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20th in series | 2026

08 To 11 JAN 2026

SOUVENIR 2026

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जीवनशैलीची सुरुवात !
नवीन घर घेणे हे आपल्या प्रत्येकाच्या आयुष्यातील एक स्वप्न असते.
सर्व सुखसुविधांनी परिपूर्ण असणारी 'हिलव्हयू रेसिडेन्सी' ने
४८० सदनिका धारकांची यशस्वीपणे स्वप्नपूर्ती केलेली आहे.
hillview
RESIDENCY
२ व ३ बेडरुम अपार्टमेंटस्
कोथरुड
महात्मा सोसायटी जवळ
फेज-२
बुकिंग सुरु
Actual site photograph - Night view - Phase I
SBI, HDFC
व ICICI Bank
मान्यताप्राप्त
गृहप्रकल्प
साईट : पार्ट ऑफ सर्व्हे नं. ६९ व ७०, महात्मा सोसायटीजवळ, कोथरुड, पुणे-४११०३८
• स्विमिंग पूल, जिम्नॅशियम, क्लब हाऊस, पार्टी लॉनसह मल्टी-पर्पज हॉल, लँडस्केप्ड पोडियम, चिल्ड्रन्स प्ले एरिया, शॉपिंग सेंटर, सिनिअर सिटिझन्स् पार्क व जॉगींग ट्रॅक इ. सुखसुविधा • महात्मा सोसायटी, डहाणुकर कॉलनी, पौड रोड आणि कर्वे रोड इ. विकसित परिसरांच्या सान्निध्यात वसलेला गृहप्रकल्प • शहरातील प्रमुख भागांशी सुलभरित्या जोडलेले व मुंबई-पुणे हायवे लगत असणारे उत्कृष्ट लोकेशन.
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SOUVENIR

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Since 1983

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Er. Narendra Kothari
President, PCERF

Ar. Shirish Kembhavi
Convener, Souvenir 2026

Rs.250/-

Section A

Technical Volume - Section B

From President's Desk

Dear Industry colleagues and friends,

PCERF is glad to host CONSTRO 2026, 20th in the series with great pride and pleasure. We are glad to make CONSTRO a yearly event on the request and demand.

It only because of the consistent faith and trust bestowed by all the construction Industry professionals as well as the manufacturers of various machineries and materials related to our Industry that we could see the movement of CONSTRO flourish over the years.

The tremendous efforts of the various Chairman of the Constro exhibition over the years along with the professional teams involved from the industry have given the different flavours to the event and it stands out as compared to any other commercial exhibition organized anywhere else.

This year's theme of 'Eco Friendly Technological Innovations' is very much in line with the tremendous technological changes happening in the construction Industry. There are lot of new challenges with the increase in number of high rise constructions and also high speed growth requiring a large infrastructure push for development of roads, ports, airports and transportation. All in all, there is a need for this new materials and techniques to achieve the challenges India is going to face with the ever growing demand. Hence there is an effort by PCERF to focus on this topic at this CONSTRO 2026.

PCERF has already conducted a series of knowledge sharing sessions on various aspects of construction focused towards innovative techniques all through the year which were very well received and attended by the professionals from the Industry.

The basic underlying objective of organizing Constro International exhibition by PCERF is to give professionals an opportunity to educate and update their knowledge by visiting this event. The souvenir being published concurrent to this exhibition is a step ahead to present a collection of articles on the subject by experts in their fields.

One more feature added this year to PCERF's activities is the formation of YOUCONS the youth wing of PCERF. Young professionals and students have been actively involved here and are exposed to the activities and organizational work of PCERF. We are glad that this group will be a bridge between the academia and industry in the years to come.

I take this opportunity to thank all the authors who have contributed for this souvenir of CONSTRO 2026 and wish them the very best for their continued efforts to innovate and create new techniques for the betterment of the industry.

PCERF looks forward to keep working on the various facets of the Construction Fraternity on the fronts of development, education, research and promotion. All interested professionals are welcome to join this movement of PCERF.
Thanking you and wishing you all a very successful 2026.

Shri. Narendra Kothari

President, PCERF

Pune Metropolitan Region Development Authority (PMRDA)

CONCEPT PARTNER, CONSTRO 2026
Message by Metropolitan Commissioner (PMRDA)

The Pune Metropolitan Region is home to a multitude of economic activities of the country including some of the best educational institutes of the country, one of the largest automobile manufacturing hubs, Information Technology hub and the upcoming AI-ML based Industry 5.0. Furthermore, it is the cultural capital of Maharashtra and encompasses the excellent natural setting endowed by the Western Ghats.

The Pune Metropolitan Region Development Authority, established in 2015, is dedicated to creating a future that offers optimal living conditions for citizens and excellent economic opportunities for global investors. Our vision is to make the Pune Metropolitan Region as India's Most Livable Habitat and we have committed to realize this vision by carving out five actionable goals which includes Providing Convenient Mobility, Prudent Economy, Resilient Environment, Efficient Infrastructure and Self-Sufficiency in Housing and Social Amenities.

The PMRDA through its Development Plan 2041 and the infrastructure projects undertaken (the Pune Metro Line 3 Hinjewadi to Shivajinagar, the Ring Road, the Affordable Housing Complex, the Indrayani River Rejuvenation etc.) is on its way to make this dream possible.

The PMRDA's Pune International Exhibition and Convention Centre situated at Moshi, Pimpri-Chinchwad is a State of the Art Next Gen Convention Centres with the aim of providing the best in class platform for businesses to come together and collaborate and pave way for economic prosperity through Collaborative Development. Our association with Constro is a testimony of our approach of Collaborative Development towards achieving our Vision 2041.

I wish the Organizing Team the very best for Constro 2026.

Dr. Yogesh Mhase (I.A.S.)

Metropolitan Commissioner &

Chief Executive Officer, PMRDA, Pune

Constro International Expo 2026
20th in Series

From Chairman's Desk

Esteemed Industry Colleagues, Co-sponsors, Concept Partners, Collaborative Partners, and Friends,

It gives me immense pleasure to announce the 20th Edition of "Constro" from 8th January to 11th January 2026, at the Pune International Exhibition & Convention Centre (PIECC), Moshi, Pune, India.

This edition of Constro will be the largest Constro till date with over 8000 Sqm of stall areas, promising the exhibitors and visitors a great experience.

This event promises to create awareness about the latest technological developments and showcase Contemporary latest Materials, Machinery, Methods and Technologies.

We are honoured to have with us, the Pune Metropolitan Region Development Authority (PMRDA) as the esteemed 'Concept Partner' for CONSTRO-2026.

Additionally, I am delighted to share that the Pimpri-Chinchwad Municipal Corporation (PCMC) has associated with Constro as the 'Collaborative Partner'.

This exhibition is a prominent platform for nationwide exhibitors and visitors, to build mutually rewarding associations.

PCERF Safety Summit will be of great value at Constro 2026. This summit is designed to foster collaboration and prioritize safety across all stakeholders of the Construction Industry.

I call upon all professionals in the construction Industry to join hands to make CONSTRO 2026 a Grand success.

With heartfelt gratitude!

Er. Jaideep Raje
Chairman - Constro 2026

Since 1983

From Hon. Secretary's Desk

Dear Friends from the Construction Fraternity,

Greetings for the New Year!!!

It is a great pleasure to bring to you this edition of the Souvenir of Constro 2026. The Souvenir consists of technical papers related to varied topics related to our Industry.

Leading practitioners have contributed to this journal and PCERF is indebted to them for sharing their valuable insights and experiences for the benefit of the fraternity.

The Souvenir is supported generously by the members from the Industry by providing their advertisements and enabling us with presenting this valuable document. We are indeed thankful to them for their support.

As Always, Er. Mahesh Mirani Sir has provided editorial support for the Souvenir to ensure technical correctness and we thank him sincerely for all his effort.Wish you a great experience at Constro 2026!!!

Ar. Shirish Kembhavi
Ho. Secretary
P C E R F

About PCERF

Founded in 1983 by distinguished professionals from the construction sector, the Pune Construction Engineering Research Foundation (PCERF) stands as an esteemed NGO. The core mission revolves around addressing industry challenges, fostering awareness about cutting-edge technological advancements, and facilitating solutions for day-to-day predicaments.

Through unwavering commitment, PCERF propels the construction industry forward, elevating quality, knowledge, technology, and research & development (R&D) standards. PCERF platform comes alive through dynamic workshops, seminars, conferences, and professional development options, each becoming a corner stone for progress.

Constro International Expo, a testament to dedication, has graced the industry since 1985. It's unwavering focus on 'Education through Exhibition' embodies Constro's essence. Recognized as Western India's paramount construction expo, Constro converges construction machinery, materials, methods, and projects on a grand stage. Setting benchmarks, it orchestrates the event with facilities and an overall business environment that parallel international norms.

PCERF Kumar Beharay Safety Awards - The Award provides a perfect avenue to engage different layers from this sector including contractors, site management and frontline workers in promoting Safety, Health & Environmental culture.

PCERF B.G. Shirke Vidyarthi Awards - This award is an initiative to give exposure to the creativity of students, create a platform for interaction with industrialists and network with a cross section of various construction industry professionals.

YOUCONS - YOUCONS is a forum started by Pune Construction Engineering Research Foundation for young civil engineers / architects / interior designers / any other individual associated with construction industry with the aim to make them industry ready and aware at an early age.

Research and Development - PCERF aims to promote a research culture in Civil Engineering by mentoring, assisting and implementing innovative research projects and technology advancements. This research makes significant contributions to the construction industry and enhances the knowledge and skills of Civil engineers/ Architects.

Objective:

Our mission is underscored by a set of clear objectives that shape our purpose and drive our endeavors:

Advancing Research and Development: We are committed to the establishment of a state-of-the-art laboratory and a comprehensive training center. Through focused research and development initiatives, we aim to lead the charge in revolutionizing construction materials and methods.

Knowledge Enrichment: Empowering professionals with cutting-edge insights is at our core. We orchestrate seminars, workshops, and refresher courses that serve as knowledge catalysts. By staying up-to-date, we ensure that professionals are equipped to navigate the dynamic landscape of the industry. Our commitment extends to publishing insightful books, newsletters, and reports, contributing to the enrichment of the building industry.

A Confluence of Industry Minds: At the heart of our efforts lies the establishment of a shared space – a platform that unites manufacturers and users. This platform facilitates invaluable interactions, fostering collaboration and innovation. Our illustrious 'CONSTRO' Exhibition stands as a testament to this ethos, where new materials and machinery find their spotlight, igniting progress through exchange and exploration.

Executive Committee

Pune Construction Engineering Research Foundation, (PCERF)

Since 1983

Er. Narendra Kothari
President

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Vice - President

Er. Sanjay Vaichal
Vice - President

Ar. Shirish Kembhavi
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Er. Manoj Deshmukh
Member

Er. Ramnath Bhat
Member

Er. Siddharth Shah
Member

Er. Satish Kumar Nair
Member

PCERF – B.G. Shirke Vidyarthi Awards 2025

Since year 2016, PCERF has been organizing a competition for students of Architecture and Civil Engineering, at UG and PG and Diploma levels. This year we have introduced M. Planning Category. All Educational Institutes in Civil Engineering and Architecture, with Under Graduate and Post Graduate streams, which also includes Institutes under Open Universities and Deemed Universities of Mumbai and Pune jurisdiction, are eligible to participate in this competition. This is the 9th year of these awards, which includes cash prizes, Trophy and Certificates.

This award is an initiative to give exposure to the creativity of students, create a platform for interaction with industrialists and network with a cross section of various construction industry professionals.

