and temperature variations, that occur in integral bridges, the middle piers were made into twin piers with reduced dimension in longitudinal direction of the bridge. Shape of superstructure, specially the depth, was so chosen that for the large spans, only a few segments near the piers would have deeper and varying depth segments requiring special pre-casting moulds. Others could be casted using regular pre-casting moulds.

Fig. 5 : Specially designed and fabricated segment launcher

PRECAST SPLICED GIRDER SUPERSTRUCTURE

Spliced girder system is also a form of segmental structure. In this system of segmental construction, precast segments of concrete girder (RCC or PSC), smaller than the whole span length are cast, in order to restrict the length and weight of the segments to be handled. These girder segments are placed on permanent piers and temporary steel trestles for assembling through either concrete stitch or epoxy jointing. These segments are then post tensioned to make them a full span or multi span unit, as the case may be. Subsequent to removal of temporary trestles, deck slab and diaphragms are cast. Alternatively, post-tensioning is carried out after casting of deck slab and diaphragm, in which case the temporary trestles are removed later. See figures 26 & 27 for Spliced Girder system.

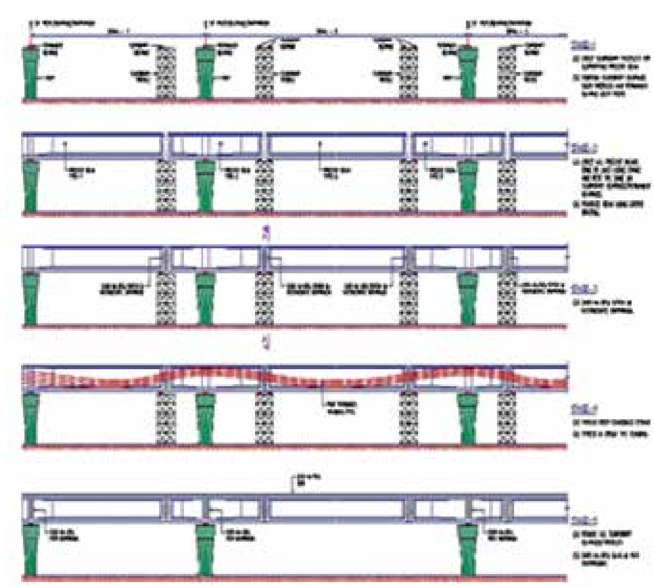

Fig. 26: Schematic view of spliced girder superstructure

Fig. 27: Spliced girders at Cochin international container trans-shipment

PRECAST SPINE-WING SEGMENTAL SUPERSTRUCTURE

This is an upcoming technique of construction, wherein apart from longitudinally, even transversely multiple segments are joined using epoxy or cast-in-situ concrete stitch and transverse pre-stressing, figure 28. This system facilitates use of smaller segments from transportation and handling point of view. In this system, first a spine comprising box girder

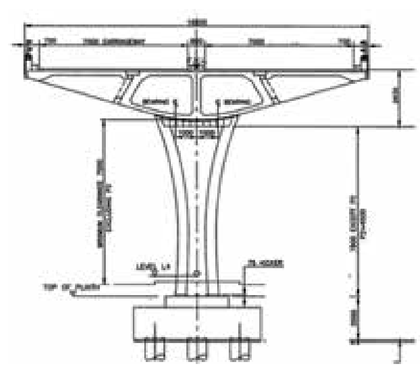

Fig. 28: Typical spine-wing superstructure

segments is erected through epoxy jointing and pre-stressed. Thereafter, transverse wing segments are erected and pre-stressed. This system is equally fast and has the advantages stated above.

METHODS OF PRE-CASTING

Feeding of Precast Concrete Box Girder Segments for the huge construction activity required a proper planning of number and location of pre-casting yards, apart from pre-casting technique, to keep pace with the launching at the site. For the purpose, two commonly known techniques, Long Line Method and Short Bench Method of pre-casting were employed. Figure 29 depicts a Long Line Pre-casting Bed. Figure 30 depicts a method of continuous water curing of segments. Figure 31 elaborates method of multi-tier stacking of segments. The long line method requires longer pre-casting bed, but it makes it easier to handle pre-casting. Figure 32 depicts a method of making a manoeuvrable Long Line bed in order to adjust the segment profile.

Fig. 29: Long line precasting bed

Fig. 30: Curing of segments

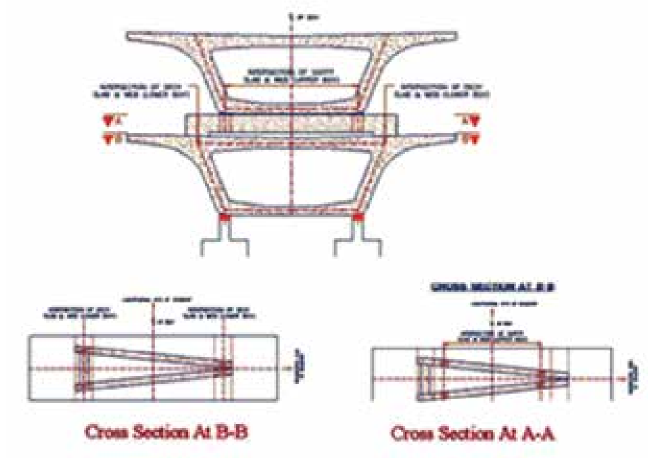

Fig. 31: Two tier stacking of segment

Fig. 32: Modified long line pre-casting method

The Long Line method requires the constructors to replicate the span of a particular construction stage as casting bed, wherein all the segments are cast next to each other by Match Casting technique. The scheme requires more casting space, but it is simpler whereas the Short Bench method requires only two beds. The previously cast segment is shifted away and the main bed cleared for casting of the next segment against the previously cast segment by Match Casting technique. This technique is superior and faster in nature. In this technique, the outer shutter is placed on collapsible platform for easy removal, see figure 33. The inner shuttering is made cantilevering type, which can be inserted into the outer shutter and extracted, easily. The bed at bottom is attached to a shaft, which can pull the bed on rails, after lowering the segment on to the moveable bed. In order to further speed up the process of pre-casting, the entire reinforcement cage of the box girder segment is prefabricated elsewhere in the pre-casting yard and lowered into the outer shutter using a crane, see figure 34. Since, the reinforcement cage is not structurally strong enough to take the handling forces, it is temporarily strengthened using structural steel sections and lifting of the reinforcement cage is spread over 3-4 locations. Figures 35 & 36 depict the arrangement of manoeuvring the segment to transversely & longitudinally to match the required alignment.

Fig. 33 : Internal Shutter on Rail & Counter Weight

Fig. 34: Prefab reinforcement cage transported by 20t gantry

Fig. 35 : Jack for transverse adjustment

Fig. 36 : Jack for longitudinal adjustment

CONCLUSION

A careful planning of erection technique for erection & launching of precast segments for buildings & bridges can lead to desired speed and economics coupled with aesthetics and quality. Speed of construction is of paramount importance because the infrastructure facility is always a prerequisite to development of an area. More so, in the BOT projects, the concessionaire has a commercial stake, wherein he has to start collecting toll as soon as possible. Use of precast concrete makes the structure amenable to better aesthetic appeal, due to better finish and adaptability to innovative shapes. Being a factory like product, the quality & durability, therefore, is generally better.

A SMART SUSTAINABLE SOLUTION FOR SURFACE ILLUMINATION AND INFRASTRUCTURE ENHANCEMENT

PRADIPTA KU PANIGRAHI* AND ANSUMAN KAR**

Abstract

This paper discusses the design, manufacturing process, technical features, applications, and potential impact of Paver 360 in revolutionizing urban and transportation infrastructure. The original research undertaken by CarbonOut is presented to highlight its potential in transforming urban planning and sustainable infrastructure development.

INTRODUCTION

The demand for intelligent infrastructure solutions has increased in the face of urban expansion, transportation challenges, and sustainability goals. Indian Railways and road safety authorities require durable and energy-efficient surface indication systems to enhance commuter safety. Additionally, modern IT buildings, data centres, and office complexes require smart pavers for Wi-Fi connectivity and illumination, helping to break monotony and enhance aesthetics. Traditional solutions such as painted markers, embedded lights, and tactile paving suffer from durability issues, high maintenance costs, and limited effectiveness in adverse conditions. Paver 360 addresses these challenges by offering an advanced, modular, and eco-friendly alternative.

Paver-360 is an innovative smart illuminated paver block designed to enhance safety, navigation, and infrastructure sustainability in railway platforms, roads, and smart city applications. Developed using recycled plastic, the paver integrates LED illumination, solar power, and IoT capabilities.

PROBLEM IDENTIFICATION IN RAILWAY & ROAD INFRASTRUCTURE

Railways and road authorities face challenges such as poor visibility of traditional indicators in extreme weather conditions, high maintenance and frequent replacement costs, a lack of energy-efficient and sustainable solutions, and the growing need for IoT-enabled smart infrastructure to enhance connectivity and data collection. Paver 360 aims to address these issues by integrating energy-efficient lighting, durable materials, and smart features into a single, robust platform, ensuring improved safety, reduced maintenance, and enhanced functionality.

*Founding Director, CarbonOut Techcom Pvt. Ltd. and
** System Developer, CarbonOut Techcom Pvt. Ltd.

Fig.1: Traditional Paver

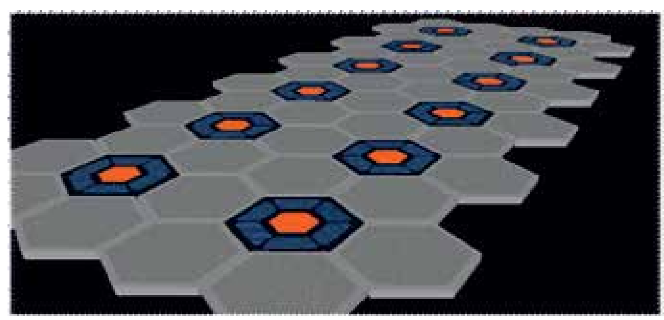

Fig.2: Smart Paver Intermittently placed

Fig. 1 shows the installation of traditional paver blocks, while Fig. 2 highlights Paver-360 integrated alongside them. Paver-360 enhances safety, aesthetics, and smart infrastructure with IoT technology, transforming roads into intelligent, connected surfaces for a more advanced solution.

DESIGN AND INNOVATION

Paver 360 integrates advanced engineering and sustainable materials to create a versatile and long-lasting solution. Key features include:

- **Material Innovation:** Made from recycled plastic sourced from CIPET Bhubaneswar, Paver 360 ensures high durability, UV resistance, and fire retardancy. Its robust design enhances longevity while promoting sustainability. The material withstands harsh environmental conditions, making it ideal for long-term use.
- **Reinforced Structure:** Designed to withstand a point load of 6kN and a traffic load of 40 tons, verified through NABL-certified testing.
- **Smart Illumination:** Integrated LED lighting system with customizable RGB patterns enhances surface indication, improving visibility in all weather conditions. The lighting can be programmed for dynamic effects, traffic signalling, pelican signals, Zebra crossing, curve stone signals or aesthetic enhancements, making it suitable for roads, railways, and commercial spaces. Parking Indicators with smart control and navigation has scope to manage traffic in a modern way by using floor indication.
- **Energy Independence:** Solar-powered operation reduces reliance on external power sources, lowering electricity costs and supporting sustainable infrastructure. The built-in energy storage ensures uninterrupted functionality, even in low-light conditions, making it ideal for remote or off-grid locations. Integration of solar tiles has opened an unmatched opportunity for harnessing solar power on the footpath, pathways, paved roads, eco cottages with battery storage.
- **IP67 & IK10 Certified Protection:** Ensures waterproofing, dust proofing, and high-impact resistance, making it suitable for harsh environments. The rugged design withstands heavy loads and extreme weather, ensuring long-term reliability with minimal maintenance with thermal insulation.
- **IoT Integration:** Enables real-time data collection, remote control, and predictive maintenance in smart city applications. The system can be integrated with traffic management, security networks, and environmental monitoring, providing valuable insights for urban planning and safety enhancements.

RESEARCH AND PROTOTYPE

The research and prototype development of Paver 360 which was carried by CarbonOut focused on creating a durable, energy-efficient, and smart surface indication system. Extensive material testing was conducted using recycled plastic sourced from CIPET Bhubaneswar to ensure strength, fire retardancy, and UV resistance. The prototype integrates customizable RGB LED lighting, IoT connectivity, and solar-powered operation for enhanced sustainability. The mould was developed with the help of CTTC, and the prototype was tested at Indian Railways to validate its real-world performance. The final prototype developed by CarbonOut demonstrates a robust, low-maintenance solution for railways, road safety, and smart city infrastructure.

ACCREDITION OF THE PRODUCT BIS, NABL

Paver 360 developed by CarbonOut has undergone rigorous testing to ensure compliance with industry standards. The product is accredited by the Bureau of Indian Standards (BIS)(having No -Registration/CRS 2024-7396/R-52000345) for electrical safety and performance, ensuring reliable operation in various environmental conditions. Additionally, it has been tested in NABL-certified laboratories for mechanical strength (Test Report No-00957 dated 12.09.2023 From LARPM, CIPET, Bhubaneswar, Odisha, India), verifying its durability under high load and impact conditions. These certifications validate Paver 360's quality, safety, and suitability for large-scale deployment in railway platforms, road infrastructure, and smart city applications.

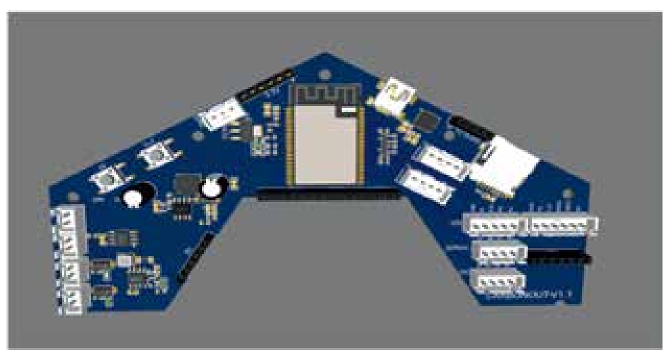

Fig.3: Electronics PCB

Fig. 3 presents the custom-designed Electronics PCB for Paver-360, enabling IoT connectivity and sensor integration for real-time data collection. Featuring high-performance ICs and multiple microcontrollers, it supports PWM-controlled lighting, Wi-Fi, and Bluetooth, ensuring seamless smart city integration. Built to industrial-grade standards, this PCB enhances durability and reliability, making Paver-360 a future-ready solution for smart infrastructure.

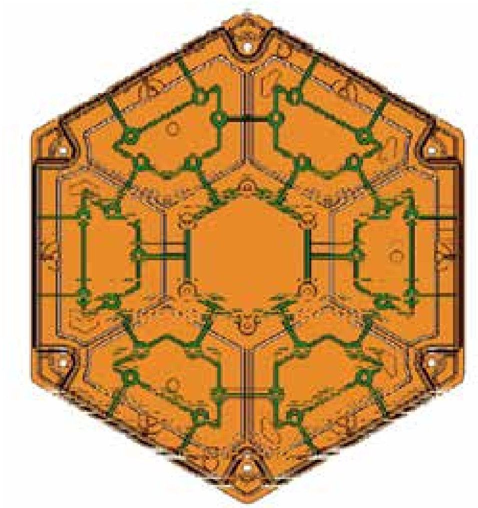

Fig. 4: Top Cover

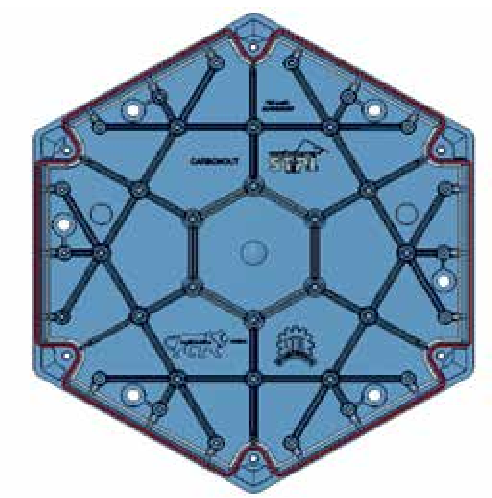

Fig.5:Bottom Cover

The Paver-360 features a two-part assembly for easy installation and maintenance. The Top Cover (Fig. 4) is 30mm high, serving as the visible surface with integrated LEDs for enhanced visibility. The Bottom Cover (Fig. 5) is 50mm high, housing the IoT-enabled PCB, sensors, and power modules for seamless functionality. Designed to match traditional paver dimensions, it ensures perfect compatibility with existing infrastructure, preventing misalignment while integrating smart features effortlessly.

MANUFACTURING PROCESS

The production of Paver 360 follows a systematic approach to ensure precision, durability, and performance:

Material Selection & Processing

- Sourcing ABS Plastic, recycled plastic materials and processing them into a durable polymer composite. Recycled plastics collection in an organizational setup is already being carried out by development authorities of municipal corporations, ensuring a steady supply of raw materials for sustainable manufacturing. CarbonOut is engaged with CIPET, Bhubaneswar centre for sourcing the plastic/plastic waste with aligned agencies of CIPET.

- Incorporating UV stabilizers and fire-retardant additives for enhanced longevity.

Injection Moulding & Reinforcement Integration

➢ Utilizing a 1400 kg mould to manufacture paver tiles weighing approximately 1 kg each, with a size of 9 square inches or approximately 1 square foot. The paver blocks are available in three height variations: 30mm, 50mm, and 80mm, catering to different application needs in urban and infrastructure development. The mould consists of P-20 HH materials and is produced in CTTC, Bhubaneswar and Training program has been conducted.

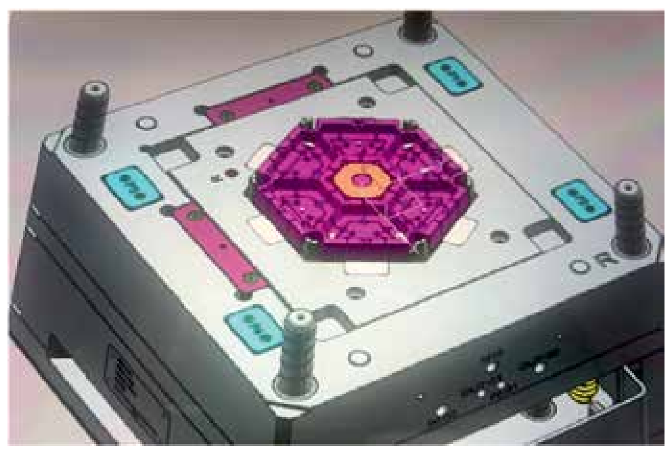

Fig.6: Mould

Fig. 6 displays the injection mould for Paver-360, a 1400 kg P-20 HH mould designed for producing 1 kg paver tiles of 9 square inches in 30mm, 50mm, and 80mm heights. It features reinforced ABS composites for strength and brass inserts (M4) for electrical connectivity, ensuring seamless smart infrastructure integration.

- Integrating reinforced structures within the mould to enhance strength, the reinforcement is provided in the form of plastic composite materials refined from ABS. Brass inserts with an M4 screwing size are integrated to facilitate electrical connections and signal connectivity, ensuring durability and seamless functionality in smart infrastructure applications.