Eligibility Criteria:-

Discipline	Course	Eligibility
Architecture	Undergraduate Post graduate	Fourth year project – 7th / 8th Semester Final year Thesis projects
Civil Engineering	Undergraduate Post graduate Diploma	Third or Final year projects First or second year projects Final year Diploma projects
M. Planning	Post Graduate	Final year Thesis projects

The Selection Process :-

i. On selection from the top 10 entries from each category, participants have to present the project to Jury Members. Participants may decide the best/ appropriate mode of presentation e.g. using power point tool, working model, perspective views, walkthroughs, videos etc. In case of any specific requirement for the presentation, it has to be given along with the report to PCERF well in advance.

ii. In case if participant is unable to attend the Final Jury Presentation Round, a virtual presentation may be allowed with prior permission.

iii. The winners shall be felicitated at the renowned exhibition Constro 2026 at Pune in front of an audience comprising of eminent stalwarts of the construction sector. The winners will get a chance to exhibit their projects / work in Constro 2026.

M/s. B.G. Shirke Construction Technologies Pvt. Ltd. has been associated with these awards as sponsor.

Ar. Mrinalini Sane, Executive Committee Member of PCERF is the Convener of these Awards. Er. Manoj Deshmukh, Executive Committee Member of PCERF is Co-convener of these Awards.

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PCERF – Kumar Beharay Construction Safety Awards 2025

'Construction Safety' is a key factor occupying the minds of Construction industry professionals and companies alike. To create maximum awareness of Construction Safety and to transform and inculcate it in organization's culture, PCERF has been organizing 'PCERF – Kumar Beharay Construction Safety Awards'. The overall approach and methodology of awards focuses on the education and improvements in the knowledge level of participants and audit system about construction safety at site. Year 2025 is the 12th in series edition of these awards.

The details of Safety Awards 2025 are as below:

The Award provides a perfect avenue to engage different layers from this sector including contractors, site management and frontline workers in promoting Safety, Health & Environmental culture.

The awards are constituted for the following categories:

	Master Category		
1.	Eligible participants shall be as per PCERF's guidelines.	-	Only those participants are eligible as per PCERF'S guideline and who received invitation from the PCERF. This is based on consistent participation in previous awards and number of awards they won.
2.	**Building Contractors – A**	-	Project value above 100 Cr.
3.	**Building Contractors – B**	-	Project Value Less than 100Cr.
4.	**Building Contractors – C**	-	Project Value up to 50 Cr.
5.	**Building Developers - A**	-	Project Value Above 300 Cr.
6.	**Building Developers – B**	-	Project Value Less than 300 Cr.
7.	**Building Developers – C**	-	Project value up to 50 Cr.
8.	**Industrial Projects**	-	Any site engaged in industrial buildings, development of industrial area
		-	No Project cost limitations
9.	**Infra-Structure**	-	Projects related to infrastructure development like Flyovers, Metro rail, Highway Projects, STP, Sea Link Projects, Tunnels, River Front Projects, Water Supply, Heritage restoration Projects etc.
		-	No Project cost limitations
10.	**Regional Category**	-	Regional Contractors outside Pune District or Company Registration outside Pune.
		-	No Project cost limitations

A "Gold & Silver Helmet Trophy" and certificate will be awarded to the Winner & First Runner-up in each category respectively in a ceremony that shall be held at CONSTRO 2026. A "Certificate of Appreciation" will be given to all the participating companies.

M/s. Kumar Beharay Properties LLP have been associated with these awards as Sponsor.
Er. Ramnath Bhat, Executive Committee Member, PCERF is the Convener of these Awards and Er. Satishkumar Nair, Executive Committee Member, PCERF is Co-Convener of these Awards.

About Constro 2026

"Since 1985, Constro International Expo has been an unwavering force in the construction industry, championing the ethos of 'Education through Exhibition.' As an India's premier construction expo, Constro unites machinery, materials, methods, and projects at a grand scale, setting industry standards. In the ever-evolving landscape of India's infrastructure development, Constro International Expo takes the spotlight, illuminating diverse aspects of infrastructure creation. This vibrant event offers a dynamic platform for nationwide exhibitors and visitors, fostering mutually beneficial B2B collaborations in a welcoming business milieu.

CONSTRO 2026 International Expo takes center stage, spotlighting the multifaceted realm of infrastructure creation. Experience the transformative power of the latest construction methods that elevate efficiency, curtail costs, and accelerate project timelines. Situated at the state-of-the-art PUNE INTERNATIONAL EXHIBITION AND CONVENTION CENTRE, MOSHI PUNE – a purpose-built government facility – the exhibition provides an ideal platform for fostering progress and collaboration.

CONSTRO 2026 is uniquely categorized under Sub Themes including Green Eco-Friendly, Concrete, Structural Steel, Sustainability, MEP, Fire Safety, Landscape Design, Affordable Housing, Retro Fitting, RCC, Masonry, Woodwork, Factory Infrastructure, Chimney Systems, Pipelines, and an array of other pivotal areas.

A curated series of seminars and technical workshops aligned with these sub-themes pave the way for a seamless transition into the exhibition itself.

Adding to the prestige of the event, the Pune Metropolitan Region Development Authority (PMRDA) stands as the esteemed 'Concept Partner.' PMRDA's visionary role in the planning and execution of numerous infrastructure projects for the region contributes immeasurably to the expo's significance and impact. Pimpri Chinchwad Municipal Corporation (PCMC) has associated with Constro as the "Collaborative Partner". It is the first Municipal Corporation in the country to make a conscious effort towards promoting sustainable development and wise use of natural resources by adopting GRIHA-The national rating system for green buildings in India.

About PCERF Safety Summit 2026

Pune Construction Engineering Research Foundation (PCERF) is organizing a **PCERF Safety Summit** during Constro scheduled from **8th January to 11th January 2026** at **PIECC, Moshi, Pune**. The **Safety Summit** will be held on **9th January 2026**.
The Safety Summit aims to promote awareness and best practices in industrial and construction safety. As part of the event, we are planning the following activities:

- **Expert sessions on safety** by eminent professionals.
- **Safety equipment demonstrations** showcasing the latest technology.
- **Safety equipment displays at stalls** for awareness and adoption of modern tools
- **Safety Professionals United Under One Roof**

The Safety Summit will be especially beneficial to Engineers, workers, contractors, and supervisors, as it will help them to:

- **Gain hands-on knowledge** about the use of safety equipment.
- Understand **best practices and guidelines** to prevent accidents.
- Learn the importance of **personal protective equipment (PPE)** and safe work methods.
- Increase awareness about **legal and regulatory aspect**s of workplace safety.
- Build a culture of safety that leads to **reduction in accidents** and improvement in productivity.

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Dynamic Leadership of Success

Pune Construction Engineering Research Foundation, (PCERF)
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Constro -1987, 1989, 1991


Late Shri. K. P. Baney
Constro -1994


Late Shri. N. V. Kanitkar
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PCERF Recognized at the

16th CIDC Vishwakarma Awards 2025

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with Achievement Award for

Research & Development in Construction Domain

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- Architects Engineers & Surveyors Association – AESA
- Ashrae, Pune Chapter
- Builders Association of India, Pune Centre
- CREDAI, Pune
- CIDC New, Delhi
- Electricals Contractors Association of Maharashtra, ECAM
- Ferrocement Society (India)
- Fire and Security Association of India – FSAI
- India Concrete Institute, Pune Centre
- Indian Plumbing Association – IPA, Pune Chapter
- KUSHAL, A CREDAI Pune Metro Initiative
- MCCIA, Pune
- MES Builders Association of India, Pune Centre
- Spun Pipes Manufacturers Association of Maharashtra
- The Institution of Engineers (India), Pune Local Centre
- Alumni Association of College of Engineering, Pune
- CEEAMA, Maharashtra
- Indian Institute of Interior Designer (IIID), Pune Chapter
- Indian Green Building Council
- Indian Society of Structural Engineers (ISSE)
- Indian Society of Lightning Engineers
- MASMA
- MBVA
- Water Proofers Association of India (WAI)
- Indian Geotechnical Society (IGS)
- International Water Association (IWA)
- Association of Designers of India (ADI)
- ISHRAE Pune Chapter
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- MMCOA, Pune
- PCCOE, Ravet, Pune
- VPKBIET, Baramati
- SCOE, Vadgaon Bk. Pune
- ADYPSOE, Lohgaon
- AITRC VITA
- RMD, Warje, Pune
- PK Technical Campus, Pune
- SCSCOE Dhangawadi, Pune
- BVCOE Lavale, Pune
- VPSCOA, Baramati

Constro International Expo 2026
20th in Series

Exhibitor's Profile

1. ALLIED PRODUCTS
- Escalators & Elevators
- Heating & Air-conditioning System
- Window & Door System Accessories

2. BUILDING MATERIALS
- Glass & Pyramid
- Tiles & Lighting

3. CONSTRUCTION
- Reinforcement Products
- Heavy Construction & Civil Engineering

4. CONSTRUCTION MATERIALS
- Construction Materials, Chemicals, Sealants, Finishes
- Cement
- Coating, Colour

5. CONSULTING
- Planning, Consultancy & Project Management

6. DESIGN
- Design and Drawing Aids, Automation Products, Office Equipment, Furniture, Computers, Software Packages etc.

7. EQUIPMENTS
- Testing Equipment & Services
- Surveying & Leveling Instruments
- Electrical Equipment & Services

8. MACHINERY
- Construction Machinery, Equipment Building Machinery & Material Ceramic Machinery

9. PRECAST
- Precast / Pre-stressed Concrete Products

10. PRE ENGINEERING
- Pre-engineered Construction Techniques – Designing, Pre-engineered & Pre-fabricated Material (Steel, Welding Machines & Road Self-trapping Screws)

11. RETROFITTING
- RCC structure retrofitting
- Structural steel retrofitting

12. SAFETY & SECURITY
- Firefighting & Safety Equipment
- Security Systems

13. SUSTAINABILITY
- Technology for Sustainability
- Water Resource Management

14. TECH & AUTOMATION
- Automation
- Mechanized
- Intelligent Technology

15. TRAINING
- Consulting & Training Services

16. TOOLS
- Drilling, Piling and Ripping Tools, Hand Tools, Power Tools

17. WATER SYSTEM & SOLUTION
- Sanitization and Water Supply
- Façade & Roofing Solutions

Constro® International Expo 2026
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Since 1983

Pune Construction Engineering
Research Foundation (PCERF)

TECHNICAL ARTICLES
Section - B

SOUVENIR
2026

Section B - Technical Article

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About Us: Zain Corporation

"Zain Corporation" was formed in 1985 with a simple business philosophy in mind: offering the best products at the best prices, with the best service.

This is the basis for over 25 years of success. Our locations in the heart of Pune Business district is placed to offer our customers shorter lead times, reduced freight rates, and better service.

AZTRO PROTECH 1.0 MESH FENCING SYSTEM

uses a panel with a mesh size of 50mm x 200 mm with a wire diameter of 4/4.5/5mm, with an Attractive colour. V-bend adds to the aesthetic Appeal of this fence and square posts along with spider fittings are used for installations.

Key Advantages :

- Easy to Install
- Best Quality
- Safety and Protection
- Varied Size
- Ideal for Indoor & Outdoor use

Applications :

- Parks / Public Spaces
- Sports Clubs & Stadiums
- Bungalow Villas / Housing Society
- School & Colleges
- Industrial Fencing

AZTRO PROTECH 2.0 MESH FENCING SYSTEM

Anti Climb Weld Mesh System is popularly known as 358 mesh fending and has a mesh opening of 76.2 mm x 12.7 mm. The mesh opening is so small that it is difficult to cut using conventional hand tools & it is also impossible to climb.

Key Advantages :

- Uninterrupted Visibility
- Highly Durable
- Anti Corrosion Coating
- Easy to Install
- High Rigidity

Applications :

- Prison
- Military Institutions
- Laboratories
- Dangerous / Chemical Goods Storage
- Power Plants

CHAINLINK FENCING WITHCONCERTINA WIRE

Chain-link is a fencing system produced with quality galvanized wire, which is extensively used for fencing purposes. the popularity of chain-link fence is due to its relatively low cost and ease of installation. A further advantage is that due to the open weave.