LED & Solar Panel Integration

- Embedding PWM-controlled RGB LED modules enhances visibility and customization, allowing dynamic lighting patterns for surface indication, traffic management, and aesthetic applications. The Pulse Width Modulation LED controller regulates brightness and colour transitions efficiently, ensuring optimal energy consumption and extended LED lifespan.
- Installing solar panels for independent power generation reduces reliance on external power sources, ensuring sustainable operation even in remote locations while lowering energy costs.
- Ensuring waterproof electrical circuits to maintain an IP67 rating protects the system from dust, water, and harsh environmental conditions, ensuring long-term durability and reliable performance in outdoor and high-impact areas. The sealed circuitry uses conformal coating and encapsulation techniques to prevent moisture ingress and corrosion, enhancing overall reliability.

Testing & Quality Control

- Mechanical strength testing to verify load-bearing capacity is conducted to ensure durability under heavy loads, making it suitable for high-traffic areas. It has been tested and certified by a NABL-certified lab, confirming its structural integrity and long-term reliability.
- Weatherproofing assessments (UV, fire, and water resistance) are performed to ensure the material withstands harsh environmental conditions without degradation. The materials used inherently possess these properties, ensuring longevity and consistent performance in extreme climates.
- Functional checks for LED efficiency, solar performance, and IoT connectivity are carried out to guarantee optimal operation and seamless integration into smart infrastructure. Advanced diagnostics and real-time monitoring help maintain efficiency and detect potential issues proactively.

APPLICATIONS & USE

Railway Platforms: Smart surface indication for improved passenger safety

- Case Study: In Bhubaneswar Railway Station, Platform No. 1, a total of 117 Paver-360 units have been installed as a pilot project across a 300m stretch of the platform surface. This implementation has significantly enhanced platform aesthetics while providing a safer and more visually appealing environment for passengers. The project has demonstrated the effectiveness of Paver 360 in transforming railway infrastructure with modern, sustainable solutions.

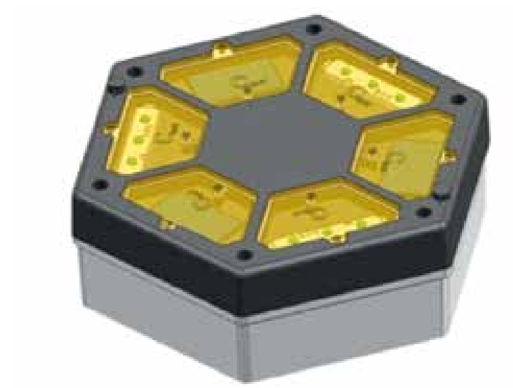

Fig.7: Paver-360

Fig.8: Smart Paver on Pathway

Fig. 7 presents the physical design of Paver-360, highlighting its durability, smart technology integration, and aesthetics.

Fig. 8 demonstrates the real-world use of smart pavers on pathways and footpaths, improving pedestrian safety, navigation, and urban aesthetics, while enabling IoT connectivity for smart cities.

Fig.9: showcases the deployment of Paver-360 as platform surface indication lights at Platform-1 of Bhubaneswar Railway Station, under the East Coast Railway Division. Inaugurated by Shri Ashwini Vaishnaw, Hon'ble Minister of Railways, this pilot project enhances passenger guidance, safety, and accessibility, setting a new standard for railway platforms.

Fig.9: Implementation

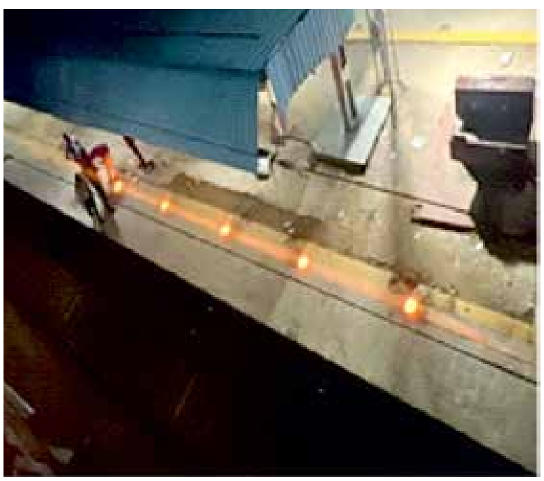

Fig.10: Surface indication on ECOR

Fig. 10 highlights the expansion of this smart infrastructure with the installation of surface indication lights at Lingaraj Temple Road PH Railway Station, further improving visibility, accessibility, and passenger experience while advancing next-generation railway infrastructure.

- **Road Safety & Highways:** Application in smart barricades, U-turn markers, and pedestrian crossings.
- **Smart Cities:** Integration into pedestrian pathways with IoT-enabled connectivity.
- **Industrial& Mining Zones:** Hazard indication and navigation lighting in high-risk areas.
- **Rural Electrification:** Solar-powered lighting for remote areas.
- **EV& UAV Charging Infrastructure:** Serving as network transmitters and power backup devices.
- **Airports:** Used as surface indicators for guiding passengers and ground vehicles, enhancing navigation and safety. It also helps in marking restricted areas to prevent unauthorized access, ensuring better operational efficiency and security at airport premises. Currently CarbonOut is engaged with BPIA for launching pilot project on this area.

COMPARATIVE ANALYSIS & UNIQUENESS

Paver 360 distinguishes itself from conventional solutions through its technological integration and sustainability as shown in Table 1.

Table 1: Comparative Analysis - Traditional Vs Paver 360

Feature	Traditional Solutions	Paver 360
Material	Concrete/Metal	Recycled Plastic
Durability	Moderate	High (6kN point load, 40-ton traffic load)
Power Source	NA	Solar-powered/ auxiliary
Smart Features	None	IoT-enabled, RGB LEDs
Weather Resistance	Limited	IP67 & IK10 Certified
Maintenance Cost	Low	Moderate

FUTURE SCOPE & SCALABILITY

The integration of Paver 360 with 5G networks and IoT-based urban planning opens new avenues for:

- Smart road infrastructure with real-time traffic data collection enables efficient traffic management by monitoring vehicle movement and congestion patterns. IoT-enabled sensors within the paver blocks help gather data, optimizing traffic flow and reducing bottlenecks.

- Enhanced emergency response systems with SOS-enabled paver blocks provide a rapid communication link in critical situations. These smart pavers can alert authorities and guide responders to precise locations, improving safety in urban areas, highways, and public spaces.
- Renewable energy-based urban designs incorporating solar-integrated walkways contribute to sustainable infrastructure by generating clean energy for street lighting and IoT applications. These walkways enhance urban aesthetics while promoting energy efficiency.
- For railway surface indication systems, we are planning visually friendly tiles to assist commuters, including those with disabilities. An RFID tag embedded inside the tile interacts with an RFID reader in a blind person's walking stick, providing real-time audio or vibration alerts about dangerous locations, improving accessibility and safety for visually impaired passengers.

COMMERCIAL ASPECT OF PAVER-360

The introduction of smart illuminating recycled plastic based paver tile is integrating many common problems of plastic pollution with tailer made packages meeting to the geographical need of the locations. Hence specific product-based projects for urban planning, rural requirements have diverse flexibility on the commercial side through this mitigation of carbon footprint with SDG goals. This will make larger projects and buildings to adapt this new edge smart Paver-360 for carbon credit, moving towards net zero buildings and green projects. The tentative price tag for smart illuminating paver tile block ranges between 1899/- to 7999/- depending on its utility with MOQ of 100 as an introductory pricing. The detailed workouts depending on customized solutions will be more appropriate and effective looking to customers budget and taste.

CONCLUSION

Paver 360 is a groundbreaking innovation that combines safety, sustainability, and smart technology into a single solution. By addressing the challenges of railway and road infrastructure with energy-efficient and durable surface indication, Paver 360 sets a new standard for future urban development. Its patent-pending technology positions it as a key player in shaping intelligent transportation and smart city solutions. The product and the technology will lead to smart public utilities including hospitals, IT buildings, Public Parks, Railways platforms, Airport Terminal buildings and highways with thrust on Road Safety and navigation. The scope for execution is primarily defined above and it has the scope of uses in many sectors depending upon the choice of the Think Tank.

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PLANNING AND DESIGNING NET ZERO CARBON BUILDINGS IN HILL AREAS- ISSUES, OPTIONS & STRATEGIES

Jit Kumar Gupta*

Abstract

Occupying more than 17% physical area and housing more than 10% of total population of the country; hill areas are known and valued for housing abundance of natural resources, providing quality environment, diverse ecology, unique bio-diversity and wealth of flora and fauna These valuable resources remain crucial for balanced growth and development of any community, state and nation. Considering their criticality, role, relevance and importance, these natural gifts need to be protected, preserved and promoted, during the process of planning, designing of human settlements and creation of built environment. With rapid increase in population, growing tourism and rapid urbanization, hill areas are experiencing rapid urban growth and addition of large number of buildings. Built environment is known to be large consumers of energy, resources and generators of waste. Buildings are also known to be responsible for promoting global warming and climate change. Undertaking designing and construction of buildings, without caring and giving due consideration to local resources and eco-system, is known to adversely impact the ecological balance of hill areas. Considering prevailing fragility, buildings have to be designed and constructed with care and caution for minimizing consumption of resources, energy and generation of waste, in order to minimize its adverse impact on fragile environment and ecology. Looking at the peculiarities of land and topography in hill areas, designing &constructing zero carbon buildings remains both challenging, complex and intricate, requiring different and distinct skill sets and thorough knowledge and understanding of the basic structure/fabric of the hill areas. In order to make buildings carbon neutral and least consumers of energy, resources and generators of waste; paper looks at the options of designing buildings based on circular economy, leveraging nature, valuing local climate, respecting orientation, using natural light, minimizing building foot prints and optimizing solar energy, for heating and lighting the buildings besides using local materials and exploring innovative technologies etc.

INTRODUCTION

Hill areas and hill settlements have always been source of great attraction, fascination, learning and inspiration besides being most prized places to visit and stay. Hill areas have been valued, because they are known to be reservoir and storehouse, having abundance of natural resources, quality environment, diverse ecology, unique bio-diversity and wealth of flora and fauna. These natural assets are known to be crucial and critical for the balanced growth and sustainable development of any community, state and nation. However, despite being bestowed with enormous natural gifts, hill areas, due to its sensitivity and fragility, are fast becoming victim of the unplanned growth and unsustainable development. Hill areas are being subjected to forces generated by ever rising population, concentration of population in few settlements, rapid in-migration, uncontrolled tourism, unplanned urbanization, increasing mobility, mechanized traffic and transportation, and increasing globalization. Under the impact of unplanned and unregulated development, majority of natural gifts of hill areas are being diluted, muted, marginalized and destroyed.

** Former Director, College of Architecture, IET Bhaddal, Chandigarh, Punjab*

Majority of emerging challenges in hill areas, can be attributed to the manner in which scarce and valuable resources in hills are being used, abused, diverted, deprived/denuded. Majority of ills in hill areas have genesis in the manner in which valuable land resources is being managed and sub-divided/converted from forest/agriculture to non-agricultural uses involving residential, commercial, industrial, institutional, transportation and tourism. In addition, hill areas are also suffering due to unplanned and haphazard manner in which buildings are being planned, designed and constructed, without caring for the climate, orientation, existing terrain, slope, fragility, vulnerability, load bearing capacity, flora and fauna. In addition, irrational and unscientific pattern of planning, designing and creating highways, have also made hill states vulnerable to soil erosion, landslides, climate change and global warming.

Under the impact of ever increasing developmental pressure generated during last seven decades, hill areas in India have recorded rapid population and physical growth besides increased demand for land, infrastructures, services and amenities, for catering to the needs of the people and activities housed therein and large number of tourists/ visitors coming into the hill areas. Considering fragility and sensitivity; various development activities undertaken in hill areas, without caring, valuing and giving due consideration to local resources and prevailing eco-system, are known to adversely impact the environment and ecological balance of hill areas. Accordingly, hill areas need to be understood and appreciated for its strength, weaknesses, opportunities and threats, related to its physical, structural, environmental, cultural and social peculiarities before suggesting policies and launching programs to make then sustainable.

Looking at the peculiarities and complexities, designing& construction of sustainable buildings in hill areas, invariably remains challenging, complex and intricate task, requiring different and distinct professional skill sets and thorough knowledge and understanding of the basic structure/fabric of the hill areas. It also requires understanding and appreciation of valuable resources, fragile environment, diverse ecology, bio-diversity, flora and fauna, which need to be protected, preserved and promoted during planning, designing and construction of buildings.

MAKING BUILDINGS NET ZERO CARBON

In order to bridge the gap, existing in the available literature, techniques and methodologies for planning /designing/construction of buildings in hill areas, it will be prudent to understand the issues of vulnerability prevailing in hill states and look for possible options to address the emerging developmental challenges to make the built environment safe. In order to define the roadmap for making buildings sustainable, safe and supportive of environment and ecology, example of SECMOL school building, constructed in Leh, has been taken as a role model of sustainable, vernacular and solar passive architecture. The building remains zero-energy and zero-waste. 'The Student's Educational and Cultural Movement of Ladakh (SECMOL)', located in Leh, is the brain child of engineer Sonam Wangchuk, an alumnus (1987) of the National Institute of Technology, Srinagar.

STUDENT'S EDUCATIONAL AND CULTURAL MOVEMENT OF LADAKH (SECMOL)

Located in the heart of Leh, nicknamed the cold desert, having one of the most hostile climate for human living and habitation, with temperature fluctuating wildly, bordering on extreme cold and moderate heat , educational campus known as, 'The Student's Educational and Cultural Movement of Ladakh (SECMOL)', has clearly demonstrated and showcased , how potential and inherent strength of art and science of Architecture can be appropriately leveraged, to overcome the extreme challenges posed by climate and adversities created by nature, by effectively, efficiently, appropriately and intelligentially, using the same very nature and natural resources, to create qualitative, environment friendly, safe, cost-effective, energy/ resource efficient, zero-carbon, zero energy and sustainable example of built environment in hilly regions. Salient feature of planning, designing and construction of the buildings in the SECMOL campus, which makes it unique, can be enumerated as under;

i. Site

- Site selected for the SECMOL campus is located in the Phey village approximately 18 kms away from the Leh Town of the Indus Valley. (Fig.1)
- Site is located at an altitude of 3500 meters, from MSL, in one of the most hostile climates, with temperatures ranging from 20°C in summer and -30°C in winter
- Site is flat, with no undulation and is spread over an area measuring 20-acre, having little vegetation and water.

Fig.1: Site of the SECMOL School; Phey Village

ii. Design Approach

- Design with limitations: Design approach used for SECMOL school was primarily led by overcoming the challenges posed by trinity of tough terrain; peculiar climatic conditions and difficulty in bringing outside building materials.

- Design with Nature: Approach adopted for planning and designing of the buildings in the campus, is based on the principle of, designing with nature, using natural elements of Panch-bhutas, comprising of Agni(Sun), Prithvi(Land), Jal (Water), Vaayu(Air)and Aakash (Space), as integral part of design solution.

- Design with Climate: Design of the buildings and the campus also include challenges posed by Climate; options created by Orientation and sunlight/ heat provided by Solar movement besides ably supported by local materials and ancient construction technologies.

- Design Compact: Considering the need for conserving heat and avoiding loss of heat, buildings have been designed compact, so as to seal the inner spaces for minimizing the heat loss.

- Opting for Passive Architecture: Design option used for buildings is based on Passive Architecture, which involves creating supportive environment within buildings, for human living and working, without resorting to mechanical means of air, light, ventilation and air conditioning. In addition, buildings have been designed to have large thermal mass due to thick earthen walls, which are known to retain lot of solar radiation, falling during the day, and making it available at night for heating the inner spaces.

- Net Zero Energy Building: Buildings have been planned and designed to be- Net zero-energy - requiring no energy sourced from conventional sources/supplied by Grid. Buildings have no electric connection nor it burns fossil fuel for heating, even during peak winter months. Solar panels have been used for sourcing / generating solar energy for meeting the power requirements of buildings.

- Natural Lighting – Building envelop provides enough openings for bringing sun and sunlight for lighting, which is available in abundance, eliminating the electricity needed for lighting the spaces within the buildings in daytime. Orienting rooms south and providing large size openings have been used as the principle to ensure maximum solar heat gain. In order to source maximum sunlight, glass to wall ratio has been placed at 80% in the southern side. (Fig.2)

- Using Skylights-Understanding the distinct advantages offered by skylight in terms of sourcing natural light and heat, Skylights have been made integral part of the roof design. Three Skylights have been appropriately designed and covered with glass/clear plastic to allow light and eliminate seepage of water etc. Two skylights are provided over the two staircases, placed on either side of the building, for providing adequate light to staircases. whereas the third skylight has been provided over the library, for ensuring optimum l natural light for reading.

- Making optimum use of Site: Main School building has been planned, designed and constructed, based on detailed study and analysis of prevailing, soil characteristics, site conditions, tough terrain / peculiar climatic conditions and difficulty in sourcing and transporting building materials for construction.

- Creating Greenhouses - Considering the distinct advantage of sourcing light, trapping heat and heating the inside air, greenhouse mechanism has been included as design element, placed on the south side for trapping heat of sun. Accordingly, in winters, huge plastic sheets are rolled down to create a big greenhouse which works as a solar collector. In summers, these plastic sheets are rolled to allow fresh air to come into the building, for ventilation and modulating inside temperature. Creating green- house space has helped the institute in creating supportive environment for growing vegetables in the harsh cold climate, which are used for cooking food for the inhabitants, making the institute self-reliant to a large extent.

Fig.2: Positioning of Buildings in South- North Orientation

iii Planning

- Rectangular Shape; School building has been planned and designed, based on opting for a rectangular shape, known for its simplicity in working and providing efficient planning of inner spaces. School Building has an overall length of

45 meters and depth of 13.5 meters with spaces planned in a symmetrical manner, along a central corridor. Proportions of the depth to length of the building have been placed in the ratio of 1:3, for reasons of natural lighting, efficient working and optimum space utilization.

- Low-rise structure: Considering the limitations imposed by cost, climate, materials and construction, buildings have been planned and designed to be low-rise, double storied structures.
- Compact Planning: Buildings have been planned and designed around a centrally positioned, doubly loaded corridor for reasons of simplicity, space efficiency and having higher order of carpet area.
- Doubly loaded corridor: Planning of the building revolves around a central corridor, to minimize the area under circulation and to increase the efficiency of the building. Higher proportions of space have been allocated to the area to be used for main/primary uses as compared to spaces which are supposed to be sub-servient/ secondary, to the main use of the building.
- Classifying Spaces: Spaces within the building have been categorized into two distinct zones. Spaces which are largely inhabited by human beings and spaces where human habitation remains minimal. Looking at the positivity of the Southern side, spaces which are inhabited by human beings including; class rooms, offices, technical workshop, assembly hall, have been placed in the Southern side, whereas spaces where human habitation remains minimal i.e., earth lab, stores, toilets, reception-cum-waiting, stairs etc., have been placed on the Northern side.
- Trapping Heat: For facilitating and creating conditions which are, warm, cozy, conducive and comfortable, class rooms and activity spaces, have been placed on the Southern side and have been appropriately recessed from the adjoining space allocated to Assembly Hall, workshop and office, for sourcing solar heat during winter by putting a thick polythene sheet in the winter.
- Zoning Spaces: In order to minimize heat loss; making optimum use of space and effectively managing the inside temperature, the entire building has been divided into three distinct zones, which despite being connected through a common corridor could still be made to operate and function independently.
- Entrance: For minimizing heat loss from the building, entry to the building has been provided from East side with minimum opening.
- Natural Light: Building has been planned in such a manner, that all inner spaces have the distinct advantage of adequate natural light during the day, in order to eliminate the need of using power sourced from conventional sources, for lighting.
- Making use of Geo-Thermal Energy: Northern side/portion of the building, housing, stores, toilets and part of the assembly hall, staircases etc., have been designed to be one meter below ground level, in order to source earth required for construction of the building and for making use of geo-thermal energy for heating the cool northern side.
- Multiple use of Spaces: In order to make optimum use of limited space available in the building and to overcome the limitations imposed by the cold climate, large central space earmarked as assembly area, is used for performing multiple activities like teaching, meeting, undertaking cultural activities and entertainment and accordingly remains heart and soul of the school building. (Fig. 6)
- Making use of Geo-Thermal energy: Portion of the building falling on the northern side, has been planned and designed to be lower than normal ground level- and has accordingly been kept, one meter below the prevailing ground level - because earth's temperature at this depth has been recorded to be relatively warm in winters / cool in summers- which helps in creating comfortable living conditions in the northern part of the building, through the use of geo-thermal energy (Fig1).

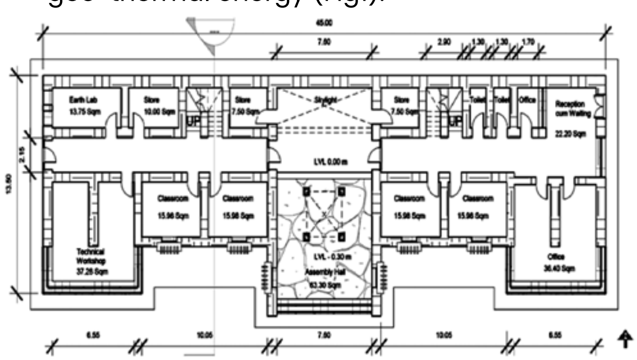

Fig. 1: Ground Floor Plan of School Building

iv. Orientation

- Understanding Solar Movement: Buildings have been planned and designed after detailed study and in-depth analysis of the orientation of the site and behavior/movement of the sun, during summer and winter seasons, in the cold and dry climatic region.

- Optimizing Solar Heat: Orientation has been embedded as integral part of building design in order to make optimum use of solar heat and light, in order to overcome the challenges posed by extreme cold and non-availability of the light from the power grid/conventional sources of power.

- Orienting South: Considering the distinct advantages offered by the Southern side, building have been oriented with larger part of buildings housing human activities, facing South direction. South orientation keeps buildings warm in winters through passive solar heating, providing most cost-effective option of creating ambient living and working conditions within buildings.

- Large Windows provided on Southern side: For making best use of sun light and sun heat, building envelop has been designed with larger openings provided on the southern direction. (Fig.2)

Fig. 2: Large Windows facing South for sourcing maximum sunlight and Heat

v. Structure

- Simple: Structure system adopted for the building has been kept simple, for the ease of construction; use of locally available material and avoiding the use of steel and concrete.

- Walls: The compact double-storied building has been constructed with one-two feet thick walls, madeof rammed earth, sourced from the site itself, which also act as load bearing structures. Thick rammed earth walls keep building warm in winters /cool in summers; act as heat bank; absorbing heat from sun during day, storing it and releases to rooms at night.

Fig. 3: Wood and Earth sourced locally used as main Material

vi. Material

- Using Local Materials: Considering the non-availability of latest building materials and high cost of building technologies used in the modern construction and restrictions imposed by the cost and absence of skilled labor ; using available local building materials based on earth and traditional construction technologies were considered the best and most appropriate option for making of the energy efficient and buildings carbon neutral.(Fig. 3)

- High Mass Building Envelop: Majority of material used for construction in the campus buildings includes, wood, sand, earth and clay, which are known for distinct qualities to havea high thermal mass and low thermal conductivity, which has helped in creating high mass building envelop, ensuring the retention of solar heat within the building.

- Using Rammed Earth: Material used for construction of thick walls is made out of rammed earth, sourced locally, by digging the north portion of building. Earth sourced from site, mixed with sand and clay, in a pre-determined proportion and put in a wooden frame at the site to create the structure. The mixture is then rammed /compacted with pounders to create bricks, which are then used for construction of walls.

- Building Envelop: Building envelop has been carefully and thoughtfully designed so as to minimize heat loss, maximize heat gain and admit maximum day-light within the building. Accordingly, for making building envelop efficient, material used for creating building envelop is bricks made of rammed earth. Thickness of walls varies from one- two feet, which not only act as structural walls, supporting the live and dead load of building but also work and operate as the heat bank. Outer walls, are insulated by erecting another jacket wall, which is separated from inner wall be a gap of 6 inches. Gap between two walls is filled with low-cost insulating materials involving saw dust, wood shaving, waste paper and plastic. Cow dung mixed with clay and earth is used for wall finishes, which have been found to be both cost-effective and energy efficient.

- Sourcing Earth from Site: Earth used in the construction was sourced from Northern portion of the building, which was dug one meter below the ground level, to source earth required for construction. process also helped in making innovative use offer-thermal energy, to promote heating during winter and cooling during summer. In addition, the space dug out on the northern side was also made to act as the foundation and to provide stability to the building.
- Minimizing Carbon footprints : Sourcing earth, the main building material used in building, from site itself eliminated the need of transportation basic material from long distance, reduced the embodied energy of the building besides making construction of building both cost-effective/economical and energy efficient. When construction work was finished, site had no debris to be thrown away resulting in making environs neat and clean
- Insulating Roof: Waste generated from wood work undertaken during construction was mixed with rammed earth to promote insulation in the Roof; which led to minimize heat loss from roof.

vii Promoting Landscape

- Despite the fact that SECMOL is locate and built in a desert, having very little availability of water, still institution has been able to use i innovations to landscape the campus by planting fruit trees and creating vegetable gardens.
- The approach road to the SECMOL is lined with fruit trees including apricot, mulberry and apple, whereas vegetable gardens have been created behind the kitchen in the space, housing students. Institution uses the mechanism of green houses to trap heat to grow vegetables even during the extreme cold months to meet the needs of fruit and vegetables required for the consumption of residents.
- In addition, trees like; Poplar, Willows Russian Olives and Robina (kikar), are also grown in the campus which take care of the needs of the wood/timber required for making additions/ alterations to the construction undertaken in the campus. In addition, campus also has planted numerous local plants including Sea buck thorn and Leh Berry, which provide edible fruit and juice for human consumption.
- All this has been made possible by the use of grey water, which is generated through the kitchen and bathrooms, for meeting the needs of the water for the landscape and plants.

viii Outcome

- **High Degree of Energy efficiency:** During its operation for last more than 25 years, building has clearly demonstrated and established that it remains both energy and resource efficient. The success of the building and building envelop in combatting cold, can be observed from the fact that, when outside temperature was recorded as low -25°C in winters, inside temperature recorded was as high as +14°C, without support of any mechanical means/fuel used for heating.
- **Reducing Operation and Maintenance Cost:** Considering the need for conserving heat, building design and use of mudas material of construction, has ensured that building stays warm. In addition, to combat cold and to overcome the problem of heating the water SECMOL has also innovated by creating its own solar water heater, costing merely Rs 3000/100 liters as compared to commercial heater costing Rs 25,000/100 liters in the market. Further, since water is heated by Solar heat so no cost is involved in the heating of the water, which also, reduces the operational cost of building.

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Note: This article is based on the material, sketches and literature sourced from the above articles-which is thankfully and gratefully acknowledged.

INNOVATIONS IN BUILT ENVIRONMENT

Rajdeep Chowdhury*

Abstract

Cracking at the junction, in sufficient anchorage, thermal expansion and contraction, time intensive process, weight addition are some of the practical challenges masonry construction witnesses with traditional RCC band.

Here comes the Steel Mesh Masonry Bed joint reinforcement(SMMBJR) is an innovative construction material, an alternate system of traditional RCC Band used for structural reinforcement in masonry. It is available in roll able steel reinforcement mesh. Murfor Compact is the Trade name of SMMBJR. It's lightweight, easy to transport, and simple to store on-site. It can be cut to size as needed.

SMMBJR is having high strength, made from high-tensile steel, ensuring durability and reliability in masonry construction. The product is available in galvanized or stainless-steel options for protection against corrosion. It has huge potential to reduce water usage in the construction of the wall. As the product will be embedded in the bed jointing mortar so there won't be any requirements of pre or post water curing unlike traditional RCC Band.

Murfor Compact SMMBJR is widely recognized in Europe for its contribution to innovative and sustainable building practices, making it a preferred choice in modern construction projects. Now BJR is also available in India and finding encouraging response from Industry stakeholders.

INTRODUCTION

Like concrete, masonry has a high compressive strength but a limited tensile strength. This lead to cracking when tensile and/or shear stresses develop. This phenomenon is more prominent in AAC Block masonry. By providing reinforcement to resist such stresses, the chance of cracking is substantially reduced.

Cracks in masonry appear due to a variety of causes. BIS – 6041 – 1985 (code of practice for Construction of AAC Block Masonry) also stated reasons in point 4.6, some of the prime reasons are as follows:

- Shrinkage due to drying out and movement due to external situations.
- Movement due to fluctuating temperatures.
- Flexural or tensile stresses resulting from loading.
- Stress concentrations around openings, in the masonry course immediately below beam.
- Movement of partition walls due to the deflection of the supporting structure.
- Long term creep effects.

**FIE, CE, Business Head – VAP & TPO, Biltech Building Elements Ltd.*

AAC Block masonry can be reinforced with steel mesh reinforcement, using general principles like thoseassociated with reinforced concrete. Murfor Compact (MC)is a steel mesh masonry Bed Joint reinforcement (SMMBJR) product manufactured by M/s Bekaert, Belgium. Since 2016 MC has been in use in various countries of Europe.

SMMBJR is a convenient, purpose-made, reinforcement for masonry for use in the horizontal bed joints. It limits the risk of cracking and increases the tensile and flexural strength of masonry. The unique structure and user-friendly size of this type of reinforcement optimizes the construction process and use of materials.

Murfor Compact have been evaluated by competent International nodal agencies like EOTA for use as masonry joint reinforcement product complying with various International Building codes like IRC, IBC CBC, FBC .

PRODUCT USE

SMMBJR is used as bed joint reinforcement in AAC Block masonry. It is made from high tensile strength steel that has been galvanised to protect the steel from corrosion, a minimum of 15mm cover to the surface of the block is recommended to increase the protection for the steel. SMMBJR have been used in many projects for many years in Europe and have been preforming as expected in the respective applications.

The unique structure and user-friendly size of this type of reinforcement optimizes the construction process and use of materials. SMMBJR enhances the structural performance of AAC wall by increasing the tensile capacity of the masonry, which significantly increases the in plane and out of plane capacities of the structure.

Depending on width, SMMBJR consists of a series of 7 to 14 longitudinal steel wires with polypropyleneyarn longitudinally affixed to each steel wire. The longitudinal wires and yarns are held together with fibreglass cross fibres at predetermined spacings.

DIMENSION:

Product/ Brand	Mesh	Width (MM)	Thickness (MM)	Length (Meter)
Murfor Compact A-40	7 steel cords	40	1.75	30
Murfor Compact A-80	14 steel cords	80	1.75	30

Properties:

Sl. No.	Properties	Murfor Compact A-40	Murfor Compact A-80
1	Area of one long cords (mm2)	0.69	0.69
2	Total Area of Steel cord (mm2)	4.83	9.66
3	Yield Strength (MPa)	1770	1770
4	Tensile Strength (Mpa)	2100	2100
5	E- Modulus (GPa)	180	180

DESIGN

The SMMBJR longitudinal steel wires may be designed as horizontal bed joint reinforcement for flexural tension in the direction of the bed joint reinforcement in masonry walls.

The use of SMMBJR conform to the guidelines of BIS: 6041 – 1985 clause no 4.6.3.1(b) which state "Incorporating steel reinforcement either in the form of nominal RCC Bond beams (see 4.6.4) or horizontal joint reinforcement (see 4.6.5). Horizontal joint reinforcement serves much the same purpose in crack control as RCC bond beams; it increases the tensile resistance to cracking. Due to the generally closer spacing adopted in bed joint , bed joint steel reinforcement may be more effective in crack control than bond beams".

BENEFITS

1) **Water-Free Installation:** Unlike RCC bands, SMMBJR doesn't require any water during installation or curing. There is no water dependency, reducing the strain on water resources and minimizing environmental impact.

2) **Reduced Carbon Footprint:** By eliminating the need for cement concrete, controlled use of Steel, SMMBJR significantly reduces the carbon footprint associated with traditional RCC construction. SMMBJR ensures a greener, more eco-friendly building process.

3) **Streamlined Construction:** With SMMBJR, the integration of construction projects is seamless. Embedding this innovative reinforcement solution into polymer-modified block joining mortar streamlines the construction process, saving time, resources, and energy.

4) **Quality assurance:** SMMBJR is manufactured adhering to stringent quality standards of European codal guidelines. MC is ETA certified for structural use, which allows the products to use CE marking and confirms requirement of SHE protection.

5) **Minimal Waste Generation:** Use of traditional RCC Band System often results in significant material waste during mixing and curing processes. In contrast, Murfor Compact offers a more efficient solution with minimal waste generation. Its precise integration into block joining mortar reduces the likelihood of excess material usage, leading to less waste and lower environmental impact throughout the construction.

6) **Lean construction practices:** SMMBJR can help to minimize the environmental impact of construction by reducing waste, cost, improved Project Management and optimizing resource utilization.

DESIGN ASPECTS

- SMMBJR MC is used as a structural bed joint reinforcement to increase the out of plane capacity of masonry walls.
- SMMBJR MC can be used to replace the in situ RCC band beams to increase construction speed and reduce overall labour costs and time consumed for building and hardening of the concrete bond beams.
- In order to find out of plane capacity of the RCC band beam, the following equation was used:

$$Mrd \approx 0.95 \times d \times as \times fys / \gamma s$$

Diameter of steel considered in RCC band beam : 10 mm ; $f\gamma s$=250[MPa] ; γs= 1.15

d= distance from the face of the wall to the bar in tension [mm]

The safety factor for masonry is taken as: γm=1.5

For 4m x 3m Typical Wall Section				
Thickness	**2 RCC Band Capacity (Mrd)**	**Moment capacity (KN-m)**	**No. of layer of MCA**	**Moment resisted by per joint (KN-m/ joint)**
100mm	2.33	0.584*4=2.336	6	2.336/6=0.389
125mm	2.93	0.906*4=3.624	6	3.624/6=0.604
200mm	5.385	2.344*4=9.376	5	9.376/5=1.875

MOMENT OF RESISTANCE FOR DIFFERENT WALL THICKNESSES FOR BOND BEAM

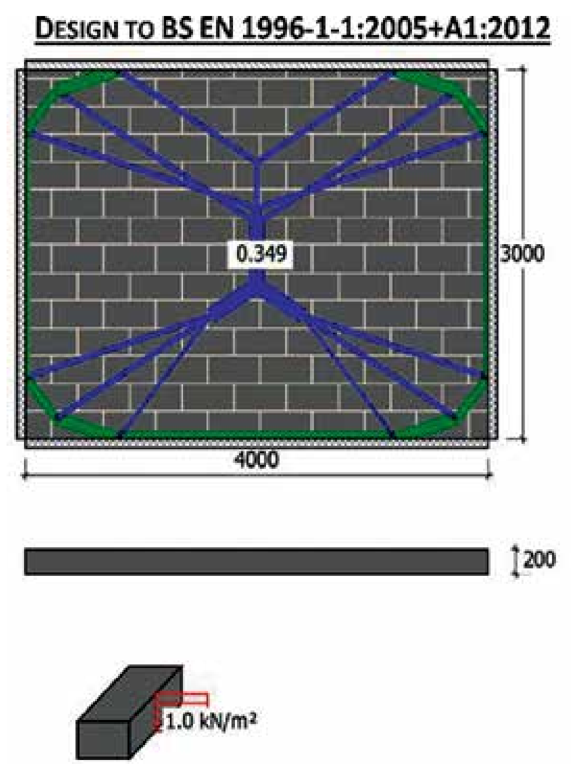
The following cases have been evaluated in the design, with the corresponding Murfor Compact reinforcement and compared with the traditional RCC beams solution.

Notes:

- The moment capacity values are derived from calculations from BS EN 1996 provided in Master Key.
- The number of MCA layers is determined based on the recommended placement details from Master Key.
- For Moment Capacity of 200 mm wall, please refer to the design shared below.

DESIGN OF WALL WITH MURFOR COMPACT

For example a typical wall of 4m x 3m in 200 mm thick AAC Block Wall , Structural Calculation done using Master Series Software.The wall is consideraedReinforced Two Way Spanning, Laterally Loaded, Single-leaf Wall.



SUMMARY OF DESIGN CALCULATION:

Sl. No.	Design Criteria	Value	Achieved	Remarks
1	Minimum % Bed Reinforcement	0.0084 (Minimum)	0.0087	ok
2	Lateral Load			
2.a	Unreinforced Panel – Yield line analysis	1.5 (Maximum)	0.613	ok
2.b	Reinforced Panel – Yield line analysis	1.5 (Maximum)	0.349	ok
3	Design Moment -Minimum of Design Moment and Moment of resistance to be considered	2.344	ok	

Number of MC Layers :

Wall Length	Wall Height	Wall Thickness	Number of Murfor Compact (MC) layers in 80 mm widthfor 3 m high wall	Vertical Spacing of MC Layers
4 m	3m	0.2 m	5 layers	550 mm

BIS : 6041 GUIDELINE FOR RCC BAND BEAM & BED JOINT REINFORCEMENT :

Clause 4.6.5 Joint Reinforcement Here BIS mentioned about Ladder type Bed Joint reinforcement which is used worldwide, it comes in standard lengths of 3to 6 meter in length. SMMR Murfor Compact is the latest and new standard Bed joint reinforcement which comes in a roll of 30 meter and very easy to handle and store.

SPECIFICATION & METHODOLGY

Providing and laying of steel mesh masonry reinforcement (SMMBJR) on Autoclaved Aerated Concrete (AAC) blocks. The SMMBJR shall be embedded in premix AAC block joining mortar (BJM) in 3-4 mm thickness. In case of conventional Cement sand Mortar, the joint thickness can be of 10-12 mm. the AAC Block shall have minimum Compressive strength of 4 N/mm2. The BJM shall have minimum Tensile adhesion strength of 0.4 N/mm2 , Split Tensile strength of 0.4 N/mm2 and Compressive Strength 7 N/mm2 at 28 days.

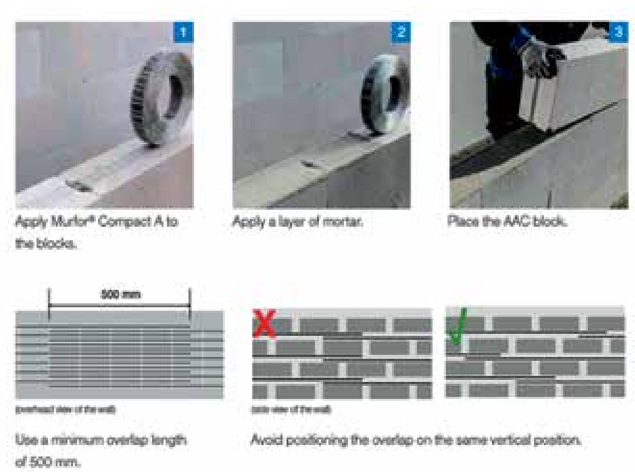
Typically, in 4 m x 3 m AAC block wall (non-load bearing) having thickness 100 /125/150 mm , minimum 6 layers of SMMBJR in 40 mm width shall be placed on AAC block and in case of AAC Block thickness more than 150 mm for a wall size of 4m x 3 m , minimum 5 layers of SMMBJR in 80 mm shall be placed on AAC Blocks. However, depending on specific requirements like wind load, wall size etc. the number of SMMBJR layer shall vary as per structural requirement laid down in BS EN 1996-1-1:2005+A1:2012 design guidelines.