Key Advantages :

- Affordability
- Variety
- Low Maintenance
- Visibility
- Quick Installation

Applications :

- Parks / Public Spaces
- Sports Clubs & Stadiums
- Bungalow / Villas / Housing Society
- Schools & Colleges
- Industrial Fencing

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Pune Metro Line 3 - Technical Overview

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1. Executive Summary

Pune Metro Line 3 is a 23.203 km fully elevated rapid transit corridor linking the IT hub at Hinjawadi / Maan to Shivajinagar District Court. The line features 23 stations along its route. It is being developed under the government's 2017 metro policy as the first PPP project built on DBFOT basis. The project is being implemented by a special purpose vehicle Pune IT City Metro Rail Ltd (PITCMRL), with execution by a joint venture of TRIL Urban Transport Pvt Ltd and Siemens Project Ventures GmbH. With modern signalling, electrification and lightweight rolling stock, Line 3 aims to transform commuting between Pune's IT-residential belt and its core city improving connectivity, reducing congestion, and supporting sustainable urban mobility.

2. Project Background

- **Implementing Agency**: Pune Metropolitan Region Development Authority (PMRDA)
- **Project Company:** Pune IT City Metro Rail Ltd (PITCMRL)
- **Execution Model:** DBFOT PPP under Central Government's 2017 Metro Policy — first such effort in Pune.
- **Concession Period:** As per earlier documentation (your base), 35 years (standard for DBFOT)
- **Objective / Purpose:** Provide seamless, reliable metro connectivity between Pune's rapidly growing IT hub (Hinjawadi / Rajiv Gandhi IT Park) and central Pune (Shivajinagar / Civil Court), thereby: reducing road-traffic congestion, shortening commute times, enabling sustainable mobility, and supporting urban expansion in a structured manner.

3. Corridor Specifications

- **Total Length:** 23.203 km
- **Stations:** 23 stations planned along the route.

- **Alignment:** Fully elevated along the Hinjawadi – Wakad – Baner – University – Shivajinagar corridor.
- **Execution / Contracting:** Precast segmental box-girder viaducts with typical pier spacing around 28–34 m
- **Interchanges / Integration:** The corridor connects to existing metro stations at Shivajinagar and Civil Court, enabling interchange functionality. Also improved multimodal commuter flows at Balewadi stn.

4. Systems Engineering & Rolling Stock / Signalling / Infrastructure

- The project will feature modern metro rolling stock — AC 3-coach trainsets (as per planning documents). Local media reports suggest trains supplied by leading vendors, configured for efficiency, comfort and safety.
- **Signalling:** The corridor is planned with advanced signalling — enabling automation and safe, high-frequency service (though public sources describe it broadly as "metro-grade signalling"; your assumption of CBTC is consistent with modern PPP-metro standards, though official website does not explicitly mention CBTC).
- **Electrification:** The metro will use standard electrification; third-rail or overhead systems are typical in elevated metros (your specification of 750 V DC third-rail aligns with common metro practice, though publicly available PMRDA sources do not explicitly list voltage).
- Operations and maintenance will be handled from the depot at Maan village (Hinjawadi side), where stabling, maintenance and Operations Control Centre (OCC) will be located — ensuring smooth operations. This was part of project's design planning.
- **Headway / Capacity:** Once operational, the system is expected to support 2min headways to cater to high commuter demand from IT hub and city centre — boosting capacity and convenience.

5. Construction Challenges & Implementation Issues

During project execution, several challenges have been reported:

- Urban congestion & traffic management: Since the route passes through busy arterial roads (IT-areas, university/research zones, residential and commercial neighbourhoods), shifting existing utilities, managing traffic diversions and ensuring minimal disruption posed major challenges.
- Utility shifting and permissions: Delays in obtaining permissions for certain stretches (e.g. integrated flyover segment between University Chowk and E-Square junction) hampered progress, particularly for flyover / ramp / deck slab works.
- Integrated Flyover Component: A 1.7 km integrated double-deck flyover (road + metro) — vital for smooth alignment through a critical stretch — has been delayed. Until this is built, the full corridor cannot become operational.
- Administrative / Land acquisition / Clearances: Land handovers, especially near critical zones (government land such as Raj Bhavan, educational institutions) required coordination across multiple departments — leading to delays. These complexities caused multiple deadline extensions: originally aimed for March 2025, the deadline was successively extended — first to September 2025, and then to March 2026.

6. Project Progress as of 2025

- As of late 2025, about ~88–90% of physical work is reportedly completed.
- However — only 10 out of the 23 stations had been completed by early November 2025, per government review.
- The integrated flyover component and certain station work (escalators, track integration, utility shifting) remain pending — leading to revised operational timelines.
- Authorities have clarified that full corridor opening is now planned in a single phase (i.e., all 23 stations together), by March 2026 — subject to completion of all pending civil and system works.

7. Expected Benefits and Projected Impact (Point 10)

Once operational, Pune Metro Line 3 is expected to deliver substantial benefits:

- **Large reduction in commute time:** Travel between Hinjawadi (IT hub) and Shivajinagar (city centre / Civil Court) — which presently can take well over 60–90 minutes by road during peak traffic — will be cut drastically (possibly to ~25–35 minutes, depending on headway and integration) due to high-speed, dedicated metro transit and bypassing of road congestion. (This projection aligns with the purpose and typical metro-time savings — your earlier estimate of "90 mins → 25 mins" is plausible.)
- **Decongestion of roads and lower vehicular emissions:** With a high-capacity public transit alternative, dependence on private vehicles or multiple buses will

reduce significantly — decreasing traffic congestion, fuel consumption, and associated pollution.

- **Boost to real-estate and economic growth along corridor:** Improved connectivity often leads to growth in residential and commercial real-estate along metro corridors; enhanced accessibility of IT zones may attract more employment, services, and mixed-use development along stations.
- **Sustainable urban mobility:** As a mass rapid transit system, Metro Line 3 supports sustainable mobility goals — reducing per-passenger carbon footprint compared to private vehicles, and encouraging shift toward public transport.
- **Social and inclusivity benefits:** better connectivity for workers, students (near university, research institutes), and residents — improved access to city center, educational, commercial, and recreational hubs — enhancing social mobility and reducing travel burden.

8. Risk Assessment & Mitigation

Identified risks and mitigation strategies:

Risks

- Delays in utility shifting, permissions, and land-handover (especially in congested or restricted zones).
- Complexity of integrated flyover + elevated corridor, especially over busy roads — risk to timely completion and traffic disruption.
- Farebox uncertainty: As a PPP project, ridership levels need to meet projections to ensure financial viability; lower-than-expected ridership could affect revenue.
- Geotechnical or structural risks — given elevated viaduct, heavy traffic load, urban constraints, and necessity for high durability.
- Operational risk: Ensuring maintenance, safety, and system reliability (rolling stock, signalling, power, depot operations).

Mitigation Measures

- Use of precast segmental viaduct technology — reduces on-site work, speeds up construction, limits disruption, improves quality and safety.
- Efficient project management under PPP DBFOT model — responsibility of design, construction, financing, and operation — ensuring accountability across lifecycle.
- Detailed planning and engineering for utilities, right-of-way, and traffic management, especially in dense urban sections.
- Incorporation of modern rolling stock, robust maintenance at depot, and established safety and signalling standards to ensure reliability.

- Periodic reviews by implementing authority (PMRDA), and phased milestone tracking to monitor progress (as seen in periodic status updates).

9. Initiatives to Minimize Environmental Impact and Promote Sustainability

The Pune Metro Line-3 Project has adopted multiple green and sustainable practices to reduce environmental impacts, enhance resource efficiency, and promote long-term ecological balance. Key initiatives include:

Energy Efficiency and Green Building Measures

- Regenerative braking technology and optimized train scheduling reduce energy waste, achieving up to 30% lower energy consumption than conventional systems.
- Installation of energy-efficient equipment, including LED lighting and optimized ventilation systems, significantly lowers electricity usage.
- Natural lighting and ventilation are maximized through green building–based station design to reduce dependence on artificial systems.

Renewable Energy Integration

- Solar energy is being integrated into the metro system, with a target of meeting 50% of total energy demand through solar power in the initial phase.
- Deployment of solar panels across stations, depots, and other infrastructure ensures cleaner energy usage.

Waste Management & Resource Conservation

- Adoption of robust waste management and recycling practices, including segregation and reuse of construction waste in line with the RRR (Reduce, Reuse, Recycle) principles.
- Provision of recycling facilities at stations promotes commuter participation in sustainability.

Water Conservation

- Implementation of low-flow fixtures, water-efficient landscaping, and rainwater harvesting systems at every station to support groundwater recharge and reduce water demand.

Noise and Vibration Mitigation

- Installation of noise barriers along viaducts near sensitive zones (schools, hospitals, VIP areas).
- Use of acoustic insulation and vibration-isolation systems to minimize disturbance to surrounding communities.

Sustainable Construction Practices

- Extensive use of precast elements (viaduct segments, pier arms, girders) to reduce carbon footprint, limit on-site pollution, and accelerate construction.

BIM-based project planning enhances efficiency, minimizes material wastage, and improves coordination.

Tree Transplantation & Afforestation:

- Compensatory plantation: 6,294 trees with 100% Survival rate. Geo tagging of all plants done.
- Transplantation: 1383 trees transplanted and having Survival rate of 85%.

10 Environmental Monitoring and Compliance

- Quarterly Environmental Audits by the Concessionaire Engineer under SHE-COC ensured continuous monitoring and improvements.
- Under ISO 14001:2015, Environmental Aspect/Impact Assessments were conducted, and targeted Environmental Management Programs (EMPs) were implemented, improving overall environmental performance.

Green initiatives during the construction:

- 5.86 Lac cum of concrete has been used and 35% Cement has been replaced with GGBS helped to save natural resources and reduce carbon footprint. Limestone saved estimated as 39,900 MT
- CO2 emission was reduced by 27200 MT thus, reducing carbon footprints. (As per the data provided by GGBS supplier M/s JSW)
- Thermal energy was saved by 22400 Kcal (As per the data provided by GGBS supplier M/s JSW)
- Electrical energy saved by 2620 KWH (As per the data provided by GGBS supplier M/s JSW)
- Achieved Lower permeability and RCPT values resulting higher durability of structure.
- Replaced conventional water curing with Chemical Curing Compound, more than 57 Crore Litres of water saved.
- Tankers and bulkers were used for Chemical admixtures, Cement and Slag Materials to reduce wastage of plastic bags and plastic drums.
- Mechanical couplers are used instead of conventional lapping in reinforcement, saved more than 2000 MT of steel.
- Sewage Treatment Plant (STP) water is recycled and used for gardening and dust suppression water spraying, thereby saving huge quantity of fresh water.

Collectively, these initiatives have led to reduced carbon emissions, lower operating costs, enhanced energy efficiency, and a more sustainable and environmentally responsible metro system.

11. Expected Impact

Pune Metro Line-3 is expected to generate multi-dimensional benefits across mobility, economy, environment, and socio-urban development. The key impacts are:

a. Drastic Reduction in Travel Time

- The typical Hinjawadi–Shivajinagar commute currently ranges from 70–90 minutes during peak hours due to heavy congestion on the Hinjawadi – Wakad – Baner – University corridor.
- With the metro operating at up to 80 km/h, end-to-end travel will reduce to 20–25 minutes, providing predictable and reliable travel irrespective of road traffic.
- This time saving will directly enhance productivity for IT employees, students, and daily commuters.

b. Reduced Road Congestion

- Hinjawadi IT Park generates over 3 lakh daily trips, largely dependent on private vehicles and employee buses.
- Line-3 has the ability to shift a significant portion of daily commuters to high-capacity rail transit.
- Result:
  - Fewer private vehicles entering the core city
  - Reduced traffic load on Wakad Flyover, Baner Road, University Junction, Agriculture College, and the Shivajinagar Civil Court stretch.

c. Lower Air and Noise Pollution

- By reducing thousands of car/bike trips per day, Pune Metro Line-3 will help reduce:
  - **CO_2 emissions**
  - **PM2.5 and PM10 pollutants**
  - **Noise pollution**, especially near sensitive institutions (schools, research institutes, hospitals)
- Regenerative braking and solar integration will further reduce the system's carbon footprint.

d. Transit-Oriented Development (TOD) and Real-Estate Growth

- Stations at **Hinjawadi, Wakad, Balewadi, Baner, University Road, and Shivajinagar** will stimulate growth of commercial, residential, and mixed-use developments.
- **Expected impacts:**
  - Appreciation in land values along the corridor
  - Increased office-space absorption near metro nodes
  - Improved business activity in Baner–Balewadi high street
  - Boost to rental housing markets for IT employees and students

e. Enhanced Public Transport Integration

- The line will integrate with bus hubs at Shivajinagar, Hinjawadi Phase-I, and Wakad.

- Expected to reduce dependence on multi-modal road transport (buses + shared autos + bikes).

f. Socio-economic Benefits

- Better accessibility to IT hubs, universities, and public institutions.
- Improved mobility for women, students, senior citizens, and low-income groups.
- Time and cost savings for daily commuters.

11. Risk Assessment

Pune Metro Line-3, being a large urban elevated corridor, faces several technical, operational, and financial risks. These are summarised below:

A. RISKS

a. Utility Conflicts

- The alignment passes through dense urban zones containing:
  - o Water pipelines
  - o Electrical HT/LT cables
  - o Sewer lines
  - o Telecom and fibre-optic cables
  - o Storm-water drains
- Delays in utility shifting can interrupt foundation works, pier construction, and station building.
- University Road and Baner-Aundh junctions are high-risk zones for utility clashes.

b. Geotechnical and Structural Risks

- Variable soil strata along the alignment, especially nearby:
  - o Mula river crossing
  - o University Chowk
  - o Baner Hill foothills
- Risks include differential settlement, weak strata for piling, and unforeseen subsurface obstructions.
- Elevated metro construction also carries risks during launching girder operations in high-traffic areas.

c. Farebox Revenue Uncertainty (PPP Financial Risk)

- As a DBFOT PPP model, the concessionaire bears demand-risk.
- Metro ridership depends on:
  - o First/last-mile connectivity
  - o Ticket pricing
  - o Integration with other modes
  - o Availability of parking
- Any shortfall affects financial viability.

d. Environmental and Social Risks

- Tree cutting or transplantation challenges
- Noise and dust impacts during construction
- Clearances from multiple agencies (forest, environment, defence, traffic police)
- Public objections, especially near educational institutions and research zones

e. Construction Interface Risks

- Coordination issues between:
  - o Civil contractor
  - o Systems contractor (signalling, telecom, traction)
  - o Depot and OCC integration
- Delays in one work-front can delay the entire system commissioning.

f. Safety Risks

- Working at heights (20–30 m elevated viaduct)
- Risks during:
  - o Precast segment launching
  - o Heavy lifting operations
  - o Traffic diversions
  - o Night working near dense traffic

B. MITIGATION MEASURES

a. Detailed Engineering & Pre-Construction Surveys

- Extensive GPR (Ground Penetrating Radar) surveys for utilities
- Geotechnical investigations along entire alignment
- Redesign and realignment in conflict zones
- Use of micro-tunnelling for utilities to minimise disruption

b. Precast Segmental Construction

- Use of precast box girders and pier caps reduces:
  - o On-site congestion
  - o Construction time
  - o Traffic disruptions
- Higher quality control and faster erection (3–4 segments per day)

c. Predictive and Preventive Maintenance

- Adoption of condition-monitoring tools at the depot:
  - o Track health monitoring
  - o Rolling-stock diagnostic systems
  - o Predictive maintenance using vibration data

- Reduces long-term operational risks.

d. Financial Risk Mitigation

- Integrated fare strategies with PMT buses
- Non-fare revenue streams:
  - o Commercial development at stations
  - o Advertising
  - o Parking
  - o Retail leasing
- Ensures stable revenue beyond ticket sales.

e. Robust Traffic Management Plans

- Night-time lifting operations
- Pre-approved traffic diversion plans
- Coordination with PMC, PCMC, Traffic Police, and Highway Authorities
- Use of safety nets, barricades, and reflective systems

f. Environmental Management Initiatives

- Dust suppression systems, STP water usage
- Noise barriers near sensitive zones
- Tree transplantation with geo-tagging
- Use of GGBS and chemical curing to reduce carbon footprint

g. Multi-agency Coordination Mechanism

- Weekly review meetings among PMRDA, Concessionaire, IE, and PMC
- Interface management plans for Civil + Systems integration
- Digitized progress monitoring using BIM and drone surveys

12. Conclusion

Pune Metro Line 3 represents a transformative infrastructure project for Pune, combining modern metro technology, PPP financing, and elevated corridor design to bridge the city's IT-residential hub (Hinjawadi) with the heart of the city, Shivajinagar / District Court. Once completed, it promises fast, reliable, and sustainable transit is likely to reshape commuting patterns, ease congestion, reduce pollution, and stimulate real-estate and economic growth along the corridor.

Despite multiple challenges, complex urban construction, utility shifting, integrated flyover work, and administrative delays the project has reached advanced stages and is slated for full commissioning by March 2026. If executed as planned, Line 3 will significantly augment Pune's public transport infrastructure, supporting long-term urban growth, sustainable mobility, and improved quality of life for commuters and residents alike.

REDEFINING URBAN RESILIENCE: The Central Fire Fighting Headquarters, PCMC - A Benchmark in Technology, Innovation & Sustainable Public Infrastructure

Er. Pramod Ombase
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Introduction

Urban firefighting infrastructure represents the backbone of civic safety. As cities expand vertically and horizontally, the complexity of fire response equally increases. Pimpri Chinchwad Municipal Corporation (PCMC), among India's fastest-growing urban regions, has taken a decisive step toward modernizing its firefighting ecosystem through a comprehensive redevelopment strategy:

A 5.5-acre Central Fire Fighting Headquarters, 4 Divisional Fire Stations, and 7 Sub-Stations across the municipal limits.

Among these, the Central Headquarters project—designed by Solespace Architects—stands as a pioneering example of how innovative construction technologies, environmental strategies, and human-centric design can converge to create India's most advanced firefighting campus. This article presents an inside view of the engineering and architectural thought process behind the project, highlighting innovations in structure, materials, sustainability, construction methodology, spatial planning, and long-term functional resilience.

A Vision Beyond Conventional Public Buildings

Fire stations in India traditionally follow utilitarian formats focused on basic operational needs. However, the PCMC headquarters reimagines this typology by placing equal emphasis on:

Operational efficiency, Technological integration, Training, research and public education, Staff well-being, and Long-span flexible infrastructure that can evolve with time.

The architectural vision emphasizes that a fire headquarters must not only serve its functional purpose but must also become an institutional landmark representing safety, preparedness, and civic pride. Thus, the campus integrates administrative spaces, public engagement zones, residential areas, training facilities, workshops, audit spaces, recreational zones, and a rich landscape that binds the entire 5.5-acre environment into one cohesive ecosystem.

Site Planning & Spatial Strategy

The campus has been master-planned with clear zoning and seamless circulation, ensuring uninterrupted movement of fire tenders while maintaining safe and peaceful residential and office environments.

Key Zones include:

Fire Tender Bays (22 bays) with direct exit to the main road, Workshops and Boat Parking for specialized operations, Headquarters Office Block (11,500 sq.ft.), War Room & Control Centre, Fire Museum (11,500 sq.ft.) showcasing the history & technology of firefighting, 200-Seater Auditorium & Seminar Rooms, Residential Quarters (118), Dormitories for firemen & training officers, On-duty staff areas, Recreational amenities – gym, landscaped courtyards, multipurpose areas, A Grand Drill Ground & Training Infrastructure, Resistance swimming pool, Staff Canteen & Dining Spaces.

Zoning is optimized so that operational movement remains completely unhampered by civilian or residential activity, ensuring rapid mobilization at all times. Circulation is supported by a multi-level ramp system, which allows vertical segregation between public, operational flow, and horizontal segregation for residential flow without compromising efficiency.

Innovative Use of Natural Vegetation as a Climatic Buffer

One of the project's strongest innovations is the use of natural vegetation surrounding habitable spaces as an environmental buffer, significantly reducing heat gain and improving indoor comfort.

How the vegetative buffer works:

Dense rows of native trees surround the built forms and open spaces. The landscape is layered with groundcover → shrubs → medium trees → tall shade trees, forming a natural thermal shield. These layers reduce ambient temperature by 2–4°C through shading and evapotranspiration. Vegetation is strategically positioned around habitable areas to achieve natural cooling and acoustic buffering from the busy urban surroundings. This approach demonstrates that sustainability is not an add-on component but a structural part of planning, reducing long-term energy loads and enhancing environmental well-being for staff who often work under intense physical and mental stress.

Material Innovations for Durability & Low Maintenance

Given that firefighting headquarters include heavy vehicular movement, large crowds, and 24×7 usage cycles, material choice becomes critical.

Key Material Strategies:

1. Durable Cladding Systems

Façades use high-grade long-life brick cladding panels.

Advantages include: Minimal maintenance requirements, High fire resistance, Weather-proofing capability, Aesthetic uniformity across large volumes, Flexibility of future expansion.

2. High-Performance Glazing

Selective use of insulated and treated glazing ensures: Reduction in indoor heat gain, enhanced natural lighting, Reduced electricity consumption in office blocks.

3. Anti-Skid and Impact-Resistant Flooring

Operational zones, workshops, and tender bays use industrial-grade anti-slip flooring using a combination of trimix and epoxy, contributing to higher safety and longer surface life.

4. Recyclable and Locally Available Materials

With intention of obtaining IGBC Platinum rating, the architect has considered the use of regionally sourced materials to reduce environmental impact and promote local manufacturing.

Advanced Structural Systems for Large Spans

The unique challenge of designing a fire headquarters lies in creating column-free spaces that accommodate:

Fire tenders (18m long)

Heavy equipment

Workshops

Large public gathering areas

Training zones and assembly halls

To achieve this, the structural approach uses:

Post-Tensioned (PT) Beams and Slabs

PT systems drastically reduce the number of columns by enabling:

- Longer spans
- Higher load-bearing capacity
- Reduced slab thickness
- Faster construction time
- Lower material consumption

This is especially beneficial for the Fire Tender Parking Bay, which requires long, unobstructed clearances for easy movement and operational efficiency.

PT technology also future-proofs the building, allowing internal layouts to evolve without structural limitations.

Eco-Friendly and Sustainable Development Initiatives

Beyond vegetation buffers and material selection, the project integrates multiple sustainability layers:

1. Rainwater Harvesting

A campus of this scale captures significant roof run-off which can be channeled into:

Ground recharge pits

Fire drill water storage tanks

Landscape irrigation systems

2. On-Site Water Recycling

Greywater from residential blocks and dormitories is treated in a modular STP and reused for:

Landscaping

Non-potable requirements

3. Solar Energy Integration

Rooftops of administrative and museum blocks are designed to accommodate solar PV panels, offsetting lighting and equipment load.

4. Heat Island Mitigation

Large shaded areas, green corridors, and light-toned roof coatings contribute to reducing the heat island effect—critical for public buildings with high daily activity.

5. Waste Segregation & Composting

With residential units, staff quarters, and training dormitories, waste management is given priority through dedicated segregation bays and composting pits.

Architectural Character & Aesthetic Direction

The elevation of the headquarters reflects the ethos of the firefighting profession—strength, responsiveness, and clarity.

Visual Identity

Clean linear forms symbolize discipline.

Red accents subtly reflect firefighting symbolism without overuse.

Large glazing areas around the museum and training blocks promote transparency and public engagement.

Cladding gives the building a timeless institutional identity, ensuring it remains a PCMC landmark for decades.