In both the cases of SMMBJR 40 mm & 80 mm the first layer shall be on the First course of AAC Block and the last layer shall be below the last AAC block course. Remaining layers shall be equally distributed in the courses of AAC Block work.

At the edges the SMMBJR need to be anchored properly using steel cleat angle etc. proper nailing, screwing to be done with the RCC Column / RCC Mullion in case of external walling applications.

All applications, design and distribution / number of layers of SMMBJR depending on wall sizes etc. shall be carried out as per Manufacturer's guideline and instruction of Client's Engineering in Charge.

METHODOLOGY



APPLICATION OF SMMBJR

Typical Cost Comparison RCC Band and SMRR

Typical Calculation for 4 m x 3m walling area							
Block wall (MM)	**L (M)**	**H (M)**	**Qty. of MC in meter**	**Basic Rate / RM , GST Extra**	**Cost of Murfor/ wall (Rs.)**	**Cost ofRCCBand as per DSR**	**Remarks**
T-200	4	3	20	260	5200	5000	5 layers of 80 mm width MC used. In RCC Band- 2 numbers of10 mm dia. Rod and 8 mm Dia. Stirrup in 200 mm c/c used
T-100	4	3	24	130	3120	3577	6 layers of 40 mm width MC used. In RCC Band- 2 numbers of 10 mm dia. Rod and 8 mm dia. Stirrup in 200 mm c/c used.
T-125	4	3	24	130	3120	3860	6 layers of 40 mm width MC used. In RCC Band- 2 numbers of 10 mm dia. Rod and 8 mm dia. Stirrup in 200 mm c/c used.

Note:

1) For designing with Murfor Compact, the code referred is BS EN 1996-1-1:2005+A1:2012. The design has also conformed the codal requirements of Moment Capacity, Minimum Reinforcement and load factors for wall design.

2) For conventional RCC Band, the rate considered based on DSR 2021@ RCC 5.33.2.1 ; Shuttering Rate : 5.9.5 & steel rate as per 5.22A.6.

CONCLUSION

Using sustainable materials in building construction is crucial for India due to its rapid urbanization, environmental challenges, and resource constraints. With rising urbanization, adopting eco-friendly construction methods and material is not just a choice—it's a necessity. SMMBJR has a great potential to address these requirements because of its unique features and application process.

REFERENCE

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2. Master Key masonry Design for Murfor Compact Software

3. BIS : 6041

4. Various online resources

INTEGRATING CARBON-SEQUESTERING MATERIALS

Aastha Chardey* And Dr. Debashis Sanyal**

Abstract

Innovative approaches to sustainable building materials are required due to the construction industry's substantial carbon footprint. The incorporation of hempcrete and biochar as carbon-sequestering elements in architectural design is investigated in this study. By combining hemp hurd, lime, and water, hempcrete exhibits exceptional qualities like fire resistance, moisture control, and thermal insulation. It also actively absorbs carbon dioxide through lime carbonation and biogenic storage. The versatility of hempcrete is demonstrated by its ability to be used in prefabricated panels and retrofitting applications, despite its non-load-bearing limitations. In parallel, biochar—which is made by pyrolyzing biomass—improves the ability of building materials to store carbon. By using composites based on biochar instead of conventional cement and aggregates, lifecycle emissions are greatly decreased, leading to carbon negativity. Based on empirical data, it has been shown that using biochar instead of one ton of cement can reduce CO2 emissions by up to 1.5 tons. The study combines production methods, assesses thermal and mechanical performance, and discusses the financial ramifications. Architects can redefine sustainable design paradigms by utilizing these materials to balance structural integrity with ecological responsibility. This study highlights how carbon-neutral building can be advanced using hempcrete and biochar, thereby supporting sustainable development goals and global climate targets.

INTRODUCTION

About 39% of all greenhouse gas emissions worldwide come from the construction industry, making it one of the biggest contributors to carbon dioxide emissions(Gibson, 2024). The production of traditional building materials, especially cement and concrete, requires a lot of energy and has a negative environmental impact due to resource depletion and carbon emissions(Osman et al., 2024). Innovative building materials that can sequester carbon have attracted a lot of attention as countries work to meet carbon neutrality and sustainable development goals. Biochar and hempcrete are two of these that have shown promise as substitutes for sustainable architecture.(Osman et al., 2024)

Hempcrete, a composite material made of water, lime, and hemp hurd, is praised for its capacity to produce carbon-negative emissions. The material absorbs carbon dioxide from the carbonation of lime during curing as well as from the hemp growth cycle. Apart from its environmental advantages, hempcrete provides exceptional fire resistance, moisture control, and thermal insulation. Although hempcrete has a low compressive strength, its versatility in contemporary construction methods is demonstrated by its use as a non-load-bearing infill material in prefabricated panels and retrofitted structures(Kumar et al., 2020).

Incorporating biochar, a carbon-rich byproduct of biomass pyrolysis, into building materials adds another level of carbon sequestration. It is possible to achieve considerable lifecycle emission reductions by using biochar in place of aggregate or cement. According to research, using biochar in place of one ton of cement can offset up to 1.5 tons of CO2 equivalent emissions. Additionally, biochar controls moisture and improves thermal insulation while

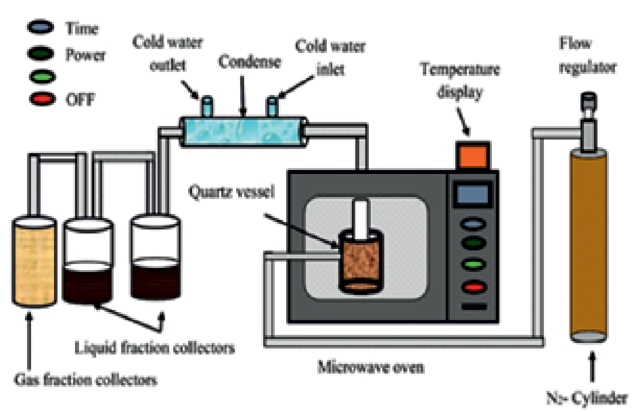


Fig. 1: Schematic diagram of microwave pyrolysis reactor(Kumar et al., 2020)

**B.Arch. Student, Department of Architecture and Planning, NIT, Raipur*

*** Associate Professor, NIT, Raipur*

encouraging the circular reuse of organic waste. (Kumar et al., 2020)

The combined potential of hempcrete and biochar to turn architectural design into a carbon-sequestering process is examined in this study. It assesses their environmental impact, mechanical qualities, and thermal performance while offering creative ways to use these materials into environmentally friendly building practices. The study intends to create a guide for environmentally friendly design that complies with international climate requirements by combining the most recent research and trial data.

Properties and Performance of Hempcrete

With a conductivity between 0.076 and 0.11 W/mK, hempcrete is a great material for thermal insulation and can help keep indoor temperatures steady. Its ability to control interior humidity enhances passenger comfort while lowering HVAC energy usage. Lime's strong alkalinity naturally prevents the hemp shiv from burning, making it fire resistant. Unfortunately, its low compressive strength (usually between 0.3 and 0.8 MPa) restricts its application to insulating infill and non-load-bearing walls, frequently necessitating structural framing for stability.

Production and Application Techniques for Biochar

The process of producing biochar uses a variety of techniques, each of which affects the product's characteristics and efficiency(Barbhuiya et al., 2024).

- Pyrolysis is the oxygen-free thermal breakdown of biomass that produces a high carbon content but necessitates exact temperature and time control.
- Gasification: Maximizes energy recovery by producing syngas and biochar.(Barbhuiya et al., 2024)
- Microwave pyrolysis: A quick and effective process that produces uniformly heated, high-qualitybiochar.

By replacing some of the cement or aggregate in concrete with biochar, embodied carbon is decreased and mechanical performance is enhanced. For consistent material qualities, the type of biochar, particle size, and blending method must be chosen carefully.

Mechanical Strength and Durability of Biochar-

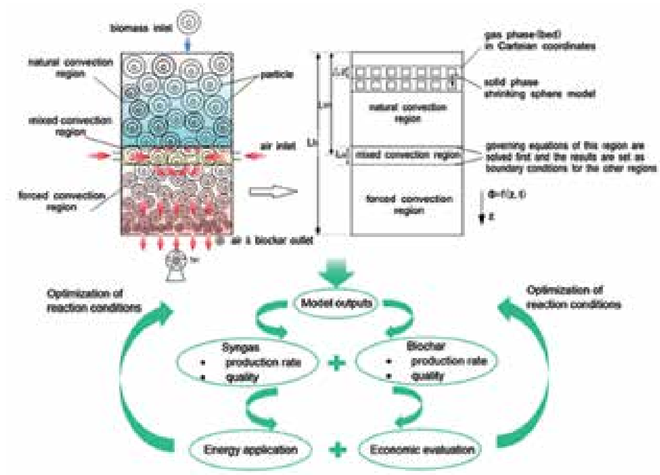


Fig. 2: Gasification method of biochar production(Barbhuiya et al., 2024)

Concrete

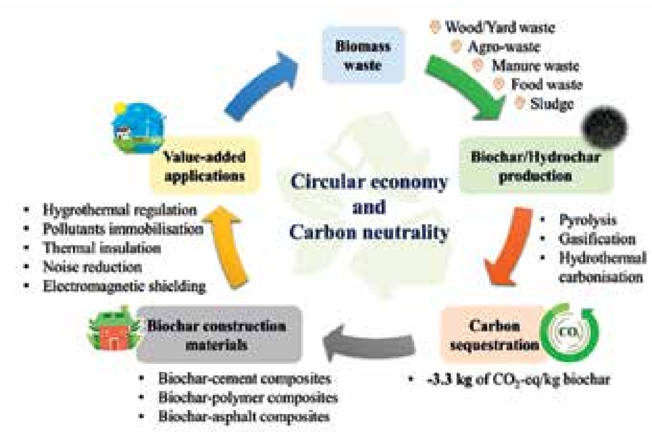
In the right amounts, adding biochar to concrete increases its strength. Research indicates that a 7% weight-based biochar component improves compressive strength by 12%. Excess biochar, however, can weaken the cementitious matrix and jeopardize structural integrity. Additionally, biochar improves durability by decreasing permeability and thwarting attacks from sulphates and chlorides. Its porous structure improves hydration and lessens cracking over time by absorbing moisture and internal curing water(Barbhuiya et al., 2024).

Thermal and Acoustic Properties of Carbon-Sequestering Composites

Superior thermal performance is offered by hempcrete, which lowers heat transport while preserving energy efficiency. Additionally, it reduces outside noise by acting as an acoustic barrier. In a similar vein, biochar increases concrete's thermal conductivity, increasing the energy efficiency of buildings. Thesecharacteristics are essential for creating calm, cozy, and sustainable interior spaces(Barbhuiya et al., 2024).

Carbon Sequestration in Architectural Design

Concrete based on hemp and biochar makes a substantial contribution to the sequestration of carbon in buildings. Both chemical (lime carbonation) and biologicalneed to be resolved. Wider use can be encouraged by regulatory frameworks, commercial incentives, and technological developments in material processing. According to life cycle assessments, these materials lower long-term operating costs and carbon liabilities even if they have greater upfront costs.



Economic and Environmental Considerations

Adoption of sustainable materials is mostly influenced by cost-effectiveness and environmental advantages. By reducing reliance on high-emission materials like aggregate and cement, hempcrete and biochar minimize energy usage and embodied carbon. However, issues including greater beginning costs, manufacturing consistency, and scalability

(plant-based) processes are used by hempcrete to store carbon. Because of its large surface area, biochar concrete adsorbs CO_2 and retains it in the material matrix, providing a practical way to build carbon-neutral or even carbon-negative structures. Global sustainability activities are supported when these materials are used strategically in architectural design.

CASE STUDIES

1: Carbon Footprint Assessment of Hemp-Based Eco-Concrete Masonry Blocks

Location: Research conducted at "Gheorghe Asachi" Technical University of Iasi, Romania.

Objective: Evaluate the environmental impact of hemp concrete blocks using Life Cycle Assessment (LCA) tools in two scenarios—Cradle-to-Grave (CtG) and Cradle-to-Cradle (CtC)(Isopescu et al., 2024).

Methodology

- **Materials Used:** Hemp shredding, calcium oxide, Portland cement, water, and sodium silicate for binding.
- **Software:** SimaPro 9.5 with IPCC 2021 GWP100 and ReCiPe 2016 Midpoint (H) methodologies.
- **Functional Unit:** 0.5 m³ of hemp-based masonry blocks(Isopescu et al., 2024).

Key Findings

- **CtG Scenario:** GHG emissions totaled 107.61 kg CO-eq, with CO uptake of -56.32 kg CO-eq.
- CtC Scenario: Recycling reduced emissions to 33.23 kg CO-eq, with a CO uptake of -53.84 kg CO-eq, resulting in a net negative carbon footprint of -20.32 kg CO-eq.

Insights

- Hemp concrete sequesters carbon during hemp growth and through lime carbonation.
- Applying circular economy principles significantly reduces lifecycle emissions and environmental impact.

2. Energy Retrofit of Historic Palazzo Jadicicco Using Hemp-Lime Plaster

Location and Historical Context:

Palazzo Jadicicco, located in Frattamaggiore, Italy, is a significant 17th-century courtyard-style historic building. Originally constructed using Yellow Neapolitan Tuff (YNT), a volcanic stone popular in Southern Italy, the structure features ornate frescoes and stuccoes indicative of Baroque architectural style. As an important heritage site, it presents challenges in modern retrofitting due to aesthetic preservation requirements and structural limitations(Agliata et al., 2020).

Objective

The primary aim was to evaluate the potential energy efficiency improvements from replacing traditional gypsum-lime plaster with hemp-lime plaster while maintaining the building's historical integrity. The study assessed thermal insulation, energy performance, and environmental impacts, including carbon dioxide emissions, under both the current and retrofitted conditions(Agliata et al., 2020).

Methodology

The study simulated the thermal performance of walls before and after retrofitting using **Termus® software.** Two scenarios were analyzed:

- **A-configurations (existing gypsum-lime plaster):** Represent the building's current state with conventional materials.

- **B-configurations (hemp-lime plaster):** Simulate the building with hemp-lime plaster applied as an alternative(Agliata et al., 2020).

Hemp-lime plaster was applied in three layers for thicknesses between 4 to 7 cm:

1. **Scratch Coat:** Rich in lime, ensuring adhesion to the masonry.
2. **Crinkle Coat:** 2-5 cm thick, applied with a trowel for thermal mass.
3. **Finishing Coat:** Lime-based to protect from moisture and atmospheric agents.

Results

1. Thermal Performance:

o Thermal Admittance: Reduced by over 50%, demonstrating improved winter insulation. However, this reduction did not fully meet Italian regulatory standards for winter thermal performance(Agliata et al., 2020).

o Dynamic Thermal Admittance: Dropped to near-zero in most B-configurations, indicating enhanced summer cooling performance. The classification for summer performance improved from "low" to "medium."

2. Energy Efficiency:

- The EPgl,nren index (non-renewable energy demand) improved by 20%, reducing from 141.27 kWh/m²/year to 112.63 kWh/m²/year(Agliata et al., 2020).
- CO Emissions decreased from 26 kg/m²/year to 21 kg/m²/year, reflecting a significant environmental benefit.
- The building's overall energy rating improved from E to D.

3. Hygrometric Tests:

- The study verified the absence of interstitial condensation and mould formation in all retrofitted walls, enhancing indoor air quality and moisture control(Agliata et al., 2020).

CONCLUSION

The incorporation of biochar and hempcrete into architectural design presents a viable route to carbon-negative building. In addition to its capacity to regulate moisture and temperature, hempcrete is a sustainable option for non-structural applications due to its capacity to sequester carbon through biogenic storage and lime carbonation. Utilizing biochar in concrete improves durability, thermal insulation, and carbon storage. Case studies show notable drops in CO2 emissions and energy consumption, underscoring the potential of these materials for environmentally friendly new construction and retrofits. Technological developments, market adoption, and policy support can all help to overcome cost and scalability issues. Together, hempcrete and biochar open the door to environmentally friendly construction methods that support the objectives of global sustainability.

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ENSURING THE SAFETY OF CONSTRUCTION WORKERS: CHALLENGES AND BEST PRACTICES

K.L. Mohan Rao*

Abstract

Construction is one of the most hazardous industries, accounting for a significant percentage of workplace injuries and fatalities worldwide. This paper explores the primary risks faced by construction workers, examines regulatory frameworks, and highlights best practices to enhance worker safety. Effective training, proper use of personal protective equipment (PPE), and technological advancements are discussed as crucial components in reducing workplace accidents.

INTRODUCTION

The construction industry plays a vital role in infrastructure development and economic growth. However, it is also known for high injury and fatality rates. This paper aims to analyse the risks associated with construction work and propose measures to improve safety conditions.

COMMON HAZARDS IN CONSTRUCTION WORK

Construction workers face numerous hazards, including:

I) **Falls from height:** Leading cause of fatalities due to scaffolding and ladder accidents. Falls from height are a significant safety risk, especially in workplaces like construction, manufacturing, and maintenance.

They can lead to severe injuries or fatalities.

Here's a breakdown of key aspects:

Common Causes

- Lack of Fall Protection (e.g., no guardrails, harnesses, or nets)
- Unstable Working Surfaces (e.g., slippery or uneven surfaces)
- Unsecured Ladders or Scaffolding
- Human Error (e.g., loss of balance, missteps)
- Weather Conditions (e.g., wind, rain, or ice on elevated surfaces)
- Lack of Proper Training

* *President, Construction Industry Development Academy*

Prevention Measures

- Use Proper Fall Protection Equipment (harnesses, safety nets, guardrails)
- Ensure Proper Training for workers at heights
- Conduct Regular Equipment Inspections
- Follow OSHA or Other Safety Regulations based on location
- Maintain Clean and Dry Work Areas
- Use Proper Ladders and Scaffolding Techniques
- Implement Fall Prevention Plans and Risk Assessments
- First Aid & Emergency Response
- Call Emergency Services Immediately
- Do Not Move the Victim Unless Necessary
- Check for Breathing and Provide CPR if Needed
- Control Bleeding if Present
- Keep the Person Still and Comforted Until Help Arrives
- If someone falls from a height, immediate first-aid response is crucial.

Here's what to do:

Ensure Safety First

Do not put yourself in danger—check for hazards before approaching.

If the area is unsafe (e.g., risk of falling debris), call emergency services immediately.

Assess the Victim's Condition

Check consciousness: Gently call their name or tap their shoulder.

Check breathing and pulse: If they are unresponsive and not breathing, begin CPR.

Look for injuries: Suspect spinal injuries, fractures, or internal bleeding.

Call for Emergency Help

Dial emergency services (911 or local emergency number).

Provide details about the fall, the height, and any obvious injuries.

Do Not Move the Person (Unless Necessary)

If they are unconscious but breathing, place them in the recovery position only if you suspect no spinal injury.

If you suspect a spinal injury, avoid moving them unless they are in immediate danger (e.g., fire, flooding).

Control Bleeding (if any)

Apply gentle pressure with a clean cloth on open wounds.

Avoid pressing too hard if you suspect fractures beneath the wound.

Treat for Shock

Keep them warm with a blanket.

Reassure them to keep them calm.

Do not give food or drinks, as they may need surgery.

Immobilize Suspected Fractures

If you see an obvious deformity or suspect a broken bone, avoid unnecessary movement.

Support the injured limb using makeshift splints or soft padding.

Monitor Vital Signs

Keep checking their breathing, pulse, and level of consciousness.

Be ready to perform CPR if breathing stops.