Atrium & Landscape Integration

A central landscaped atrium acts as the project's green lung, offering:

- Natural light deep into the building
- Communal areas for staff
- Visual relief across floors
- A passive cooling effect

This "breathing space" is one of the architectural highlights of the project.

Human-Centric Design: Spaces that Support People Behind the Uniform

Fire personnel work in extreme conditions, facing physical danger and mental pressure. The headquarters therefore integrates:

Residential Quarters & Dormitories

1.5 BHK, 2 BHK, 3BHK and 4BHK units for 118+ staff families

Student and trainee dormitories

Common dining, recreation rooms, courtyards, and play areas for family members

Recreational Facilities

Fully equipped gym

Open drill ground and recreational lawn.

Indoor spaces for wellness and relaxation

Memorial Space

A dedicated memorial plaza pays tribute to firefighters who have lost their lives in service, reinforcing the emotional centre of the campus.

Fire Museum

A public-facing museum educates visitors on:

History of fire services

Evolution of fire engines

Fire safety for schools and residents

Live demonstrations and training

Auditorium & Seminar Rooms

These support:

Workshops

Public training programs

Fire department events

Inter-departmental coordination exercises

Construction Methodology: Efficiency Meets Scale

Given its multi-layered complexities, the headquarters demanded precise construction planning.

Segmentation of Work

Construction was divided into:

Operational Block

Public Block (Museum, Auditorium)

Residential Tower

Workshops & Drill Areas

Landscaping and Site Services

Rapid Yet Safe Execution

The project aligns with PCMC's policy of using modern equipment and construction practices to reduce delays and improve structural accuracy.

Parking, Mobility & Future Scalability

A project of this magnitude demands extensive parking and mobility solutions.

Parking Provided

195 Cars

1022 Two-Wheelers

Dedicated fire tender and boat parking

Visitor parking segregated from staff and emergency bays

Multi-level parking facility for efficient space use

Future-Proof Design

Layouts allow integration of:

Training infrastructure

EV charging systems

Smart monitoring facilities

Conclusion: A New Standard for Public Infrastructure in India

The Central Fire Fighting Headquarters of PCMC is not just a building—it is a living, evolving ecosystem that reflects the future of civic infrastructure in India.

It demonstrates that public buildings can be:

Technologically advanced

Sustainably designed

Architecturally expressive

Human-centric

Operationally efficient

Capable of serving multiple generations

PCMC's vision, combined with the architectural and engineering excellence of Solespace Architects, has created a campus that stands as a symbol of safety, capability, and civic leadership.

As cities across India look to strengthen their emergency response infrastructure, this project serves as a benchmark—a reminder that great public infrastructure must be functional, futuristic, and fundamentally humane.

▪ Nachiket Tak

Beneath the City: The Khadakwasla to Phursungi Tunnel Project How a 25 km Tunnel is Securing Pune's Water?

Er. Pravin Kolhe
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1.1.Introduction

Water security forms the backbone of sustainable urban growth, agricultural development, and environmental resilience. Pune — one of India's fastest growing metropolitan regions — relies fundamentally on the Khadakwasla reservoir complex to meet its domestic and irrigation demands. Traditionally, the New Mutha Right Bank Canal (NMRBC) has served as the principal carrier of irrigation water from Khadakwasla toward Pune's eastern region and further downstream agricultural belts.

However, as the city has rapidly urbanized along the canal corridor, this open-channel water conveyance system has become increasingly problematic — suffering from massive water losses, pollution exposure, safety concerns, and severe encroachment pressures.

Recognizing the need for a modern, safe, and sustainable conveyance system, the Maharashtra Krishna Valley Development Corporation (MKVDC) has proposed a transformative shift: replacing the initial stretch of the canal with a fully enclosed, underground pressurized tunnel from Khadakwasla to Phursungi. This project goes beyond an engineering upgrade — it embodies a holistic environmental and socio-economic improvement strategy aimed at safeguarding Pune's water future for decades.

2. Existing Challenges and the Case for Intervention

The first 34 km of the NMRBC pass through densely developed urban areas under Pune Municipal Corporation (PMC) limits. Over the years, the canal has turned into a major water-management liability.

2.1 Severe Water Losses – Being largely unlined and exposed to atmosphere, the canal undergoes huge conveyance losses through seepage and evaporation. Unauthorized water lifting is rampant. Studies indicate that over 2.5 TMC of water is lost annually in this stretch due to seepage, wastage and unauthorised use — enough to cater to nearly 20–25 lakh people per year.

2.2 Environmental Health Risks - The canal has deteriorated into a polluted watercourse due to inflow of sewage, plastic waste, and industrial effluents. This degrades water quality for irrigation and domestic use and poses public health hazards.

2.3 Safety and Encroachment Pressures - Unprotected canal banks lead to accident risks as the corridor has become heavily encroached, making maintenance extremely difficult.

Thus, the transition to a tunnel-based system is not optional — it is essential.

3. Innovative Design and Planning Strategy

The key objective is to deliver the designed discharge of 42.76 cumecs (1510 cusecs) more efficiently and securely than the open canal, with minimal water loss. Therefore, it is decided to explore the alterative alignments for tunnels starting from Khadakwasala dam and ending with NMRBC near Fursungi village, avoiding densely populated urban stretch. Following table summarises the comparative analysis of alternative alignment proposals -

Alignment	Key Features	Limitations	Remarks
Alternative 1	Initially considered alignment passing from right bank near Khadakwasla	Passes through dense habitation causing severe land acquisition issues for shafts	**Rejected** due to constructability issues
Alternative 2	Modified version near original alignment	Dense habitation; difficult mucking/ventilation shaft access	**Rejected** due to issue about ventilation shaft access

Alignment	Key Features	Limitations	Remarks
Alternative 3	Bends through three turning points	Sharp transition at NMRBC connection, unsatisfactory geometry	**Rejected** due to geometry issue
Alternative 4	**Passes through sparsely populated areas; smooth transition at NMRBC; adequate ground cover even near railway crossing**	**Minimal limitations; technically sound, no major land acquisition**	**Feasible & recommended**
Alternative 5	Starts 100 m downstream of dam & tailrace	Long open cutting required in dense urban section — not possible	**Rejected** due to long open cut
Alternative 6	Some sections require open channel	Railway crossing area has inadequate cover → deep cut impossible	**Rejected** due to Railway line safety
Alternative 7	Very flat gradient (1:3504) with proposed hydropower at Ch. 25/525	Insufficient head & low velocity	**Rejected** due to hydraulic constraints

Salient features of selected alignment -

3.1 Underground Alignment for Urban Compatibility - The tunnel alignment begins near the existing Khadakwasla intake and ends with joining to NMRBC at canal chainage 34 km, near Phursungi, covering tunnel length of about 25.50 km. The depth of overburden over tunnel varies from 40 to 200 meters, ensuring zero interference with buildings, utilities, metro corridors, and road networks.

3.2 Full-Section Utilization Through Pressurized Flow - Unlike the free-surface flow of the canal, the tunnel works on pressurized flow — enabling higher velocity (~1.89 m/s) and improved hydraulic performance with no pilferage.

3.3 Structural Geometry for Stability and Efficiency - A 'D'-shaped profile — 7.80 m width and 6.15 m height — has been finalized. This improves stability in rock mass, offers efficient space utilization, and ensures ease of equipment movement during construction and maintenance.

4. Geotechnical Landscape and Underground Engineering Challenges

The region falls under **Deccan Trap Basalt**, characterized by compact basalt, amygdaloidal basalt, and occasional volcanic breccia. Borehole investigations report high **Core Recovery (CR)** and **RQD** values across major segments, categorizing rock mass as Class II/III — generally strong

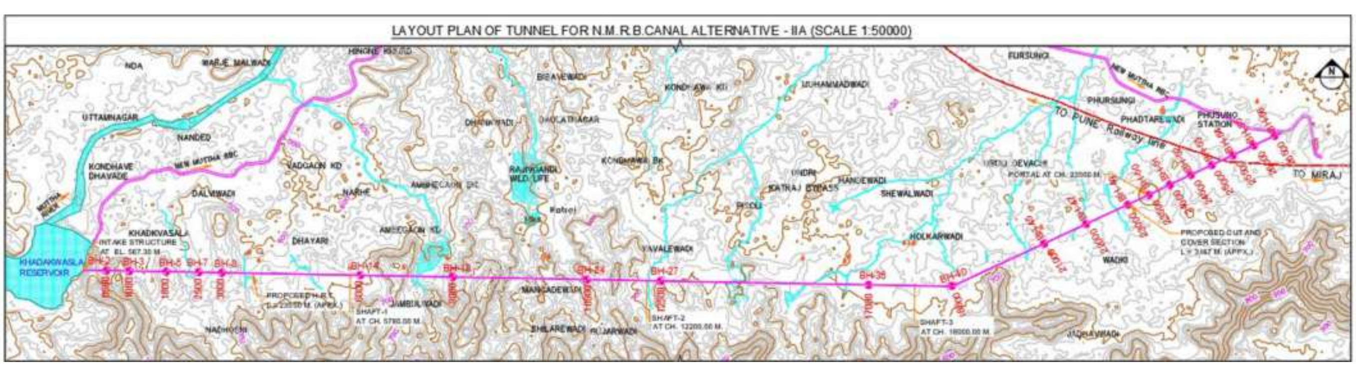

Fig. 1: Indicative Alignment of the Proposed Khadakwasla–Phursungi Tunnel Project

and competent for tunnelling. Construction of underground infrastructure in densely populated urban areas poses multiple challenges that require careful planning and mitigation. Building below a congested city necessitates controlled blasting, vibration monitoring, and precise instrumentation to ensure safety and minimal disturbance to surrounding structures. The strategic placement of access and ventilation shafts is addressed through close collaboration with the PMC to identify suitable land parcels. Handling muck in restricted urban zones is managed through sustainable disposal and reuse planning, minimizing environmental impact. Additionally, groundwater ingress in fractured zones is mitigated using pre-grouting techniques combined with robust dewatering systems, ensuring structural stability and uninterrupted construction progress.

Investigations determine subsurface soil/rock layers and properties for foundation depth, load capacity, settlements, and hazards like expansive soils. Planning involved the reconnaissance for urban/highway/rail crossings, geological mapping, and locating buried utilities; open trenches were infeasible in hilly terrain, so rotary drilling (54 mm NX cores, 500 m spacing, 2 m below bed level) and geophysics covered the alignment. Bore logs (e.g., BH-03 at CH 1000: 55 m depth, greyish-brown amygdaloidal basalt, jointed with green infill, RQD 53%, core recovery 96%) identified igneous rocks dominant in Deccan Traps.

Geotechnical investigations for the Khadakwasla-Fursungi Tunnel employed a multi-method approach to map subsurface conditions across the 25 km alignment, combining direct drilling and non-invasive geophysics investigations through Electrical Resistivity method and Seismic Refraction method. The table below summarizes key methods, their specific applications, and findings -

Based on the Geotechnical investigation, the Khadakwasla-Fursungi tunnel for substituting the first 34 km of NMRBC designed as a horseshoe-shaped, pressure tunnel with a 23.5 km length (total ~25.5 km including cut-and-cover/open channel), 6.3 m inner diameter for TBM, 1:3000 slope, 42.76 cumecs (1510 cusecs) discharge capacity at 1.3 m/s velocity, inlet at EL 567.3 m, and outlet at EL 566.7 m. It handles reservoir levels from FRL EL 582.47 m (MDDL EL 574.3 m) in Khadakwasla Dam, traversing slightly weathered to fresh basalt (Deccan Traps) with max 230 m overburden, using drill-blast (DBM) primarily, TBM optionally, and cut-and-cover for shallow cover (<15-20 m).

The horseshoe cross-section features a 6.3 m internal diameter, with variable primary support (shotcrete 50-200 mm thick per rock class I-V via Q-system), 25 mm dia. x 4 m rock bolts (SN/Swellex/self-drilling at 750 mm c/c), welded wire mesh (150x150 mm), and ISMB 150 steel ribs where needed. Final lining includes 300 mm thick M30 in-situ concrete (invert/overt), 100 mm payline thickness, side drainage (90-150 mm PVC pipes at 750 mm c/c), and contact/consolidation grouting; weep/drainage holes (70-100 mm dia., 1-20 m deep) manage seepage in drained design.

The outlet connects seamlessly to NMRBC at CH 33,400-34,000 m near Fursungi village (15-20 km from Pune), delivering 42.76 cumecs gravity-fed flow after the 26.667 km total alignment (23.45 km tunnel + 2.35 km cut-and-cover + 0.867 km open channel). Drill-blast method (DBM) accommodates variable basalt geology via 2-6 m rounds (full face in good rock, top heading/bench in poor), supported by shotcrete (50-200 mm), rock bolts, and steel ribs. Double-shield TBM offers 8-10 m/day in uniform hard rock; cut-and-cover handles shallow overburden (<15-20 m) portals with 4V:1H stepped

Method	Application	Key Findings
Rotary Drilling	10 km bores (e.g., BH-5: 75 m BH-18: 147 m); 54 mm NX cores to 2 m below bed level, 500 m spacing for RQD/core recovery	Amygdaloidal basalt (greyish-brown /black, jointed with green infill); fractures, RQD 53%, core recovery 96% via detailed logs
Electrical Resistivity	10 km coverage up to 30-100 m; electrode arrays for conductivity contrasts in hilly access-limited areas	Strata boundaries (rock vs. soil/water); shear zones, water table depth, rapid non-destructive profiling
Seismic Refraction	15 km stretches; 24 geophones with hammer impacts on plates for P-wave velocities (1 hr/240 m line)	Refracted paths revealing layering/ hydrology; minor faults, weathered interfaces, groundwater up to 80-100 m

excavation, shear keys, 100 mm PCC base, waterproofing, and backfill.

5. Construction Methodology — Technology Choice

Two main construction alternatives were evaluated: Tunnel Boring Machine (TBM) and Drill & Blast (D&B) methods suit the Khadakwasla-Fursungi Tunnel's variable basalt geology, with TBM favored for uniform hard rock stretches and D&B for flexibility in fractured zones. TBMs achieve 8-10 m/day continuous advance with double-shield types minimizing subsidence, while D&B handles changing conditions via 2-6 m rounds but demands vibration monitoring near urban Pune areas.

Following table summarised the advantages and limitations of the both approaches -

Method	Advantages	Limitations
Tunnel Boring Machine (TBM) `	Higher safety in closed environment, smooth walls reducing lining costs, low vibrations/noise, continuous mechanized advance (20 m/day peak), minimal overbreak/ground disturbance	High capital cost (150-250 Cr INR), long procurement (1-1.5 years), geology inflexibility (breakdowns in faults), maintenance delays, limited turning radius
Drill & Blast (D&B)	Flexible for varying basalt/fractures, lower initial investment, adaptable cross-sections/curves, familiar local expertise, suitable short stretches	Higher overbreak/vibrations requiring controls, cyclic process (2-6 m/day), dust/fumes/ventilation needs, safety risks from blasting, manual labor intensity

6. Sustainability and Urban Transformation Benefits

The Khadakwasla-Fursungi Tunnel exemplifies climate-resilient infrastructure by conserving 2.5 TMC of water annually through elimination of seepage, evaporation, and leakage losses in the open NMRBC canal, ensuring reliable gravity-fed supply of 42.76 cumecs (1510 cusecs) for irrigation of more than 62,000 ha command area. This enhances drinking water security for Pune's 50 lakh+ population amid rising demand.

Closed conveyance removes sewage dumping, encroachments, and garbage pollution plaguing the urban canal stretch, delivering cleaner water that cuts health risks and maintenance burdens in densely populated PMC areas like Dhayari, Hadapsar, and Fursungi. Freed canal land (500-1000 m wide, ~35 km) enables urban transformation—potential roads, green spaces, commercial hubs, or town planning schemes boosting revenue and liveability.

The project is being implemented through Engineering, Procurement and Construction (EPC) contract mode ensuring: Single-point accountability, Assured quality and timely delivery and Optimized project-risk allocation.

7.Conclusion — A Watershed Moment for Pune

The Khadakwasla-Phursungi Underground Tunnel Project marks a visionary engineering feat by Maharashtra's Water Resources Department, decisively resolving chronic NMRBC issues—2.5 TMC annual losses, sewage pollution, encroachments, and safety risks—through a 25.5 km pressurized tunnel delivering 42.76 cumecs reliably to drinking water to Pune's 50 lakh+ residents and 62,146 ha command area. Geotechnically robust in Deccan Trap basalt (DBM-led, TBM-ready), with strategic shafts and appurtenances, it exemplifies urban-compatible infrastructure under 40-230 m cover.

More importantly, it redefines the relationship between infrastructure and urban transformation — turning hidden utilities beneath the ground into thriving public assets above it. Once operational, this strategic project will provide long-term water security, support sustainable agriculture, and unlock remarkable urban redevelopment potential within Pune.

■ Shivam Sutar

Nature-Conscious Sustainable New Construction Concept

Er. Jayant Inamdar
Managing Director,
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Development is often measured in terms of rising skylines, expanding cities, improved infrastructure, and growing economic capacity. Yet, in the race to build bigger, faster, and stronger structures, one essential dimension is frequently overlooked - our consciousness towards nature.

For more than 45–46 years, my structural design work has taken me across India—from the foothills of the Himalayas to the coastal plains of Tamil Nadu, from the dense urban hubs of Mumbai and Delhi to rapidly expanding cities like Hyderabad and Pune. Through this journey, I have come to identify myself in a simple yet meaningful way: In Marathi, "मी इमारतींच्या हाडांचा डॉक्टर आहे. (**I am a doctor of the bones of buildings.**) Just as a doctor ensures the human skeleton remains strong and healthy, I ensure that the structural bones of every building stand firm, safe, and resilient for decades.

But strength alone is not enough. A building, while robust, must also breathe with nature, align with its surroundings, and enhance the natural ecosystem rather than burden it. This philosophy forms the foundation of my approach to modern structural design and sustainable development.

A Shift Toward Nature-Integrated Construction: In the last five years, Strudcom work has taken a transformative turn. While I never deviated from the basics of safe and strong structural engineering, I began to adopt a more holistic perspective - one that treats buildings not as isolated concrete masses but as **living entities that interact with the environment.**

Our main fundamental are Safety, Quality, Time, Avoid wastages and End users must be Happy.

One of the most crucial decisions in this shift was the emphasis on **structural steel** as a primary construction material. Whether the project was commercial, industrial, or residential, I began to strongly advocate for steel-intensive construction wherever feasible. While traditional construction in India relies heavily on reinforced concrete (RCC), steel offers

several advantages that are not only engineering-oriented but also environmentally beneficial.

This transition was not merely a professional preference; it was a conscious step toward sustainable development. And the results have been remarkable.

The Hyderabad Example: Saving Time, Saving Nature: A recent project in Hyderabad stands out as a testament to this philosophy. The building—towering at 150 metres—was designed and constructed using a significantly higher proportion of structural steel and reduced concrete usage.

This decision led to an extraordinary outcome:

- The **entire building was completed in just nine months**,
- Whereas the same structure, if built using RCC, would have required **2.5 to 3 years**.

This means we saved approximately 20–21 months of construction time. At first glance, this seems like a milestone in project management efficiency. But when viewed from an environmental angle, the benefits are exponentially greater.

Image 1: Phoenix Aquila, Hyderabad (2 Basements + Ground Floor + 7 Stilt Floors + 16 Upper Floors.); Height:106 mtr; Area Apx: 1.3 Million sft ;
Project Status: Structure Completed.

Environmental Impact of Time Savings: Every month of construction avoided translates into measurable environmental savings:

1. **Reduced manpower movement** – fewer daily commutes, less fuel consumption.
2. **Lower transportation requirements** – reduced trips for cement, aggregates, sand, and other materials.
3. **Decreased machinery usage** – cranes, concrete mixers, pumps, and other heavy equipment consumed drastically less diesel.
4. **Significantly less dust, noise, and air pollution** due to shortened construction duration.
5. **Minimal disturbance to local biodiversity**, which often suffers during prolonged construction periods.
6. **After 60-80 years 95 to 98% materials will be reused** as against recycle 5 to 6%
7. **User must be happy as he is getting more carpet rea 1.5 to 1.8 sq.m per column per floor.**

Thus, the 21 months saved were not merely a timeline achievement—they represented a profound reduction in carbon emissions, resource usage, and ecological impact.

In an era where climate change discussions dominate global forums, such tangible actions hold far greater value than theoretical sustainability commitments.

The Overlooked Connection: Urban Biodiversity and Landscaping: While structural engineers focus on buildings, the natural ecosystem around them—in the form of trees, shrubs, and fauna plays an equally vital role in shaping the environment. For the last 30 years, I have consistently advised landscape consultants across major cities like Pune, Delhi, Calcutta, and Hyderabad that landscaping must stay true to local ecology.

This means choosing tree species that grow **naturally** in that region, thrive without artificial support, and contribute positively to biodiversity.

Unfortunately, this fundamental principle is often ignored.

Development Without Nature Is Destruction in Disguise: Modern development often projects itself as the hallmark of progress—taller buildings, wider roads, massive bridges, and smart infrastructure. But development that does not consciously preserve nature ultimately harms its own purpose.

When natural ecosystems collapse, cities face:

- Extreme heat
- Frequent floods
- Reduced groundwater recharge
- Poor air quality
- Loss of birds and pollinators
- Declining emotional and mental well-being

Structural Steel as a Sustainable Solution:

Returning to construction practices, structural steel offers several benefits:

1. **Precision and Speed**

   Prefabricated steel components reduce onsite wastage, accelerate construction, and ensure higher accuracy.

2. **Recyclability**

   Steel is one of the few materials that can be recycled indefinitely without losing strength. Concrete, on the other hand, creates demolition waste that is hard to reuse efficiently.

3. **Reduced Carbon Footprint**

Because buildings are completed faster, the total pollution from machinery, transport, and manpower decreases.

4. **Flexibility and Expandability**

   Steel structures allow easier expansions or modifications, reducing future demolition and rebuilding needs.

5. **Lightweight Yet Strong**

   A lighter structure reduces foundation size, lowering material consumption and environmental impact.

Thus, steel-intensive buildings are not only engineering marvels—they are nature-friendly solutions.

The Responsibility of Professionals: Professionals working in construction and development have a tremendous responsibility. Each decision—whether selecting the construction material, determining the building layout, or choosing landscape species—has long-lasting implications.

For 45+ years, I have witnessed how cities evolve, how ecosystems degrade, and how small mistakes become large environmental costs. This long journey has reinforced one belief:

Development without consciousness of nature is incomplete, and often harmful. In contrast, development that respects and integrates nature leads to healthier, happier, and more sustainable communities.