When to Perform CPR

If the person is unresponsive and not breathing, start CPR:

Place hands in the centre of the chest and give 30 chest compressions (2 inches deep).

Give 2 rescue breaths if trained in CPR.

Continue until emergency help arrives.

Important: Falls from height can cause serious internal injuries that are not immediately visible. Even if the person appears fine, they must seek medical attention.

Global and Industry-Specific Statistics on fall from height

Worldwide: According to the International Labour Organization (ILO), falls from height account for nearly 20-30% of workplace fatalities in the construction industry.

United States: The Bureau of Labour Statistics (BLS) reported that in 2022, there were 850 fatal falls, with 44% occurring in the construction sector.

United Kingdom: The Health and Safety Executive (HSE) recorded 40 fatal falls from height in 2022/23, making up 30% of all workplace fatalities.

Australia: Safe Work Australia reported 169 worker fatalities in 2022, with falls from height being one of the leading causes.

II) Electrocution:

Exposure to live wires and faulty electrical systems. Electrocution is a major hazard on construction sites, often resulting from contact with live wires, faulty equipment, or improper grounding.

Here are some key points to consider:

Causes of Electrocution on Construction Sites

- Contact with Overhead or Underground Power Lines – Workers using ladders, cranes, or scaffolding may accidentally touch live wires.
- Faulty or Exposed Wiring – Damaged cables, exposed wires, or poorly maintained tools can cause shocks.
- Improper Grounding – Using ungrounded electrical systems increases the risk of electrocution.
- Wet Conditions – Water conducts electricity, making damp environments more dangerous.
- Unsafe Use of Electrical Equipment – Operating power tools or machinery without proper precautions can be fatal.

Preventive Measures

- Proper Training – Educate workers on electrical safety and best practices.
- Use of Personal Protective Equipment (PPE) – Insulated gloves, rubber mats, and safety boots reduce risk.

- Lockout/Tag out (LOTO) Procedures – Ensure power is shut off before maintenance or repairs.
- Safe Distance from Power Lines – Maintain required clearance from overhead lines.
- Regular Equipment Inspections – Check tools and wires for damage before use.
- Ground Fault Circuit Interrupters (GFCIs) – Install GFCIs to prevent electrical shocks.

When dealing with electrocution hazards, safety regulations focus on preventing electric shocks, burns, and fatalities. These regulations vary by country but generally follow standards set by organizations like OSHA (USA), NFPA, IEC, and ISO.

Here are some key safety measures:

1. General Electrical Safety Regulations

Lockout/Tag out (LOTO) – Always de-energize and lock out power sources before working on electrical equipment (OSHA 1910.333).

Personal Protective Equipment (PPE) – Use insulated gloves, face shields, and dielectric boots when handling live wires (NFPA 70E).

Voltage Limitations – Follow guidelines on safe working distances and approach limits for different voltages.

Circuit Breakers & Fuses – Ensure properly rated breakers and fuses are installed to prevent overloads.

2. Workplace & Industrial Safety

- ➢ Grounding & Bonding – All electrical systems should be properly grounded to avoid stray voltage build-up.
- ➢ GFCI (Ground Fault Circuit Interrupters) – Required in wet or high-risk areas to cut power when leakage is detected.
- ➢ Signage & Barriers – Use warning signs and physical barriers around high-voltage areas.
- ➢ Training & Certification – Workers must be trained in electrical hazards and emergency response.

3. Home & Public Safety

- ➢ Proper Wiring & Insulation – Avoid exposed wires, frayed cables, and DIY electrical work.
- ➢ No Water Near Electricity – Never use electrical appliances with wet hands or in wet environments.
- ➢ Proper Plugging & Unplugging – Always pull plugs by the base, not the cord.
- ➢ Fire Prevention – Avoid overloading circuits and using damaged extension cords.

4. First Aid & Emergency Response

- ➢ Do Not Touch a Shocked Person – Use a non-conductive object to move them away from the source.
- ➢ Call Emergency Services Immediately – Provide CPR if necessary and ensure the victim is stabilized.
- ➢ Check for Secondary Hazards – Fire risks, arc flash injuries, and unconsciousness must be handled carefully.

GLOBAL STAISTICS ON FATAL ACCIDENTS DUE TO ELECROCUTION

Electrocution remains a significant cause of accidental fatalities worldwide, particularly in occupational settings. While comprehensive global statistics are limited, data from various countries provide insight into the prevalence and circumstances of these incidents.

United States:

Annual Fatalities: Approximately 1,000 deaths occur each year due to electrical injuries, with around 400 attributed to high-voltage incidents and 50 to 300 resulting from lightning strikes.

Workplace Incidents (2011–2023): Out of 70,692 occupational fatalities from all causes, 1,940 were due to contact with electricity. Notably, 98.9% of these electrical fatalities involved men. The construction industry experienced the highest number of electrical fatalities (855), followed by professional and business services (212), and trade, transportation, and utilities (155).

Ireland:

Fatalities (2001–2020): There were 40 electrocutions or deaths from the explosive/burning effects of electricity. Of these, 25 deaths were associated with work activities, while the remaining 15 occurred in domestic situations or resulted from trespassing, vandalism, or incidents like fallen overhead power lines.

Australia:

Fatalities (2000–2011): A study reported 321 closed case fatalities due to electrocution, with at least 39 additional cases still under coronial investigation.

Sweden, Denmark, Finland, and Norway:

Fatality Rates (2007–2011): The number of electric deaths per million inhabitants was 0.6 in Sweden, 0.3 in Denmark, 0.3 in Finland, and 0.2 in Norway.

Nigeria:

Incidents (2020–Mid-2021): Data analysis revealed 126 recorded electrocution deaths and 68 serious injuries. Most electrocutions were accidental, often caused by faulty equipment or inadequate adherence to safety regulations.

Construction Industry:

Global Perspective: The construction sector consistently reports a high rate of occupational fatalities, with electrocution identified as one of the leading causes.

These statistics underscore the critical need for stringent safety protocols, regular equipment maintenance, and comprehensive training programs to mitigate the risk of electrocution across various settings.

III) Struck-by incidents:

Struck-by incidents are one of the leading causes of injuries and fatalities in construction sites. They occur when a worker is hit by an object, piece of equipment, or vehicle.

These incidents are one of OSHA's "Fatal Four" hazards in the construction industry.

Common Causes of Struck-By Incidents

1. Falling Objects

Tools, materials, or debris falling from heights

Unsecured loads on scaffolding or cranes

Poorly stacked materials

2. Swinging or Moving Equipment

Crane loads swaying

Excavators and backhoes swinging unexpectedly

Heavy machinery movement in tight spaces

3. Flying Objects

Power tools ejecting particles or materials

Nail guns misfiring

Saw blades or grinding wheels breaking apart

4. Vehicle-Related Incidents

Being struck by construction vehicles like dump trucks or forklifts

Poor visibility in work zones

Reversing vehicles without spotters or alarms

Prevention Measures

Personal Protective Equipment (PPE)

Hard hats to protect from falling objects

Safety glasses and face shields for eye protection

High-visibility vests in vehicle zones

Work Zone Safety

Barricades and warning signs to separate workers from vehicles

Flaggers and spotters for traffic control

Backup alarms and cameras for reversing vehicles

Proper Material Handling

Secure all loads properly

Use tool lanyards when working at heights

Store materials in stable stacks

Safe Equipment Operation

Inspect equipment regularly

Train workers on proper tool use

Maintain a safe distance from moving machinery

Conclusion

Struck-by hazards are preventable with proper planning, training, and enforcement of safety measures. Employers and workers must work together to reduce these risks and create a safer work environment.

Injuries from falling objects or moving machinery.

IV) Caught-in/between hazards:

Caught-in/between hazards are one of the leading causes of fatalities in construction. They occur when a worker is caught, crushed, squeezed, or compressed between two or more objects.

These hazards can result in serious injuries or death if proper precautions are not taken.

Trench and Excavation Collapses

- Workers can be buried under soil or materials if a trench collapses.
- Lack of protective systems (e.g., trench boxes, shoring, or sloping) increases risk.
- Machinery Entanglement
- Loose clothing, hair, or body parts can get caught in rotating or moving machinery.
- Working too close to unguarded or improperly maintained equipment poses a serious risk.
- Getting Caught Between Equipment and Objects
- Workers can be pinned between heavy equipment (like forklifts, cranes, or trucks) and walls, structures, or materials.
- Lack of proper signalling, blind spots, and congested work areas contribute to these incidents.
- Collapsing Structures or Materials
- Walls, scaffolding, or stacked materials can unexpectedly fall and trap workers.
- Improperly stored or secured loads may shift and cause crushing injuries.
- Caught in Power Tools or Conveyor Belts
- Hands or fingers can be caught in power tools like saws, drills, or presses.
- Workers can be pulled into conveyor belts or rollers if guards are missing.

How to Prevent Caught-In/Between Hazards

Use Proper Protective Systems:

Ensure trenches over 5 feet deep have shoring, sloping, or trench boxes.

Barricade and mark hazardous areas clearly.

Keep a Safe Distance from Moving Machinery:

Avoid standing between moving equipment and fixed objects.

Wear fitted clothing and tie back long hair to prevent entanglement.

Lockout/Tag out Procedures:

Always de-energize and lock out machinery before performing maintenance.

Stay Clear of Heavy Equipment:

Never place yourself between a vehicle and an immovable object.

Use spotters and communication signals when working around heavy equipment.

Inspect and Secure Materials:

Stack materials properly to prevent collapse.

Secure loads on forklifts and cranes to avoid shifting hazards.

By recognizing and mitigating caught-in/between hazards, construction workers can significantly reduce the risk of serious injuries and fatalities. Proper training, awareness, and adherence to safety protocols are key to preventing these incidents.

Workers trapped between heavy equipment or collapsing structures.

Exposure to hazardous materials: Risk of respiratory diseases and long-term health conditions.

V. Exposure to hazardous materials in construction industry

Exposure to hazardous materials in the construction industry is a major occupational health and safety concern. Workers may come into contact with a variety of hazardous substances that can cause short-term and long-term health effects.

These materials include asbestos, lead, silica dust, chemicals, and more.

Common Hazardous Materials in Construction

a) Asbestos

Found in older buildings (roofing, insulation, flooring, etc.)

Causes lung diseases like asbestosis, mesothelioma, and lung cancer

Requires strict handling and removal procedures

b) Lead

Present in old paint, pipes, and some construction materials

Can cause neurological damage, kidney disease, and reproductive issues

Proper PPE and safety measures are required during demolition and renovation

c) Silica Dust

Generated from cutting, drilling, grinding concrete, brick, or stone

Leads to silicosis, lung cancer, and respiratory diseases

Requires wet cutting methods, proper ventilation, and respiratory protection

d) Wood Dust

Comes from cutting and sanding wood

Can cause respiratory irritation and increase the risk of nasal cancer

Dust collection systems and PPE are essential

e) Chemical Hazards (Solvents, Paints, Adhesives, etc.)

Contain volatile organic compounds (VOCs), which can cause headaches, dizziness, and long-term organ damage

Proper ventilation, PPE, and handling procedures must be followed

f) Cement and Concrete Dust

Can cause skin irritation, burns, and lung problems if inhaled

Protective clothing, gloves, and masks are necessary

g) Mold and Biological Hazards

Often found in damp areas of construction sites

Causes respiratory issues and allergic reactions

Requires moisture control and proper PPE

h) Health Effects of Hazardous Material Exposure

Short-term: Eye, skin, and respiratory irritation, dizziness, nausea

Long-term: Lung disease, cancer, neurological disorders, reproductive issues

h) Safety Measures to Reduce Exposure

Personal Protective Equipment (PPE): Respirators, gloves, goggles, protective clothing

i) Engineering Controls: Ventilation systems, dust suppression, wet cutting methods

j) Safe Work Practices: Proper material handling, waste disposal, and training programs

k) Regulatory Compliance: OSHA and EPA guidelines for hazardous materials in construction

VI. Regulatory Frameworks for Construction Safety

Governments and organizations worldwide have established regulations to ensure worker safety.

Some key regulations include:

- Occupational Safety and Health Administration (OSHA) standards in the United States.
- The Construction (Design and Management) Regulations in the United Kingdom.
- International Labour Organization (ILO) guidelines for global construction safety.
- These regulations mandate risk assessments, worker training, and safety inspections to mitigate hazards.

VII. Best Practices for Construction Safety

Improving safety in the construction industry requires a multi-faceted approach, including:

- Proper Training and Education: Workers should undergo comprehensive safety training programs.
- Use of Personal Protective Equipment (PPE): Helmets, gloves, harnesses, and eye protection should be mandatory on sites.
- Implementation of Safety Culture: Encouraging workers to report unsafe conditions and follow safety protocols.
- Regular Safety Audits and Inspections: Identifying and addressing potential hazards before accidents occur.
- Adoption of Technology: Utilizing drones for site inspections, wearable safety devices, and Building Information Modelling (BIM) for risk assessment.

CONCLUSION

Ensuring the safety of construction workers is a shared responsibility among employers, regulatory bodies, and workers themselves. Through stringent enforcement of regulations, continuous education, and technological integration, workplace accidents can be significantly reduced, fostering a safer working environment for all construction professionals.

SAFETY AND CONSTRUCTION WELFARE MEASURES

Rajesh Kumar Das*

Abstract

Indian construction industry is the major growth engine for infrastructure and economic development. However, it is envisaged that there are several challenges for safety and welfare aspects concerning the workforce.

This paper takes an integrated view of safety and construction welfare issues within the Indian context, assessing risks, the legal framework, prevailing practices and emerging technologies. This paper critically reviews the current measures, identifies gaps and areas for improvement and will present a holistic framework for improving safety and welfare. Its content supports stakeholder engagement, proactive risk management and technological integration as essential components to thrive in a safety culture. It further extends to discuss the specific challenges facing the Indian construction industry, which includes a large informal labour workforce, diverse scale of projects and varying awareness. Addressing these specific circumstances, this research study focuses on providing actionable recommendations for the Indian Building Congress and members for a safer, healthier and more productive construction environment that would benefit the workers and the industry at large.

INTRODUCTION

Indian Construction Industry forms a significant constituent of the Nation's economy with infrastructure development and employment opportunities.

However, it is characterized by a high rate of occupational accidents, injuries and fatalities. Construction sites are dynamic and hazardous with a huge informal workforce, diversified project scales and differential levels of safety awareness, making the worker's safety and welfare highly challenging. This paper discusses critical issues with safety and construction welfare in India. It is descriptive in nature and attempts to present a comprehensive analysis of safety and construction welfare in India to propose a holistic framework for improvement. It will evaluate the present legal and regulatory scenario, identify prevalent risks and hazards, estimate the present safety practices and explore the promises of technological advancements.

LEGAL AND REGULATORY FRAME WORK IN INDIA

India boasts what appears to be a broad legal framework concerning occupational safety and health; it does little for the worker, however, to protect the most industries, the construction industry among them.

**TCS (SSG); Chief Manager, HR, ONGC Ltd, Agartala*

Following are some important legislations:

- The Factories Act, 1948: This Act mainly focuses on factories but also extends to the construction site when manufacturing processes or machinery use is implemented. It addresses elements such as working hours, leave and general considerations relating to safety.
- The Building and Other Construction Workers (Regulation of Employment and Conditions of Service) Act, 1996 or BOCW Act:

  This is the main legislation that specifically deals with the safety, health and welfare of construction workers in India.

It encompasses a broad range of aspects, such as:

a) **Registration of Establishments and Workers:** Requires the registration of construction sites and workers, which helps in better monitoring and implementation.

b) **Safety and Health Committees:** It demands creation of safety committees on the construction sites for a stipulated number of employees, comprising representatives from the management and employees for addressing safety issues.

c) **Personal Protective Equipment:** Places provision and use of PPE, such as helmets, safety footwear, harnesses, eye protection adequate for particular hazards at the construction site.

d) **Hazardous Materials:** Concerned with the storage, handling and disposal of hazardous materials found in construction worksites, including asbestos, chemicals and explosives.

e) **Working at Height:** Outlines measures for safety at work places in height, the most common source of accidents, including guardrails, safety nets and harnesses fall protection systems.

f) **Welfare Facilities:** The Act provides for basic welfare facilities for workers, which include clean drinking water, sanitation facilities (toilets and washing areas), rest areas, first-aid facilities and crèches for children of women workers.

g) **Working Hours and Wages:** It prescribes working hours and wages for construction workers.

h) **Inspections and Enforcement:** It provides for the appointment of inspectors to visit construction sites, check for compliance with the Act and rules and take action against violators.

State-specific provisions: Except for the Central Acts, every Indian State formulated its rules under the BOCW Act considering local conditions and supporting the central legislation. Rules do typically provide more detailed requirements and procedures.

Other Relevant Legislation: Other legislation also includes the Environment (Protection) Act, 1986, and the Disaster Management Act, 2005, which are pertinent towards the issues of safety and health in construction to any environmental hazards and the preparedness for emergency.

Challenges in Implementation and Enforcement:

Even with this legal framework in place, a few challenges prevent its proper implementation and enforcement:

- **Rarer Resources:** Lack of enough workforce, funding and equipment poses a problem on the side of the enforcing governments in implementing these safety regulations by conducting frequent inspections on all constructions.
- **Large Informal Workforce:** One of the factors is that large numbers of Indian construction workers work informally via contractors and subcontractors. Due to this informal nature, most of these labourers are hardly aware of the rights and regulations that apply in their workplaces and are easily victimized.
- **Lack of Awareness:** The majority of stakeholders, including the workers, contractors and some employers, lack awareness of the existing safety regulations, their rights and the importance of safe work practices. This lack of awareness leads to non-compliance and unsafe behaviours.
- **Lack of strict enforcement:** While violations are observed, the actual enforcement is quite weak because of corruption, a long legal procedure and even lenient punishment. This could give an impression that safety regulation is not considered seriously.
- **Time and cost pressure:** The construction industry is usually time and cost sensitive. Hence, some of the contractors might be tempted to compromise on the safety aspect by saving time and money, at the risk of the workers' lives.
- **Complexity of Projects:** Large and complex construction projects pose a different kind of safety challenge, which requires specific expertise and management.
- **Migrant Workers:** Most of the construction workers are migrants; they usually hail from other states. Problems related to language, unfamiliarity with local rules and fear of losing jobs can make them more vulnerable to the safety risks.
- **Limited Data and Information:** Data related to accidents in the construction sector and problems related to occupational health is scanty. Therefore, it becomes difficult to correctly understand the extent of the problem and design suitable interventions accordingly.
- **Coordination Gaps:** Coordination among various agencies in the Government dealing with safety and health may be weak. It leads to overlap and gaps in enforcement.

PREVAILING RISKS AND HAZARDS IN INDIAN CONSTRUCTION

Construction sites in India are dynamic and complex environments with a high risk of exposing worker safety to many hazards. In most cases, these risks are compounded by such factors as accelerated project timelines, diverse demographics among the workforce, including migrant and informal labourers and levels of awareness about safety as well as the application of such regulations.

The major risks identified are:

(A) Height Falls: One of the main causes of fatal and severe injury in Indian construction.

Contributing factors are:

Inadequate Fall Protection: Lack of guardrails, safety nets or proper safety harnesses.

Improper Scaffolding: Poorly erected or overloaded scaffolding, leading to collapses.

Unsafe Ladder Use: Using ladders without securing them, overloading them or using damaged ladders.

Roof Work: Working on roofs without proper fall protection measures.

Openings and Edges: There are no barriers around floor openings, stairwells and edges.

(B) Struck by Objects: The risk of being struck by falling or flying objects is always present on construction sites.