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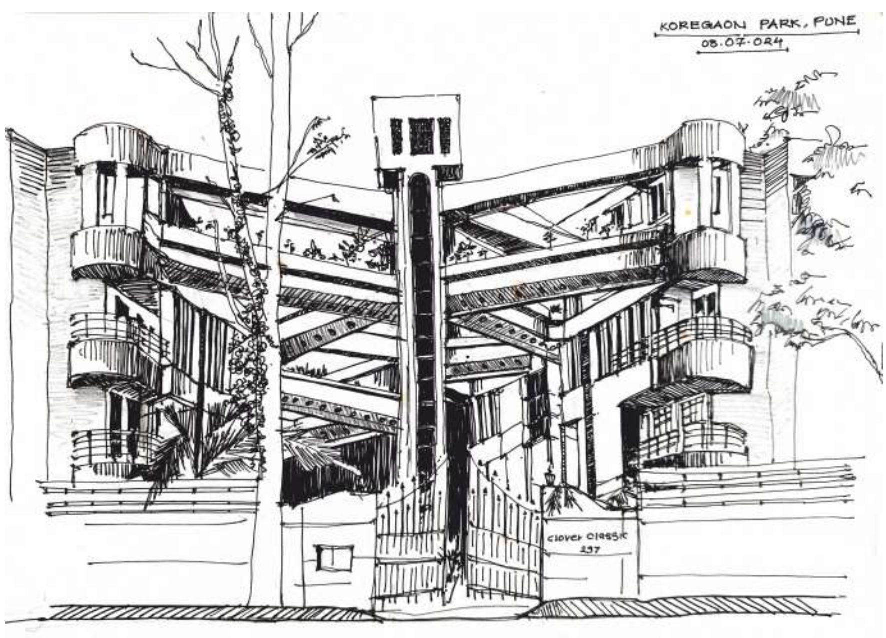

■ Shital Kulkarni

Seismic Isolation: A Simple Vibration Control Technique

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1. Introduction

The traditional method for seismic-resistant design involves adding sufficient strength, stiffness, and inelastic deformation capacity to the building structure to counteract induced inertia forces. This approach assumes that during strong ground motion, when inertia forces exceed the design earthquake levels, the structure will absorb the excess energy through deformations at specific points throughout the framework. It has been observed that even with members designed for ductility, structures do not always behave as expected, possibly due to factors such as: (i) failure of the strong column-weak beam mechanism caused by the stiffening effect of the walls, (ii) formation of short columns resulting from later modifications in wall layout, and (iii) inadequate concreting at joints due to reinforcement congestion.

Experiencing failures during earthquakes revealed that a design based solely on incorporating ductility as a safeguard against seismic effects requires critical review. In their search for alternative design strategies to reduce the magnitudes of inertia forces, engineers developed the innovative idea of introducing a flexible medium between the supporting ground and the building, thereby decoupling the structure from the energy-rich components of seismic ground motion. This strategy became known as the seismic isolation method. This paper explains the basic concepts of seismic isolation systems, their advantages and limitations.

2. Concept of Seismic Isolation

Seismic isolation is a technique used in earthquake-resistant design that aims to reduce seismic demand rather than enhance a structure's resistance to earthquakes. Proper design and implementation of this technology lead to better-performing structures that do not become inelastic under extreme dynamic loads. To lower a building's vulnerability to earthquake damage, seismic isolation has become a viable structural option. It is a sophisticated, practical approach that improves a building's seismic response by minimizing structural damage, which was previously deemed unavoidable during strong ground motion. Due to the low horizontal stiffness of this deformable medium, it changes the fundamental period of a stiff structure, making it significantly longer than that of high-energy ground motions. As a result, in its fundamental mode of vibration, the superstructure experiences much lower inertia forces, leading to a reduction (Fig. 1) in base shear.

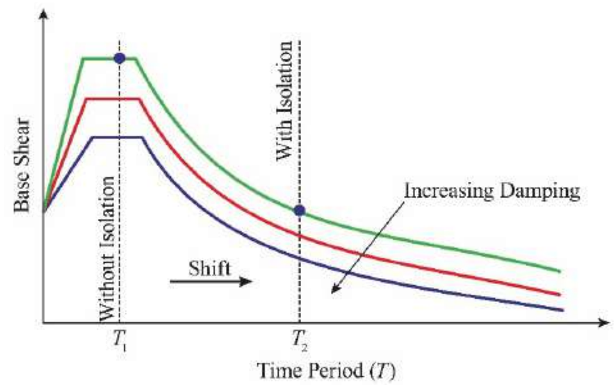

Figure 1. Effect of seismic isolation on base shear

On the other hand, if the foundation layer is soft, there is a clear potential for an increased period due to base isolation, which approaches the period during which an earthquake is likely to contain significant energy. This situation can lead to an increased response. Therefore, it can be concluded that seismic isolation is most effective for buildings with a high natural fundamental frequency (T less than approximately 1 second), especially those supported on rock or stiff soils. Reinforced concrete moment-resisting frame buildings up to about 8-10 stories and those with shear walls up to 12-15 stories are considered ideal candidates for base isolation. If a framed structure is supported on hard strata, it would deform as shown in Fig. 2 (a).

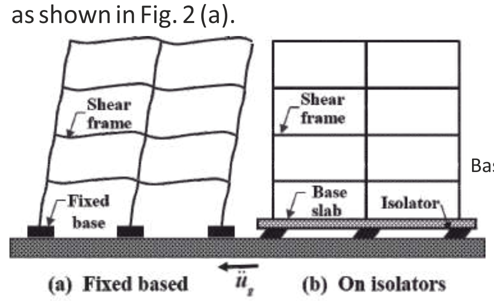

Figure 2. Behaviour of Fixed-base and Base-isolated structures during an earthquake

However, when supported on isolators, the lateral displacement in the first mode is concentrated at the isolator level, while the superstructure behaves nearly like a rigid body (Fig. 2b). As a result, buildings supported on base isolators require fewer ductile energy-dissipating regions (e.g., near beam-column joints) than conventional fixed-base structures. Nonetheless, due to limited experience with such systems and as a safety measure, codes recommend maintaining current ductile detailing. This helps prevent brittle failure during a maximum credible earthquake (MCE) or earthquakes with long-period energy inputs. Additionally, codes mandate thorough testing of the proposed isolators and peer review of the design, given that this is an emerging technology and failure could have catastrophic consequences.

Isolators should be positioned to allow easy access for maintenance, repair, and replacement if needed. A full diaphragm should be used to evenly distribute lateral loads among the isolators. Typically, isolators are installed at the bottom of columns at the basement slab level. This location has the advantage that no special treatment is required for elevator or service lines crossing the bearing level. Conversely, if they are placed at the top of the basement, the elevator shaft, internal staircase, and cladding details may require special treatment below the first-floor level.

Isolators greatly extend the fundamental period of a stiff structure but result in larger building displacements. The main difficulty in designing a base-isolated structure is balancing displacements during major earthquakes with good performance during moderate ones. Since the superstructure behaves primarily in a linearly elastic manner, the structural framework is expected to stay undamaged even during moderate earthquakes.

3. Passive Base Isolators

Seismic isolation is a passive control method used to counteract lateral vibrations. As previously discussed, an isolation system must support gravity loads, including those caused by vertical seismic acceleration, be sufficiently stiff to minimize displacements from small lateral forces like wind, be highly flexible to absorb energy during strong earthquakes, and be capable of self-centring after seismic events. Passive isolators that meet these criteria are preferred. Clearly, this means the isolator should exhibit non-linear stiffness. It should also have adequate damping properties to dissipate seismic energy and prevent excessive lateral displacement at the interface.

Even with all their advantages, passive seismic isolation systems might not be sufficient to prevent extensive damage to building superstructures during a near-field earthquake characterized by a long period, high peak acceleration, and velocity pulse. If such an event is likely, a passive system can be combined with passive dampers, such as viscous or friction dampers. These devices help manage seismic response by making appropriate adjustments within the structure as seismic excitation changes. There are two common types of passive isolators: elastomeric (such as high-damping rubber or lead-core rubber) and friction-based (e.g., friction pendulum system).

Elastomeric Isolators

Rubber isolators can be made from heavy-duty rubber or rubber reinforced with metal plates. The latter consists of layers of natural rubber vulcanized and bonded to thin stainless-steel plates using heat and pressure. Steel plates prevent bulging of rubber under vertical load and also provide significant vertical stiffness to support heavy gravity loads. A laminated rubber bearing with a central lead plug is called a Lead Rubber Bearing and is considered an ideal solution.

Rubber provides enough horizontal flexibility to withstand large strains during a major earthquake and can generate the necessary restoring force. In contrast, the lead plug offers higher initial stiffness and hysteresis damping to handle low strains caused by wind forces. An elastomeric bearing has no moving parts, maintains good aging properties, and is highly resistant to environmental degradation.

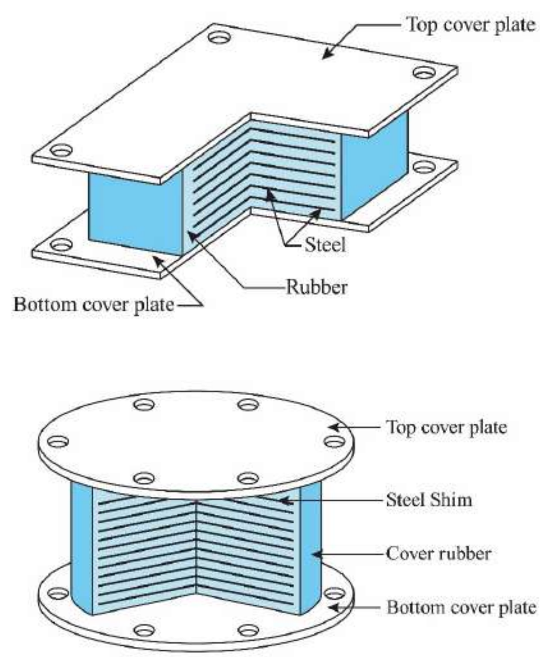

Figure 3. Square and Circular Elastomeric isolators

4. Merits of Isolators

Because of its low stiffness, using an isolator system increases the natural period of a structure compared to a fixed-base structure. This shifts the system away from the period where ground motion contains significant energy. As a result, the structure experiences lower inertia forces, leading to cost savings.

1. In the first mode of vibration (often the dominant mode), primary displacements occur only at the isolator level, while the superstructure behaves almost like a rigid body.
2. Floor accelerations are reduced, which decreases inter-storey drifts.
3. Hinge regions in fixed-base structures must undergo inelastic deformation over many reversible cycles while maintaining sufficient strength and stiffness to ensure stability and integrity. Excessive plastic deformations can cause substantial damage to structural and non-structural components. This issue is lessened in an isolator-protected structure.
4. In case of a larger-than-assessed seismic event, the damage concentrates in the isolation system, which can be restored relatively easily. As a result, the structure can often be commissioned into service quickly. This is especially important for buildings such as hospitals and those that house emergency services providers.
5. It is an ideal and sometimes the only means of retrofitting buildings of historical importance.

5. Demerits of Isolators

An isolator system does not significantly assist a flexible structure that is already adaptable. Therefore, when used alone, it has limited application for high-rise buildings. However, this limitation is becoming less relevant as reducing damage to expensive equipment (such as in hospital buildings and other critical structures) grows more important to ensure business continuity.

1. With a seismic isolation system, peak base displacements can be significant, necessitating enough rattling space to prevent the structure from hitting nearby elements.
2. Caution is essential when designing buildings with a high aspect ratio, as large overturning moments could generate net uplift forces on the isolators.
3. It is less effective for a building resting on soft soil.
4. Since isolation systems are vertically stiff, they do not prevent vertical acceleration amplification. Therefore, it is advisable to protect equipment with secondary systems to guard against vertical earthquake motion.
5. Special flexible joints must be incorporated into supply lines to accommodate displacements when crossing the isolator interface. Additionally, rigid structures crossing the interface (e.g., stairs, walls) should be able to absorb lateral displacements.
6. There are additional costs for the foundation.

There are many applications of base-isolated buildings in India, the first one being the Bhuj hospital.