This includes:

Falling Tools and Materials: Tools, bricks, pipes and other materials falling from height.

Flying Debris: Debris generated by demolition activities or powered tools.

Crane and Lifting Operations: Loads shifting or falling during lifting operations.

Vehicle Movement: Materials or equipment falling from moving vehicles.

(C) Caught in/Between: Such injuries are very likely to be grave or fatal.

Examples include:

Machinery Accidents: Getting caught between and by the moving parts of a crane, an excavator or a concrete mixer.

Structures or excavations collapse: When trapped by crumbling trenches, excavations or under construction.

Caught between: Being compressed by equipment, material or structural parts.

Collision with a moving vehicle: Run over or caught between building construction vehicles.

(D)Electrocution: Electrical dangers are present everywhere on the construction site:

Live Wires Contact: Broken or not properly insulated wires, overhead power lines.

Malfunctioning Tools and Equipment: Defective electrical tools and equipment.

Poor Grounding: Poor grounding of electrical installations.

Water and Electricity: Wet environments pose a high risk of electrocution.

(E) Exposure to Hazardous Substances: Construction workers are likely to be exposed to different dangerous materials:

Asbestos: Exposure to asbestos fibres, which causes lung cancer and mesothelioma.

Chemicals: Contact with paints, solvents, adhesivesand other chemicals, which cause skin irritation, respiratory problems and other health issues.

Dust: Inhalation of dust from concrete, wood and other materials, which leads to respiratory diseases.

Silica: Exposure to silica dust, a known carcinogen found in concrete and masonry.

Leads: Exposure to lead-based paint or other lead-containing materials.

Somatic Injuries from Handling: Construction works require heavy labour, which in turn causes muscular and skeletal troubles:

Heavy Lifting: Heavy loads handled in such a manner that the lifting of the load is not executed properly or no lifting gadgets is used.

Repeated Motions: Frequently performing some specific activity such as hitting or sawing.

Awkward Postures: Working in constrained spaces or unnatural postures.

Lack of an Ergonomic Design: Tools and equipment are not designed with the user's comfort in mind.

(F) Heat Stress: India's climate, especially during summer, is very prone to heat-related illnesses:

High Temperatures and Humidity: Working in hot and humid conditions can lead to heat exhaustion, heatstroke and other heat-related illnesses.

Lack of Shade and Water: Inadequate access to shade and cool drinking water can aggravate heat stress.

Physical Exertion: Tiring physical work in hot weather increases the chances of heat-related problems.

(G)Vibration and Noise: Long-term exposure to vibration and noise can cause serious health issues:

Hand-Arm Vibration Syndrome (HAVS): Caused by using vibrating tools, damage nerves, blood vessels and joints.

Hearing Loss: Gradual loss of hearing caused by exposure to loud noise from machinery and equipment.

Tinnitus: Ringing in the ears, often caused by exposure to loud noise.

CURRENT SAFETY PRACTICES AND CHALLENGES

Most Indian construction companies claim to have adopted safety measures, but there is a great deal of challenges:

- There is a variation in the implementation of different safety practices among varied projects and contractors.
- Not all the workers, especially those of the informal sector, are aware of the existing safety regulations and safe work practices.
- Cost pressure sometimes compromises with safety.
- Less Resources: Small contractors do not have the ability to implement integrated safety programs.
- Enforcement Problems: The problem of enforcement of safety regulations is also due to less resources and manpower.

NEW TECHNOLOGIES FOR SAFETY IMPROVEMENT

Technologies are rapidly changing the construction industry, with new solutions in improving safety and well-being at work. There are a few key developments especially relevant to the Indian context:

(A) BIM: Building Information Modeling:

BIM is the digital representation of a building or infrastructure project.

- Safety related benefits:

Hazard identification and analysis during Design: BIM enables project teams to visualize the entire project in 3-D. This allows the project team to identify potential hazards, for example, clashes between structural elements and utilities or confined spaces, at design. This is very important for safe proactive planning during construction.

Safety Planning and Simulation: BIM is used to simulate construction sequences to identify potential safety risks associated with different construction methods. This leads to the creation of safer work procedures.

Clash Detection: With BIM, clash detection occurs automatically between building systems, such as ductwork and piping. This prevents costly rework on site and the risk of accidents.

4D Scheduling: The involvement of time, as added in BIM, enables visualization of the construction schedule in order to identify safety risks that are associated with particular project phases.

(B) Wearable Technology: Wearable equipment is constantly being developed and may be very useful in many potential safety areas:

Smartwatches and fitness trackers: Those can track all vital signs such as heart rate, body temperature of workers with an alert possibility about health danger from heat stress. They will be able to trace the whereabouts of the employee and his working activities.

Fall Detection: They can help in detecting any falls and transmitting signals to a supervisor automatically with this device which allows for speedy reaction in a case of mishap.

Proximity Sensors: Alert workers when they are closing in on hazardous zones or apparatus.

Smart PPE: Add sensors to PPE's like hard hats or harnesses that provide real-time information regarding the safety of workers and environmental conditions.

(C) Drones: The UAVs, or drones have become indispensable equipment on construction sites:

Site Inspections: Drones can be used to perform an aerial inspection over roofs and bridges, thus allowing fewer workers into dangerous locations.

Monitoring of Progress: Photos and videos of the project by the drones will enable the project managers to track the progress and they would then know when to warn about potential delays and develop an early warning on safety issues.

Hazard Identification: Cameras and sensors in the drone are meant to scan for hazards such as poorly constructed scaffolding, exposed wire or materials stockpiled in inappropriate ways.

Thermal Imaging: It is provided with thermal cameras that detect any possible fire hazard or equipment overheating.

(D) Virtual Reality Training: VR will provide a safe yet immersive means for construction workers to train in safety:

Realistic Simulations: The VR will be used to simulate a real-world scenario of construction, allowing the workers to practice safe working procedures and responding to emergencies.

Hazard Recognition Training: VR is helpful for the training of workers about recognizing and avoiding construction site hazards.

Equipment Operation Training: Virtual reality gives proper realistic training about the safe heavy equipment operations.

Cost-Effective Training: As the chance of onsite accidents will reduce with less onsite training and the chance of occurrence during the training in virtual reality.

(E) Exoskeletons: Exoskeletons are wearable machines used for the augmentation of strength and endurance capabilities.

Reduces Physical Strain: Lifting of heavy objects minimizes a great deal of manual handling injuries through the help of exoskeletons for workers.

Better Posture: Exoskeletons can assist workers to support proper posture and thereby reduce strain on the backs and other joints.

Increased Productivity: With a reduction in fatigue and risk of injury, exoskeletons can enhance the productivity of the workers.

(F) Artificial Intelligence (AI): AI is being used to gain insight into data and enhance safety through the following ways:

Predictive Analytics: AI algorithms can possibly examine data coming from various sources including accident reports, sensor data, and weather data in discovering patterns and forecasting future dangers.

Computer Vision: AI-driven computer vision can be used in real-time to monitor construction sites and detect unsafe behaviours, for example, non-wearing PPE or operating in unauthorized zones.

Automated Safety Inspection: AI will automate the inspection of safety features through images and videos captured from drones or cameras.

STAKEHOLDER ENGAGEMENT AND COLLABORATION

Effective safety and welfare management involves the active participation of all stakeholders, including:

- Employers and Contractors: Responsible for providing a safe work environment and implementing safety measures.
- Workers: Responsible for following safe work practices and reporting hazards.
- Supervisors: Responsible for enforcing safety rules and providing guidance to workers.
- Clients and Developers: Safety performance can be affected by having stringent safety requirements placed in the contracts.
- Government Agencies: These include creating and implementing the safety laws and regulations.
- Safety Professionals: Experts to be sought and consulted in order to establish safe management.
- Industry Associations: This includes organizations such as the Indian Building Congress that help advance awareness of safety practices and policies.

INTEGRATED FRAMEWORK FOR INCREASED SAFETY AND SECURITY

This research proposes a multi-faceted, holistic framework to significantly improve safety and welfare in the Indian construction industry. It recognizes that a single approach is insufficient and that progress requires addressing multiple interconnected factors.

The framework encompasses the following key elements:

(A) Strengthening Legal and Regulatory Framework: The legal and regulatory framework must be robust, up-to-date and effectively enforced.

This involves:

Review and update: Regular review of existing legislations, which include Factories Act, BOCW Act, and the state rules of the concerned state, to respond to the emergent challenges and technological changes in the context of new safety hazards. Obsolete or inadequate provisions should be modified.

Gap analysis: Thorough gap analysis to ascertain the lacuna in the current legal framework to be strengthened or supplemented.

Effective Enforcement: Improve the enforcement capacity by resource infusion, training, and modernization. More severe punishment of offenders must be enforced without compromise.

Simplified Rules for SMEs: Safety regulations should be prepared as simple and suitable to the small and medium enterprises (SMEs), since these SMEs usually lack all resources possessed by the big ones.

(B) Developing a Safety Culture: Real safety culture comes from a significant change in behaviour and attitude from the top level down:

Leadership Commitment: Top management commitment to safety is visible and irreversible. Safety needs to be ingrained as part of the business culture, rather than just complying with the letter of the law.

Worker Empowerment: Educate workers so that they actively participate in managing safety, so that they would report hazards promptly and are allowed to join in safety committees.

Positive Reinforcement: Reward safe behaviours and practices. Focus on positive reinforcement rather than solely on punishment for violations.

Open Communication: Open communication about safety concerns. Create channels for workers to report hazards without fear of reprisal.

Safety Awareness Campaigns: Regular safety awareness campaigns to reinforce safe work practices and raise awareness of hazards.

(C) Investment in Training and Education: A skilled and safe workforce depends on comprehensive and continuous training:

Programmed training for various worker groups: To develop specific targeted training programs for all worker groups, including supervisors, operators and general labourers, in accordance to their distinct roles and responsibilities.

Hands-on or on-site training: Practical training that replicates real construction practice; use simulation technologies such as VR where practical.

Refresher Courses: To offer refresher courses to regularly refresh safety knowledge and bring new regulations and best practices to workers.

Training for Informal Workers: To design training for informal workers who are usually denied formal training opportunities. To engage NGOs and community organizations to train this vulnerable population.

Language Accessibility: Ensure that training materials and programs are in the languages that can be understood by the various languages of the migrant workforce.

(D) Leveraging Technology: To improve safety performance by embracing new technologies.

In this case, (a)BIM for Safety Planning (b)Wearable Technology (c)Drones for Site Inspections(e)VR Training (f) AI for Predictive Analytics can be utilised as mentioned.

(E) Improving Stakeholder Cooperation: Effective safety management involves the cooperation of all stakeholders:

Government Agencies: Improve collaboration among various government agencies responsible for safety and health, labour, and environment.

Industry Associations: To involve industry associations like the Indian Building Congress to facilitate safety best practices and create industry standards.

Contractors and Subcontractors: To enhance collaboration between contractors and subcontractors to ensure uniformity of safety standards across the chain of supply.

Worker Organizations: To encourage worker organizations and unions to participate in safety management and training.

Research Institutes: To collaborate with institutes conducting research on occupational safety and health in construction with the aid of innovative solutions.

Improving Data Collection: Strong data collection and analysis form the foundation of understanding safety trends and implementing effective interventions:

Standardized Reporting Systems: To implement standardized systems for reporting accidents and near misses.

Data Analysis: To analyse accident data to identify trends, root causes and high-risk activities.

Information Sharing: To share safety data and lessons learned with the industry to prevent similar incidents from occurring.

(F) Addressing Occupational Health: Occupational health is often overlooked but is just as important as physical safety:

Hazard Identification and Control: Occupational health hazards like dust, chemicals, noise and vibration are identified and controlled.

Health Surveillance: Health surveillance programs are implemented to monitor the health of workers and detect early signs of occupational diseases.

Ergonomic Design: The use of ergonomically designed tools and equipment is promoted to reduce the risk of musculoskeletal disorders.

(G) Welfare Measures: Providing adequate welfare facilities is a basic human right and contributes to worker well-being and productivity:

Clean Drinking Water: To ensure availability of clean and cool drinking water, at all times.

Sanitation Facilities: To make available clean toilets and washing facilities.

Rest Areas: Shaded rest areas to allow workers to rest.

First-Aid Facilities: First aid facilities and trained first aiders available on the work site.

Healthcare: Facilitating access to healthcare services for workers, this includes occupational health services.

Crèches: Crèches - children of women employees at work, subject to the provisions of the law.

CONCLUSION

Enhancing safety and construction welfare is a fundamental imperative for the Indian construction industry. By embracing an integrated response encompassing strengthening regulations, cultivating a culture of safety, harnessing technology and developing stakeholder cooperation, the industry will effectively improve its safety performance. The Indian construction sector can only create a safer, healthier and more productive workplace for its workers and thus ensure the growth and sustainability of the industry.

POST FIRE INVESTIGATION & STRUCTURAL MITIGATION OF RC FRAME BUILDING: A CASE STUDY

RAM BABU PRASAD*

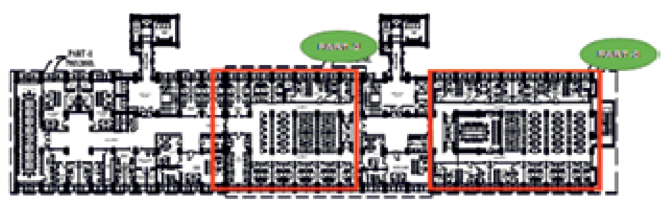
Abstract

Fire is a major hazard that can severely damage building structures, necessitating thorough evaluation of their reusability. This study investigates the fire-induced distress in the structural members of Visvesvaraya Bhavan (Technical Secretariat), located in Patna, Bihar. The building comprises seven floors, with six floors constructed as a moment-resisting reinforced concrete (RC) frame structure with masonry infills, and the seventh floor made of steel columns and trusses. The building houses several departmental offices. Visual inspections revealed significant fire damage on the fifth floor and the sixth floor, affecting beams, columns, and slabs, resulting in a reduction in the structural capacity. Concrete neutralization tests indicated that these structural members were exposed to temperatures exceeding 500°C during the fire. Rebound hammer test (RHT), ultrasonic pulse velocity (UPV), and concrete core tests confirmed the loss of strength in the affected areas, with core tests showing compressive strengths ranging from 6.0 to 14.3 MPa. To restore the building's structural integrity, 3D numerical model was prepared, incorporating both original and reduced strength parameters. Retrofitting recommendations were based on IS 15988-2013 and ACI 549.4R-20. Post-retrofit testing, including UPV, RHT, and core tests, confirmed that the target strength for the columns, beams, and slabs was achieved. Additionally, the restored slab capacity was verified through static load testing. The restoration and retrofitting efforts successfully reinstated the structure's strength and ensured its safety for continued use.

INTRODUCTION

Visvesvaraya Bhavan, also known as the Technical Secretariat, is located at Bailey Road, Patna. It houses multiple departmental offices, including BCD, RWD, Road Construction Department (RCD), and the Bihar State Planning Board. The building is a seven-story structure, with six floors consisting of moment-resisting reinforced concrete (RC) frames with masonry in fills, while the seventh floor is constructed with steel columns and trusses. On May 11, 2022, a fire broke out in the part-2 area of the fifth floor and quickly spread to the adjacent part-3 area. The fire escalated due to the presence of highly flammable materials, including paper, plastics, and wooden items. The fire, which lasted for several hours, spread via expansion joints containing electrical and air conditioning wiring, affecting both the fifth and sixth floors. Figure 1 illustrates the affected areas of the fifth and sixth floor, respectively. The objective of this study is to evaluate the residual capacity of the affected structural elements (beams, columns, and slabs) through non-destructive tests (NDTs) such as neutralization test of concrete, UPV test and rebound hammer test (RHT) and consequently, to retrofit the damaged structural members and restore its original capacity.

*Superintending Engineer, Design Building Construction Department, Govt. of Bihar



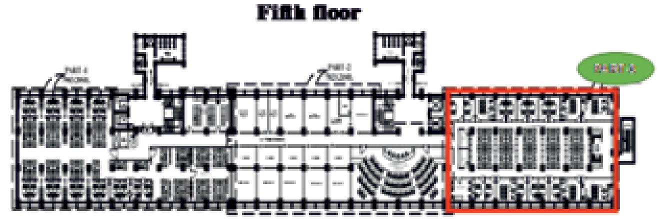


Fig. 1: Fire affected areas of fifth and sixth floor.

DAMAGE EVALUATION

Visual Inspection

The fire-induced damages were primarily observed in the beams and columns of the affected parts on the fifth and sixth floors. Notable distresses were observed including the spalling of the concrete, accompanied by pink discoloration in the areas where spalling occurred. Several exposed plain reinforcement bars were visible at various locations due to the concrete spalling (Ref. Fig. 2a). The presence of shattered glasses, distorted ceiling fans, aluminum wires, and over burnt wooden doors confirmed the significant rise of temperature beyond 500˚C due to fire (Ref. Fig. 2b to 2e). The mortar plaster on the ceilings were delaminated at several locations exposing the burnt surface of concrete as seen in Fig.2f.

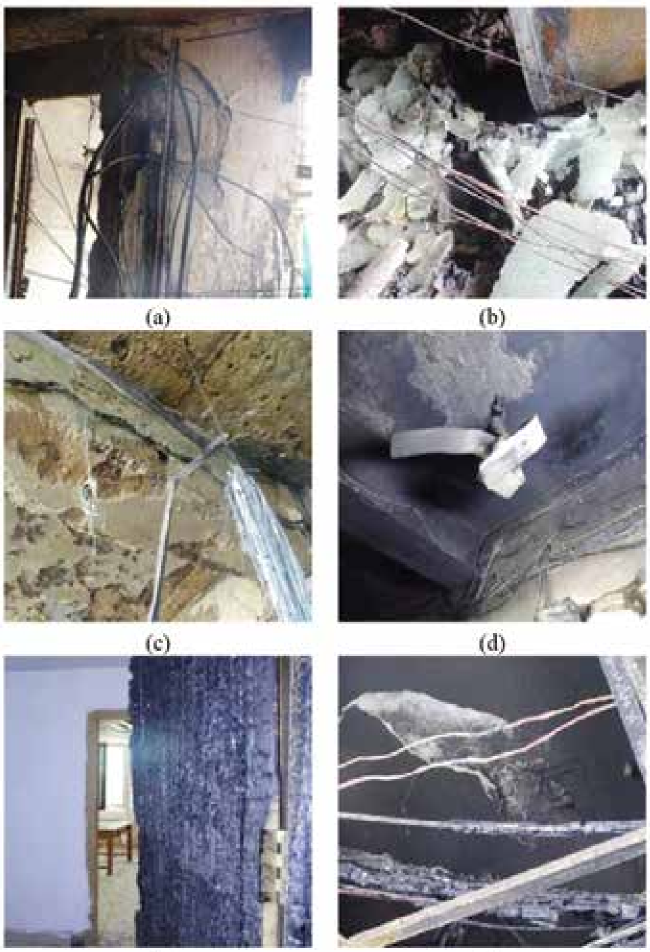


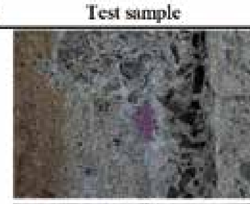
Fig. 2 :(a) Exposed plain reinforcement bars (b) Shattered glasses, (c) Melted iron sections, (d) Distorted fans due to heat, (e) Burnt wooden door, and (f) Delaminated plaster of ceiling.

The presence of pink discolouration on surface of concrete exposed to fire revealed that the temperature has risen above 300˚C [1], which resulted in the degradation of strength of concrete mechanical properties. As a result of such an elevated temperature, the properties of the exposed reinforcing bars also reduced.

Neutralization Test

The neutralization test of the concrete was performed using the phenolphthalein method by evaluating its pH level. The change in the colour of the phenolphthalein solution inferred about the neutralization depth in the concrete member and consequently its level of degradation due to exposed temperature. 1% phenolphthalein solution was used for the test. The changed dark pink colour signified the temperature level was below 500˚C [2] whereas no change in colour indicated a temperature level of above 500˚C. Few concrete sample exposed to fire showed light pink color. The possible reason could be that the calcium oxide (CaO) produced upon chemical decomposition of calcium hydroxide [Ca(OH)2], at elevated temperature (>500˚C), converted back to Ca(OH)2 due to application of water while fire fighting. Table 1 presents the summary of the results of the neutralization test.

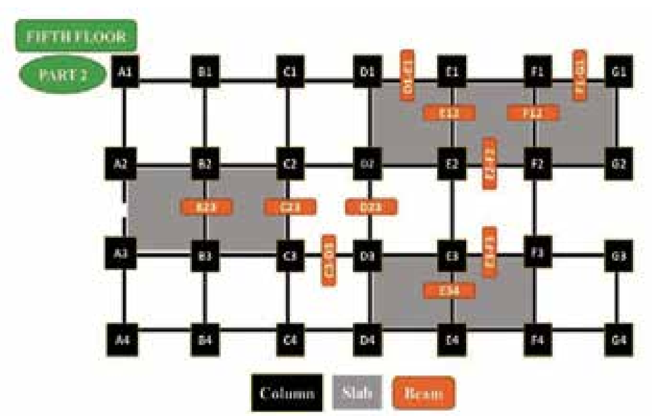
Table 1: Summary of the neutralization test

S. No.	Exposed surface color	Test sample	Remarks
1.	Sample 1-Pink		Temp < 500˚C
2.	Sample 2-Light pink		Temp> 500˚C
3.	Sample 3- colorless		Temp> 500˚C

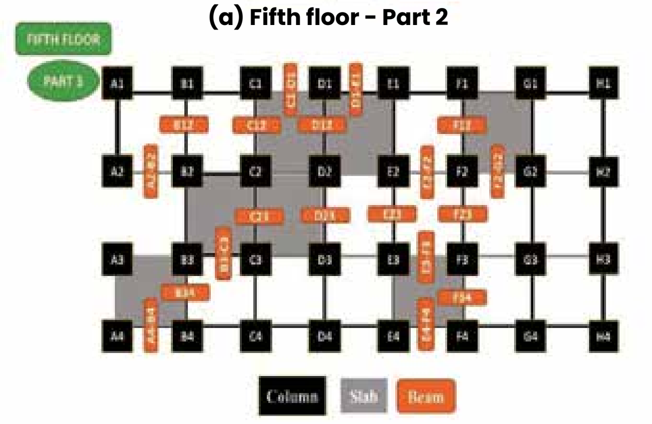
Non-Destructive Tests

- **Rebound Hammer Test**

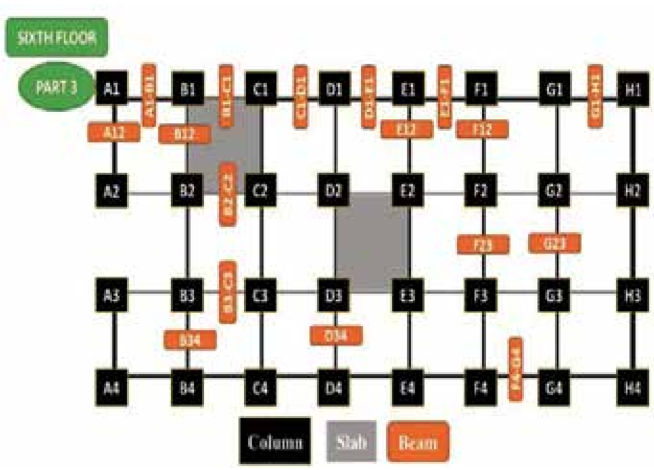
Figure 3 illustrates schematic diagram of the beams, columns and slabs of the parts of the fifth and sixth floor, respectively which were mostly exposed to fire. Rebound hammer test was conducted on these selected elements of the respective floors. This test is used to access the quality of concrete and is based on the principle of mass rebounding which depends on the hardness of the surface against which it strikes. When the plunger of the rebound hammer is pressed against the surface of the concrete, the spring-controlled mass rebounds. The surface hardness and the rebound are related to the compressive strength of the concrete (IS-13311-part 2,1992) [3]. Results of this test has been presented in Fig. 4.



(a) Fifth floor - Part 2



(b) Fifth floor- Part 3



(c) Sixth Floor –Part 3

Fig. 3 : Location of beams, columns and slabs on (a) & (b) floor 5, and (c) floor 6.

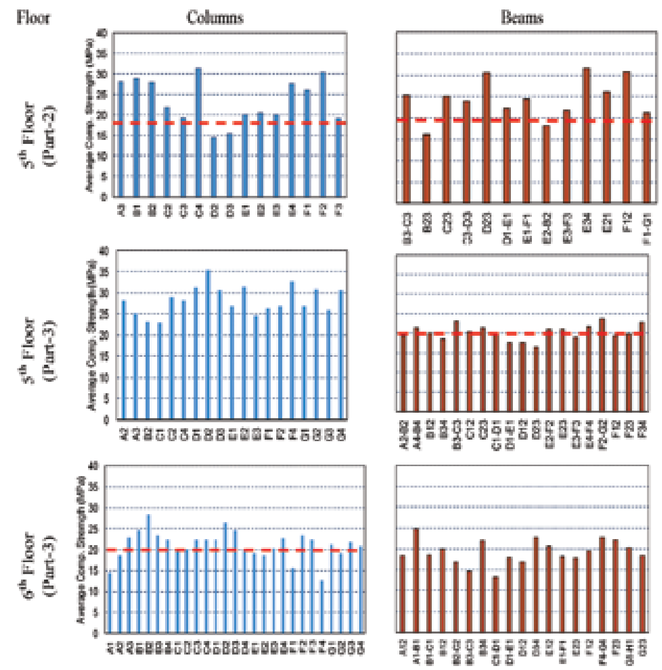


Fig. 4: Compressive strength of columns and beams of fifth floor & sixth floor.

Results of rebound hammer test for the part 2 and 3 for the beam and column was found to be lower than 20 MPa (Fig.4), whereas few locations of slabs were tested where average strength after fire exposure was found to be below 15 MPa. Similar results were observed for the respective members of floor 6 (Figure 4).

- **Ultrasonic Pulse Velocity Test (UPV).**

As a result of spalling of concrete from the damaged elements, few locations were chosen to conduct UPV test as per IS 516 part 5: sec-1, 2018 [4]. Presence of cracks caused difficulty to perform this test.

- **Concrete Core Test**

Five core samples were extracted from the damaged sections of the 5th and 6th floors of Visvesvaraya Bhawan using the core cutting procedure. These core samples were initially processed using a cutting machine to smoothen the loading surface (see Fig. 5a), preparing them for compression testing in a Universal Testing Machine (UTM) in accordance with IS 516 Part 4 (BIS, 2018) [5]. The samples were subsequently tested in the UTM under a displacement-controlled process at a loading rate of 1 mm/min (as depicted in Figure 5b). The compressive strength values obtained from these tests, along with the necessary corrections, are presented in Table 2.

(a) (b)

Fig. 5: (a) Core samples, and (b) compression test in UTM.

Table 2 : Summary of results of compression test of core samples.

Member	Dia (mm)	Height (mm)	H/D	CF for Dia	CS (MPa)	CF for H/D	Final CS (MPa)	Equ cube strength (MPa)
C4	68	151.98	2.24	1.06	10.5	1.03	11.42	14.27
E2	65.9	118.59	1.8	1.06	5.86	0.98	6.07	7.59
A2	68.17	75.22	1.1	1.06	7.30	0.90	6.97	8.72
F1*	66.85	59.09	0.88*	1.06	7.73	0.88	7.19*	8.98
Floor	67.04	93.32	1.39	1.06	4.87	0.93	4.82	6.03

CF- correction factor; CS- compressive strength,* sample not considered as H/D <1.

Based on the evaluation of the results, it was concluded that grade of concrete greater than 20 MPa was originally used for columns and other structural members. The results of core compression test indicated a significant reduction in the compressive strength. The above analysis emphasized that the exposed columns, beams, and slabs suffered a significant reduction in strength as a result of distresses caused due to fire. Therefore, the elements of the respective parts of the floor need appropriate restoration through proper retrofitting techniques.

RESTORATION VIA RETROFITTING

Numerical Modeling

3D model of the affected building was prepared using ETAB software (Figure 6). The numerical analysis was performed using the original strength and geometrical data as well as with the reduced strength after fire. Results showed an average reduction up to 30-40 % in axial (Figure 7a), flexural (Figure 7b) and shear strength (Figure 7c) in columns and beams due to fire exposure.

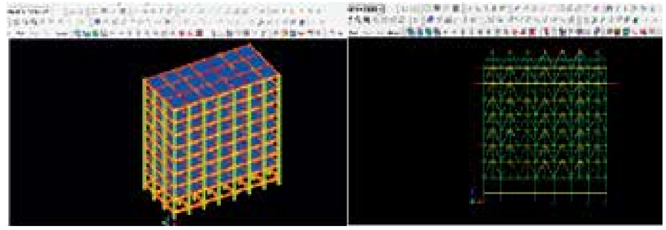


Fig. 6: 3D Model of building.

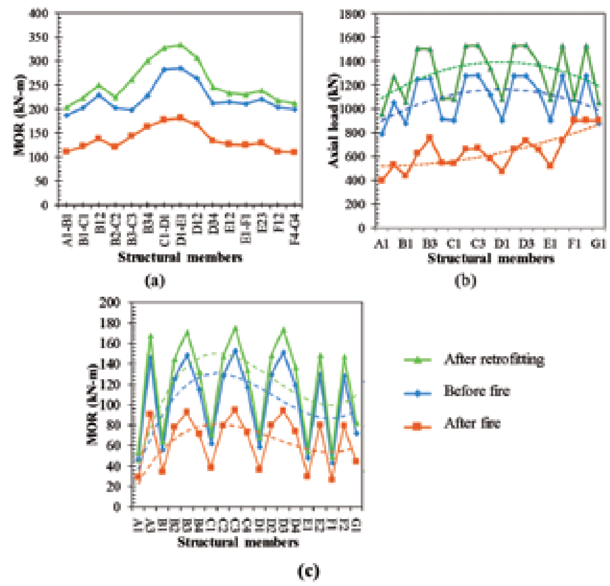


Fig. 7:(a) Flexural strength of beams, (b) Axial capacity of columns, and (c) Flexural capacity of columns.

Proposed Retrofitting Technique

The surface and structural retrofitting of the damaged beams, columns, and slabs was done. Surface repair work was performed using PU (polyurethane) based epoxy-injection grouting. The structural capacity such as axial, shear and flexural capacity of columns were restored to its original strength using reinforced concrete jacketing as per the recommendations of IS 15988-2013 [6]. The flexural strengthening of RC beams and slabs were done using carbon reinforced fiber cementitious matrix, as per the recommendation of ACI 549.4R-20 [7].

- **Column retrofitting-RC jacketing**

The entire loose mortar and plaster all around the column was initially removed and thoroughly cleaned, and any exposed reinforcement after cleansing was applied with a full coat of anticorrosive treatment. The surface cracks and voids were repaired by injecting PU based epoxy. The jacketing was designed considering the compressive strength of existing concrete column as 8 MPa. In order to ensure the retrofitted column has axial capacity equal to column of grade M20, RC jacketing of thickness of 100 mm was recommended (Fig. 8).

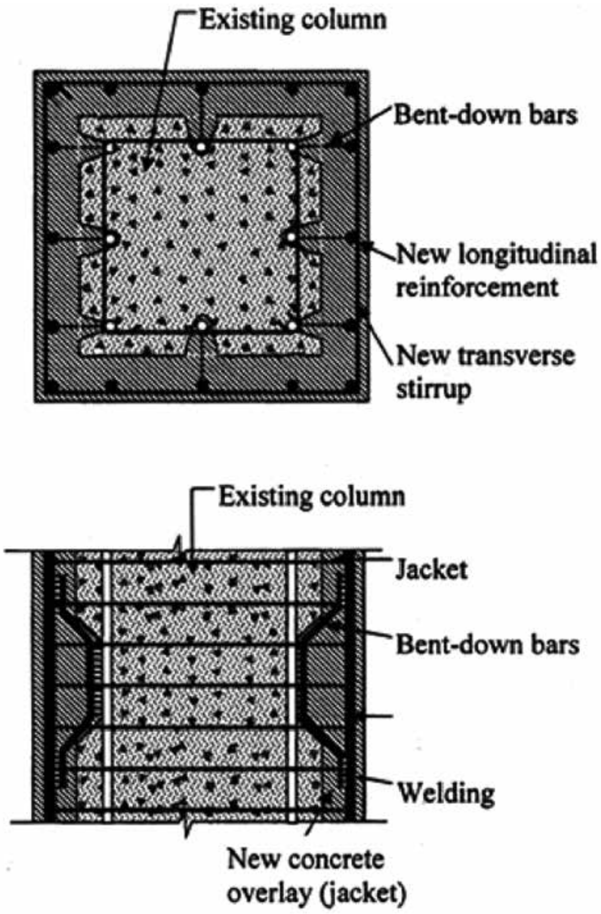


Fig. 8: Proposed reinforced concrete jacketing

The jacketing was provided with 4-16 mm diameter reinforcement bars at the corners and 12-12 mm diameter bars of grade Fe500 were uniformly distributed along the edges as depicted in Figure 8. Bent-down bars of diameter 10 mm was employed along the bottom, middle and top of the column to enhance the anchorage of added new concrete. A clear cover of 30 mm was maintained to avoid exposure to environment. Adequate shear reinforcement bars of diameter 10 mm were provided at spacing of 100 mm c/c to avoid shear failure of column as per IS 15988-2013. The grade of concrete was adopted as M25.

- **Beam and slab retrofitting**

The loose concrete portions from the existing beam and slab were removed through light hammering. These areas were then thoroughly cleaned, and the entire surface underwent sandblasting to expose the underlying concrete and the present debris was then removed from the reinforcing bars. After cleaning, the exposed surface was treated with a full coat of anti-corrosive treatment to prevent further deterioration. Surface cracks and voids were repaired by injecting a PU-based epoxy resin to restore the integrity of the structure.

For the flexural strengthening of the reinforced concrete (RC) beam and slab, carbon fabric reinforced cementitious matrix (FRCM) was utilized, in accordance with the recommendations outlined in ACI Code 549.4R-20. The average strength of the concrete core was found to be 8 MPa, whereas the target required strength of the beam and slab was 20 MPa, indicating a need to increase the concrete strength by approximately 12 MPa. In accordance with clauses 4.1.7 and 4.1.8 of ACI FRCM 549.4R-20, the beam and slab was retrofitted using C5 carbon FRCM (refer to Appendix A of ACI 549.4R-20).

To begin, a 5 mm thick high-strength mortar was applied to the clean surface of the beam and slab. Subsequently, C5 carbon fabric with a density of 200 g/m^2 was adhered to the surface using stainless steel nails. Finally, a 10 mm thick layer of high-strength mortar was applied over the carbon fabric. These procedures must meet the minimum requirements specified for C5 carbon FRCM as per ACI Code 549.4R-20 as presented in Table 3

Table 3: properties of Carbon fabric cementitious composite and matrix.

Carbon fabric	Density, (kg/m3)	200
	Thickness,t (mm)	0.048
	State	Dry
	Tensile strength (MPa)	2500
	Elastic modulus (kPa)	230
Matrix	Type	Cement
	fmc (MPa)	20
	Em (kPa)	16

- **Results and discussion**

The structural capacity was reduced by 30-40% of the original capacity after exposure to elevated temperature of more than 500˚C. The damaged structures were therefore retrofitted using the proposed technique discussed in section 3.2. Further, numerical analysis was performed by incorporating all the three-stage properties (i.e. original, post-fire, and retrofitted materials). The results demonstrate that the deployed retrofitting method successfully restores the original capacity of the damaged structural elements as shown in Figure 7.

CONCLUSION

Fire is a critical hazard that can significantly compromise the structural integrity of building elements. Based on the findings from the visual inspection, neutralization tests, and various diagnostic methods, it is evident that the structural components of the fifth floor (Part-2 and Part-3) and the sixth floor (Part-3) had sustained substantial damage due to exposure to high temperatures, likely exceeding 500°C. The results from the rebound test, and concrete core indicated that the strength of the beams, columns, and slabs in these areas had been severely compromised, with concrete strength values ranging from 6.0 MPa to 14.3 MPa, which was far below the required threshold for structural performance.

The deterioration of these structural members demanded immediate attention, as they exhibited significant reductions in load-carrying capacity. Based on these findings, restoration and retrofitting of the affected columns, beams, and slabs were necessary to restore their original structural strength and safety. To address this, a 3D model of the entire building was developed, incorporating both the original and reduced strength parameters, as well as the geometric data of the structure. Detailed analysis confirmed that the target original strength could be achieved through retrofitting measures, following the guidelines set forth in IS 15988-2013 and ACI 549.4R-20 for concrete structures.

Therefore, it is concluded that, with the recommended retrofitting interventions, the structural integrity of the affected areas can be effectively restored, ensuring the building's safety and compliance with design standards.

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BUILDING SURAKSHA (SAFETY) : SMART TECH AND WORKER KALYAN (WELFARE) FOR INDIA'S CONSTRUCTION FUTURE

Lt. Col. Mohinder Pal Singh Ghai* And Lt. Col. Jayprakash Misal*

Abstract

The young India is aspiring and cruising to become $55 trillion economy in 2047 when it will complete 100 years of independence. Infrastructure growth is key contributor and mandatory to achieve such mile stone. Govt of India is pushing the capex in projects like road / rail connectivity, housing for all, make in India and many others projects and to achieve the growth the construction, industry is expanding in terms of number of people working and technological advancement. The growth adds the responsibility of creating safe work place to have inclusive development however, high accident rate and inadequate welfare provisions still persist. An effort to enhance safety and efficiency by integrating smart technology at work place is being discussed in this paper. Beyond safety, welfare programs such as health insurance, sanitation facilities, and skill development initiatives, essential for participants in the growth are being discussed with some case studies. Govt of India has tried to ensure safety and welfare through regulations particularly the BOCW Act, however there are gaps in enforcement and opportunities for reform. By integrating cutting-edge innovations with robust welfare frameworks, India can create a safer, more productive, and sustainable construction ecosystem. The findings offer a roadmap for industry stakeholders, policymakers, and developers to adopt technology-driven and worker-centric construction practices for the future.

INTRODUCTION

India's rapid urbanization has led to an unprecedented demand for construction, making worker safety and welfare a critical concern. Despite contributing 9% to the national GDP, the construction sector remains one of the most hazardous industries, with over 38 fatal accidents per 100,000 workers annually[1][2]. The industry relies heavily on manual labour, where poor working conditions, lack of personal protective equipment (PPE), and inadequate welfare programs are widespread.

To address these issues, the sector is witnessing a technological transformation. The integration of smart technologies—such as the Internet of Things (IoT), robotics, 3D printing, and Building Information Modeling (BIM) is revolutionizing construction safety. These innovations allow for real-time monitoring, automation of hazardous tasks, and predictive risk management [3].

However, safety alone is not sufficient, worker welfare measures such as health insurance, housing, sanitation, and skill development are equally vital for ensuring well-being[4]. The Building and Other Construction Workers (BOCW) Act was introduced to regulate worker welfare, but implementation gaps and lack of enforcement continue to hinder its effectiveness[5].

This paper explores how cutting-edge construction technologies can work alongside stronger welfare policies to create a safer, more sustainable, and worker-friendly construction ecosystem in India. Through case studies, policy analysis, and real-world applications, it presents a roadmap for industry stakeholders to enhance both "Suraksha" (safety) and "Kalyan" (welfare).

INNOVATIONS IN CONSTRUCTION TECHNOLOGIES[6]

Table 1: Comparison of Energy Consumption in Traditional vs. Smart Buildings

Feature	Traditional Building	Smart Building
Lighting Control	Manual Switches	Automated Sensors
HVAC Control	Manual Thermostats	AI-Optimized HVAC
Occupancy Sensing	None/Limited	Real-Time Sensors

** Structural Engineers*

Energy Monitoring	Manual Meter Readings	Digital Dashboards
Predictive Maintenance	Reactive Repairs	AI-Based Monitoring
Energy Consumption	Higher	15-30% Reduction
Waste Reduction	Minimal	Significant
Data Analytics	Limited	Comprehensive
Integration	Isolated Systems	IoT-Enabled System
Example Technologies	Incandescent Lights, Centralized HVAC	LED Lighting, Smart Sensors
Reduction in Energy Use	0-5%	15-30%

- **Smart Buildings and IoT Integration**[7]

The integration of IoT-based smart sensors in buildings is revolutionizing site safety and energy efficiency. IoT technology enables real-time monitoring of structural integrity, hazardous gas levels and worker health conditions[8].

Fig. 1: Diagram of IoT sensor network in a smart building

Case Study: Infosys Campus, Pune[9]

- Implementation: IoT sensors for energy management, fire safety, and security.
- Impact: 20% reduction in energy consumption, improved safety compliance, and predictive maintenance.

IoT-enabled wearable sensors can also track worker fatigue, detect falls, and send emergency alerts in case of accidents, significantly reducing response times in hazardous conditions [10].

- **3D Printing in Construction**

3D printing is disrupting traditional construction by offering faster, cost-effective, and sustainable building techniques. It enables:

- Rapid construction with minimal waste.
- Customization of building components.
- Lower reliance on manual labour, reducing safety risks[12].

Table 2: Comparison of Construction Time and Costs for Traditional vs. 3D-Printed Houses in India[11]

Feature	**Traditional Houses**	**3D-Printed Houses**
Construction Time	12-18 months	2-4 months
Labor Requirements	High (Skilled labourers)	Low (Machine Operators)
Material Cost	₹2,000 - ₹3,000/sq ft	₹1,500 - ₹2,500/sq ft
Overall Construction Cost	₹1,500,000 - ₹3,000,000	₹750,000 - ₹1,500,000
Waste Generated	High	Low
Energy Usage	High	Low
Customization	Limited	High
Sustainability	Moderate	High
Post-Construction Adjustments	Expensive & Time-Consuming	Easier & Cheaper

Case Study: 3D-PrintedTest Housing, Tamil Nadu The first Indian 3D printed house, inaugurated by the Hon. Finance Minister Ms. Nirmala Sitharaman. It was printed in modules at Tvasta Construction facility in Chennai and assembled at site. The entire project (500 sq. ft.) was completed in 21 days. This building was constructed as a 'proof of concept' structure.[12]

Fig. 2: 3D-Printed House, IIT-M, Chennai

Source : Tvasta Construction

- Implementation: 3D-printed houses for low-income communities can be achieved.
- Impact: 50% reduction in construction time, 30% cost savings, and lower material waste.
- **Robotics and Automation for Hazardous Tasks**[14]

Robots are now used for bricklaying, welding, site surveying, and demolition, reducing human exposure to hazardous environments[15].

Fig. 3 : Images of a robotic arm performing welding on a construction site

Case Study: Autonomous Mining Vehicles in Rajasthan[16]

- Implementation: Deployment of self-driving trucks in mining operations.
- Impact: 40% reduction in on-site accidents, 25% increase in efficiency.

Robotics can also improve high-risk construction activities, such as tunnel boring, concrete pouring, and hazardous material handling[17].

Table 3: List of Robotic Applications in Indian Construction Sites

Robotic Application	Description	Example in India
Robotic Bricklaying	Lays bricks automatically, reducing errors.	Bengaluru Smart City
Drones for Surveying	Conducts real-time site monitoring.	Delhi Metro Project
Autonomous Vehicles	Self-driving vehicles transport materials.	Rajasthan Mining Sites
Robotic Arms for Welding	Performs precise welding on steel structures.	Mumbai Metro
Robotic Excavation Machines	Performs deep digging in hazardous areas.	Mumbai Coastal Road
3D Printing Robots	Prints housing components layer by layer.	Tamil Nadu Housing Project
Robotic Concrete Pouring	Automates pouring in foundations.	Hyderabad Infrastructure
Robotic Demolition	Dismantles structures with minimal risk.	Gujarat Chemical Plants
Robotic Safety Monitors	AI-driven site surveillance for safety compliance.	Nagpur Metro Project

- **Building Information Modeling (BIM) for Risk Management**[18]

BIM provides 3D to 8D (even Nth D) digital simulations of construction projects, allowing for risk detection before construction begins. BIM integrates safety planning by predicting worker hazards, structural weaknesses, and compliance gaps [19].

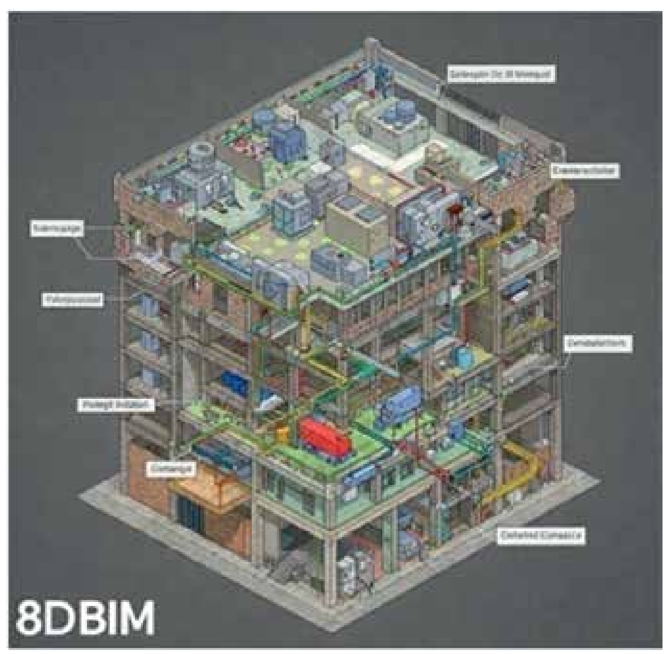

Fig. 4: 8D BIM model of a building

Table 4 : Improvement in safety planning with BIM implementation

Project/ Location	Before BIM Implementation	After BIM Implementation	Improvement in Safety (%)
Delhi Metro Rail Corporation (DMRC)	20% identified hazards early	50% identified hazards early	150%
Mumbai Metro Expansion	25% effective hazard mitigation	60% effective hazard mitigation	140%
Chardham Highway Project, Uttarakhand	10% hazard detection	40% hazard detection	300%
Bangalore IT Corridor Projects	15% risk assessment	50% risk assessment	233%
Taj Mahal Hotel Construction, Mumbai	30% construction site planning	70% construction site planning	133%

Case Study: Delhi Metro Construction[20]

- Implementation: BIM-based risk analysis for clash detection and worker safety planning.
- Impact: 15% reduction in on-site accidents due to early hazard identification.

SAFETY INNOVATIONS IN CONSTRUCTION [21]

- **Wearable Safety Technologies**[22]

Wearables such as smart helmets, sensor-enabled vests, and augmented reality (AR) glasses provide real-time monitoring of worker health and surroundings. These devices can:

- Detect toxic gas leaks.
- Alert workers in high-risk areas
- Monitor heart rates, body temperature, and fatigue levels [23].

Fig. 5: Image of a construction worker wearing a smart helmet

Table 5 : Reduction in Accident Rates with Wearable Safety Technologies

Project/ Location	Before Wearables	After Wearables	Accident Reduction (%)
Mumbai Metro Expansion	30%	21%	30%
Delhi Metro Rail Corporation	25%	16%	36%
Hyderabad IT Corridor Projects	40%	30%	25%
Bengaluru Infrastructure	15%	10%	33%
Tamil Nadu 3D-Printed Housing	20%	12%	40%

Case Study: Mumbai Metro Expansion[24]

- Implementation: Use of smart helmets to monitor worker conditions.
- Impact: 30% reduction in minor injuries, improved response times to emergencies.

- **Robotics for High-Risk Tasks**[25]

Robotic demolition machines, welding arms, and automated concrete mixers are increasingly replacing manual labour in hazardous zones [26].

Fig. 6: Types of hazardous tasks automated by robotics

Table 6: Types of hazardous tasks automated by robotics

Hazardous Task	Description	Robotic Solution	Example in India
Demolition	Demolition of old or unsafe structures involving hazardous materials such as asbestos or debris.	Robotic arms or machines equipped with hydraulic tools for controlled demolition.	Gujarat Chemical Plant: Robotic demolition for safe dismantling of old structures.
Welding	Welding at high altitudes or in confined spaces, exposing workers to burns and fumes.	Robotic arms equipped with welding tools for precise and automated welding.	Mumbai Metro: Robotic arms used for welding tasks in metro construction.
Concrete Pouring	Pouring concrete in hazardous or difficult-to-reach areas such as high-rise buildings or tunnels.	Robotic arms or automated systems to pour and distribute concrete.	Hyderabad Infrastructure Projects: Robotic concrete pouring in foundations.
Hazardous Material Handling	Handling toxic or hazardous materials such as chemicals, asbestos, or radiation.	Robotic arms or autonomous machines designed to safely handle dangerous materials.	Mumbai Coastal Road Project: Robots used for handling hazardous materials in excavation and tunnelling.
Bricklaying in High-Risk Areas	Bricklaying at dangerous heights or in unstable environments prone to collapse or accidents.	Automated bricklaying machines capable of working at heights or in precarious conditions.	Bengaluru Smart City Project: Use of robotic bricklaying in high-risk construction zones.
Underwater Construction	Construction tasks such as laying foundations or repairing underwater structures.	Underwater robots equipped with tools for construction or maintenance in submerged environments.	Mumbai Suburban Metro Project: Robotic systems used for underwater tunnel construction.
High-Altitude Work	Tasks like painting, welding, or installing components on tall buildings or bridges.	Autonomous drones or robotic arms equipped to work at high altitudes without human intervention.	Delhi Metro: Use of robots for high-altitude work like bridge installations.
Tunnel Construction	Excavating and constructing tunnels in challenging underground environments with high risk of collapse.	Robotic tunnel boring machines (TBM) automate digging and lining the tunnel walls.	Delhi Metro Tunnels: Robotic TBMs used in the construction of underground metro tunnels.
Surface Cleaning and Coating	Cleaning or coating surfaces in hazardous environments, such as removing rust or applying paints with toxic chemicals.	Robotic systems equipped with cleaning and coating tools for surface treatment.	Industrial Sites in Maharashtra: Robots used for cleaning and coating in toxic environments.
Site Inspection and Monitoring	Monitoring construction sites for structural integrity, air quality, and worker safety, often in hazardous environments.	Drones, robots with sensors, and cameras for real-time monitoring and inspection of hazardous areas.	Nagpur Metro: Drones and robots used for site monitoring in high-risk construction zones.

Case Study: Gujarat Chemical Plant Construction[27]

- Implementation: Robotic arms for handling hazardous chemicals.
- Impact: Eliminated human exposure to toxic materials, improving worker safety.

WELFARE MEASURES FOR CONSTRUCTION WORKERS[28]

- Health Insurance and Financial Security[29]

The Construction Workers' Welfare Fund provides:

- Health and accident insurance.
- Pension schemes.
- Maternity benefits and financial aid [30].

Table 7: Details of the Construction Workers' Welfare Fund

Benefit	Purpose	Eligibility	Funding Source	Implementing Authority
Health Insurance	Covers medical expenses for workers and families.	All registered workers under BOCW Act.	Employers, Employees	State Welfare Boards
Accident Insurance	Provides compensation and medical support for workplace accidents.	Registered workers under BOCW.	Employer & Employee Contributions	Labour Ministry
Pension Scheme	Monthly pension for retired construction workers.	Workers aged 60+ under BOCW.	Employer Contributions	State Welfare Boards
Maternity Benefits	Paid leave and financial assistance for pregnant workers.	Female workers under BOCW.	Employers	State Welfare Boards
Child Education Aid	Financial help for children's school & college fees.	Registered workers with children.	Government & Employee Contributions	State Welfare Boards, Education Dept.
Housing Assistance	Loans/subsidies to help workers build homes.	Workers registered in the welfare fund.	Welfare Funds & Subsidies	State Welfare Boards & Housing Authority
Skill Training	Funds training programs to upskill workers.	Registered workers seeking skill development.	Government & Employers	State Welfare Boards & Training Institutes
Safety Equipment Aid	Free helmets, gloves, and boots for high-risk jobs.	All construction workers, priority for high-risk jobs.	Government & Employers	State Welfare Boards
Emergency Medical Loan	Short-term financial support for medical emergencies.	Registered workers unable to afford treatment.	Government & Employers	State Welfare Boards
Funeral Assistance	Financial help for families of deceased workers.	Families of deceased registered workers.	Employers	State Welfare Boards

Case Study: Maharashtra Welfare Program[31]

- Implementation: State-funded health insurance for over 500,000 workers.
- Impact: Reduced out-of-pocket healthcare expenses, increased worker retention rates.

Sanitation and Basic Amenities[32]

Providing clean drinking water, sanitation facilities, and rest areas improves worker productivity and health [33].

Table 8 : Improvement in worker health with access to basic amenities

Basic Amenities	Impact on Health	Data Source	Impact Percentage
Clean Drinking Water	Reduces dehydration and waterborne diseases like diarrhoea	NSSO Reports, 2018	15% reduction in waterborne diseases
Sanitation Facilities	Decreases incidence of diseases like dysentery, cholera	ILO, 2019	20% reduction in gastrointestinal diseases
Mobile Toilets & Rest Areas	Reduces risk of infections and improves overall hygiene	NSSO Reports, 2017	10% improvement in worker health
Health Insurance Coverage	Provides access to medical care and reduces financial burden	ILO, 2020	25% improvement in workers' medical security
Adequate Shade and Ventilation	Reduces heat stroke and respiratory issues	National Safety Council Reports, 2021	30% reduction in heat-related illnesses

Example: Bangalore Construction Sites[34]

- Implementation: Mobile sanitation units, drinking water stations.
- Impact: 20% reduction in worker-reported illnesses.
- **Training and Skill Development** [35]

Equipping workers with modern skills ensures safety compliance and career advancement[36].

Table 9 : List of skill development programs for construction workers

Program Name	Objective	Implementing Agency	Target Audience	Key Features
Pradhan Mantri Kaushal Vikas Yojana (PMKVY)	Provide skill training and improve employability.	Ministry of Skill Development & Entrepreneurship (MSDE)	All youth, including construction workers	Training in masonry, carpentry, plumbing, and certification upon completion.
National Skill Development Corporation (NSDC)	Promote skill development and set national standards.	National Skill Development Corporation (NSDC)	Construction workers across India	Industry-specific training programs, financial support for training institutes.
BOCW Welfare Fund	Offer financial aid and training for construction workers.	Ministry of Labour & Employment, Govt. of India	Registered workers under BOCW Act	Financial assistance, training in safety, specific trade skills.
Skill Development in Construction Trades	Train workers in specialized construction trades.	State Governments, Industry Partners	Workers in urban & rural areas	Courses in scaffolding, welding, plumbing, electrical work.

AMRUT Skills Training	Improve skills for urban development projects.	Ministry of Housing & Urban Affairs (MoHUA)	Urban construction workers	Training in modern construction technologies & urban infrastructure.
Construction Skills Training Institute (CSTI)	Provide training in construction techniques & safety.	National Building Construction Corporation (NBCC)	Workers in large-scale projects	Courses on modern construction methods, equipment handling, safety protocols.
State-Level Skill Development Initiatives	Enhance worker skills at the state level.	State Governments (e.g., Tamil Nadu Skill Development Corp.)	Regional construction workers	Region-specific training in plumbing, electrical work, safety measures.
National Council for Vocational Training (NCVT)	Standardize and accredit construction skill training.	Directorate General of Training (DGT), MSDE	Workers seeking vocational certification	Accredited certification programs, improved job prospects, standardized skill levels.

Example: National Skill Development Corporation (NSDC) Initiatives[37]

- Training in modern construction technologies.
- Certification programs for safety protocols.

POLICY FRAMEWORK & REGULATION[38]

- **Enforcement of the BOCW Act**[39]

The BOCW Act mandates:

- Registration of workers.
- Provision of welfare schemes.
- Safety compliance in workplaces[40].

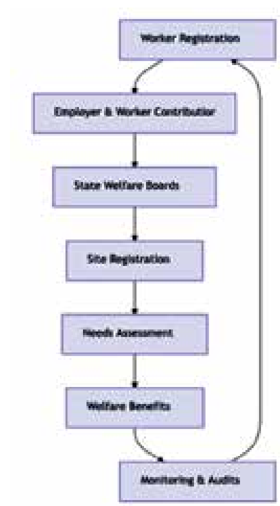

Fig. 7 : Flowchart of the BOCW Act implementation

However, compliance remains low, with many workers unregistered due to poor awareness and bureaucratic hurdles[41].

Table 10 : BOCW Act Implementation & Compliance Across Indian States

State	Enforcement Rate (%)	Compliance Level	Remarks
Maharashtra	90%	High	Strong enforcement, frequent inspections.
Gujarat	85%	High	Effective safety programs implemented.
Delhi	80%	Medium-High	Welfare programs good, but inconsistent enforcement.
Karnataka	75%	Medium	Good urban enforcement, rural areas need attention.
Tamil Nadu	70%	Medium	Welfare programs exist, but compliance lags.
Uttar Pradesh	60%	Low	Many unregistered workers, weak enforcement.
West Bengal	65%	Low	Limited enforcement in remote sites.
Rajasthan	55%	Low	Compliance weak, many projects avoid registration.
Andhra Pradesh	78%	Medium-High	Strong enforcement in cities, rural gaps exist.
Kerala	88%	High	High compliance, well-executed safety policies.

Case Study: Maharashtra's BOCW Implementation [42]

- Implementation: Digitized worker registration system.
- Impact: 90% compliance rate, ensuring more workers receive benefits.

CONCLUSION

The future of India's construction sector hinges on the seamless integration of technology and strong worker welfare policies [43]. While innovations such as IoT, robotics, and BIM are transforming safety standards and reducing accidents, ensuring workers' financial security, healthcare access, and skill development is equally vital [44]. However, technology alone cannot replace the need for human-centric policies. Without proper enforcement of welfare programs, the sector risks focusing on efficiency at the cost of worker well-being [45]. Bridging the gap between innovation and real-world impact requires a collective commitment from policymakers, industry leaders, and labour organizations [46].Construction is more than just buildings and infrastructureandis about the people who build them. By prioritizing both safety and sustainability, India can pave the way for a construction industry that not only builds cities but also secures the future of its workforce.

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Sector-VI, Kama Koti Marg, R.K. Puram, New Delhi-110022
Phone: 011-26169531, 26170197
Email: info@ibc.org.in indianbldgscongress@gmail.com
Website : www.ibc.org.in

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