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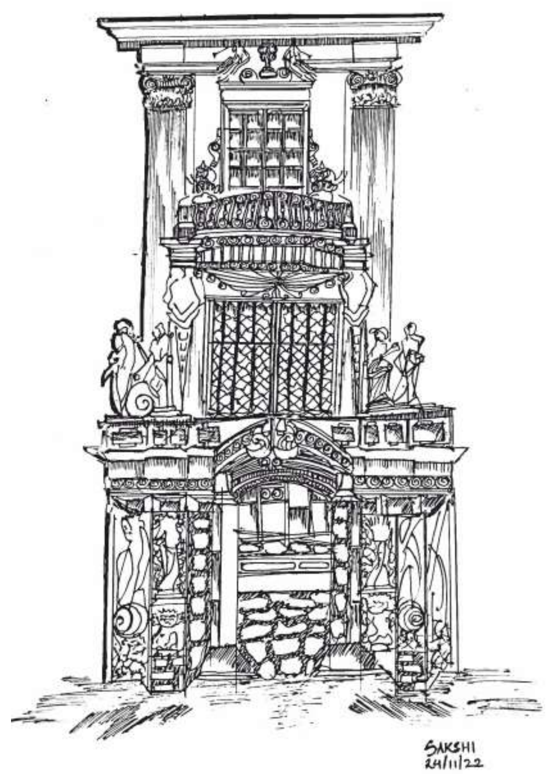


■ Sakshi Patil

A Comprehensive Guide: The Importance of Concrete Curing and Curing Compounds

Er. Amit Haridas
Concrete, Construction QA/QC Consultant & Trainer.
Business owner, ConcreteInfo

1. Introduction: Understanding Concrete Curing

Curing of concrete refers to the process of maintaining adequate moisture, temperature, and time conditions to allow the cement hydration process to continue after concrete placement. This critical process enables concrete to achieve its intended strength, durability, and impermeability characteristics. During curing, water retained in the concrete mass facilitates the ongoing chemical reaction between cement and water, forming calcium silicate hydrates (C-S-H) that bind the concrete matrix together.

Without adequate curing, concrete can lose moisture too rapidly through evaporation, leading to incomplete hydration. This results in reduced strength development, increased permeability, surface crazing, and diminished durability. Research indicates that concrete that is properly cured can achieve up to 50% more compressive strength compared to similar concrete that is left uncured.

The curing period typically extends for a minimum of 7 days for ordinary Portland cement concrete, though longer periods of 14 to 28 days are recommended for optimal strength development and durability

2. The Critical Importance of Concrete Curing

2.1. Strength Development and Hydration

The cement hydration process is time-dependent and requires continuous availability of water. Temperature also plays a vital role in the curing process. The rate of hydration increases with temperature, but excessive temperatures can lead to rapid moisture loss and thermal cracking. Conversely, temperatures below 5°C significantly slow down the hydration process, requiring extended curing periods or heated enclosures.

2.2. Durability and Permeability Control

Proper curing directly impacts concrete's resistance to environmental attack. Well-cured concrete develops a denser surface layer with reduced porosity, which enhances resistance to chloride penetration, sulphate attack, freeze-thaw cycles, and carbonation. The permeability of concrete can be reduced by up to 10 times through proper curing compared to uncured concrete.

The surface zone or cover region of concrete member, extending 10-50 mm deep, is particularly vulnerable to inadequate curing. This zone acts as the first line of defence against aggressive agents. Poor curing in this region can lead to dusting, scaling, and accelerated deterioration, even if the internal concrete mass has achieved adequate strength. This is often the layers which loses moisture the most when exposed to external weather and climatic conditions and becomes weak and unable to protect both itself and the reinforcement. Permeability is far more important than strength for long-term durability. Improperly cured concrete develops a porous, permeable surface layer that allows aggressive agents to penetrate rapidly.

2.3. Economic and Sustainability Considerations

From an economic perspective, the cost of proper curing represents a minimal fraction of total construction costs, typically less than 1%, yet its impact on long-term performance and service life is substantial. Inadequately cured structures may require premature repairs or rehabilitation, incurring costs many times greater than the initial curing investment.

In the context of sustainability, proper curing optimizes cement utilization efficiency, allowing concrete to achieve its full potential with the existing cement content. This reduces the need for higher cement contents or remedial measures, thereby lowering the carbon footprint of construction projects.

Traditional water curing, i.e. the practice of continuously wetting concrete surfaces has been the unwritten standard for over a century. However, modern construction practices, concrete technology, and project demands have revealed critical limitations of water curing as a standalone method.

While water curing has lower material costs, it is a labour-intensive work with significant supervision requirements. The construction use of water also competes with the use of water for domestic and agricultural use, the latter two of which get preference in water scarce regions.

Water curing also requires discipline and consistency that is difficult to maintain at construction sites:

Common Failures:

- **Delayed Start** : Curing begins 6-12 hours after finishing instead of immediately
- **Interrupted Application** : Workers forget weekend applications, night shifts are missed
- **Inadequate Coverage** : Edges, corners, and vertical surfaces receive insufficient water
- **Premature Termination** : Economic pressure leads to stopping at 3-4 days instead of 7
- **Weather Disruption** : Heavy rain or extreme heat disrupts curing schedule
- **Supervisory Gaps** : Lack of continuous oversight leads to missed applications

All of this leads to degradation of not just strength but the durability of the structure.

Alternatives are of course curing compounds, But are these a complete replacement of water curing, well yes and no, The curing compounds aim to significantly reduce the rate of evaporation of moisture / water from concrete matrix, making it available for hydration instead, but it is not the same as a concrete member ponded in water.

3. Specifications for Curing Compounds

Currently no Indian Standards are available specific to the Curing compounds, though IS 456 does make a brief mention about allowing it subject to the approval from engineer in charge.

Below is the list of various international codes which are available with relation to curing compound, ASTM being the most widely referred to for this.

Standard	Moisture Retention Requirement	Key Testing Parameters	Primary Application Focus
ASTM C309	≤0.55 kg/m² loss in 72 hours (95%)	Water absorption, reflectance, drying time	General purpose curing
ASTM C1315	<0.40 kg/m² loss in 72 hours	Enhanced VOC, special properties	Specialized applications
BS 7542	≥85% efficiency at 72 hours	MVTR, film integrity, weathering	European construction
AS 3799	≥90% efficiency at 72 hours	Moisture loss, film quality	Australian climate

3.1. ASTM C309 - Standard Specification for Liquid Membrane-Forming Compounds

This is the most widely recognized standard for curing compounds globally.

Key Requirements:

- **Moisture Retention:** Maximum water loss of 0.55 kg/m² in 72 hours (equivalent to 95% moisture retention efficiency) when tested according to ASTM C156
- **Reflectance:** Type 2 (white pigmented) compounds must exhibit minimum 60% daylight reflectance
- **Drying Time:** Must dry to touch in not more than 4 hours
- **Application Rate:** Typically, 200 sq.ft/gallon (approximately 4.9 sq.m/liter)

3.2. ASTM C1315 - Specification for Compounds Having Special Properties

This specification covers specialized curing compounds with enhanced properties:

- Type 1: High efficiency compounds (moisture loss <0.40 kg/m²)
- Type 2: Environmentally safe compounds (low VOC)

4. Evaluation Criteria for Curing Compounds

4.1. Performance Evaluation Parameters

Moisture Retention Efficiency: The primary criterion is the ability to minimize moisture loss from concrete. This is measured as water loss per unit area over 72 hours. High-quality compounds should achieve 90-95% efficiency compared to sealed control specimens.

Film Formation and Coverage: The compound should form a continuous, uniform film without gaps or pinholes. Consistency in application is crucial, and the compound's viscosity and spreading characteristics significantly impact field performance.

Durability and Longevity: The membrane should remain intact throughout the curing period without degradation from UV exposure, rainfall, temperature fluctuations, or light foot traffic.

Compatibility and Removability: For surfaces requiring subsequent treatments, the compound must not interfere with adhesion of paints, coatings, sealers, or overlays.

Environmental and Safety Considerations: VOC content, flammability, toxicity, and disposal requirements are increasingly important evaluation criteria.

Compound Name	Sub-Category	Chemical Composition	Primary Mechanism	Secondary Benefits	Typical Application Stage
Acrylic Resin (Solvent-Based)	Resin-Based	Acrylic polymers in hydrocarbon solvent	Forms impermeable film that prevents moisture evaporation	UV resistance, appearance preservation	Immediately after finishing
Acrylic Resin (Water-Based)	Resin-Based	Acrylic emulsion in water	Forms impermeable film that prevents moisture evaporation	Low VOC, easy cleanup	Immediately after finishing
Chlorinated Rubber	Resin-Based	Chlorinated rubber in aromatic solvent	Forms tough, chemical-resistant film	Exceptional durability	Immediately after finishing

Compound Name	Sub-Category	Chemical Composition	Primary Mechanism	Secondary Benefits	Typical Application Stage
Styrene-Butadiene	Resin-Based	SBR polymer in water or solvent	Forms flexible film	Good flexibility	Immediately after finishing
Polyvinyl Acetate (PVA)	Resin-Based	PVA emulsion in water	Forms temporary removable film	Easy removal, low cost	Immediately after finishing
Wax-Based	Wax-Based	Paraffin/microc-rystalline wax in solvent	Forms impermeable waxy film	Highest moisture retention	Immediately after finishing
Polyurethane-Based	Resin-Based	Polyurethane resin	Forms durable protective film	Excellent adhesion	Immediately after finishing

► **Application: Compound is sprayed or rolled onto concrete surface**

- Spreading: Low viscosity allows compound to spread uniformly across surface
- Solvent Evaporation: Volatile carrier (water or hydrocarbon solvent) evaporates
- Film Formation: Resin or wax particles coalesce into continuous membrane
- Barrier Creation: Membrane thickness of 25-75 microns forms in 10-30 minutes
- Moisture Retention: Film prevents water vapor transmission through surface

Some of the membrane forming curing compounds (Definition of curing compound as per ASTM C-309) need to be removed before subsequent surface treatment of the member

5.2. Reacting / Penetrating type of Curing Compounds

Unlike membrane-forming compounds, silicate-based products partially penetrate the concrete surface (typically 2-5 mm) and undergo a chemical reaction. This reaction produces additional C-S-H gel that fills capillary pores, reducing permeability and increasing surface hardness.

Compound Name	Sub-Category	Chemical Composition	Primary Mechanism	Secondary Benefits	Typical Application Stage
Sodium Silicate	Silicate-Based	$Na_2O \cdot nSiO_2$ in water (n=2-4)	Penetrates and reacts with $Ca(OH)_2$ to form C-S-H gel	Surface densification, hardening	After initial set or on mature concrete
Lithium Silicate	Silicate-Based	Li_2SiO_3 in water	Penetrates deeply, reacts with $Ca(OH)_2$	Superior densification, no ASR	After initial set or on mature concrete
Potassium Silicate	Silicate-Based	K_2SiO_3 in water	Penetrates and densifies	Surface hardening	After initial set or on mature concrete

5.3.Detailed Comparison - Externally Applied Curing compounds

Parameter	Membrane-Forming Compounds	Non-Membrane Forming (Penetrating) Compounds
Mechanism of Action	Forms a physical barrier film on concrete surface that prevents water evaporation	Penetrates into concrete pore structure and reacts chemically with calcium hydroxide to form additional C-S-H gel
Depth of Action	Surface only (0-0.5 mm)	Penetrates 2-8 mm into concrete surface
Primary Function	Moisture retention during early curing period	Surface densification and permanent hardening
Duration of Effectiveness	Temporary - 7 to 60 days depending on type	Permanent - becomes integral part of concrete
Typical Products	Acrylic resins, wax emulsions, styrene-butadiene, chlorinated rubber, PVA	Sodium silicate, lithium silicate, potassium silicate
Application Timing	Immediately after finishing, before initial set	Can be applied to green concrete or mature concrete (7+ days)
Visual Appearance After Application	Visible film (clear, white, or pigmented)	Minimal to no visible change unless pigmented; absorbs into surface
Removal Requirement	May require removal for subsequent coatings/overlays	No removal needed; compatible with most coatings
Water Retention Efficiency	75-98% over 72 hours	Not applicable (different mechanism)
Surface Hardness Improvement	Minimal to none	Significant (20-40% increase in MOH hardness)
Abrasion Resistance	No improvement	Substantial improvement (30-50% reduction in wear)
Permeability Reduction	Temporary during curing period	Permanent reduction (up to 50%)
Re-application Possibility	Generally one-time application	Can be applied in multiple treatments
Resistance to Traffic	Low to moderate; can be damaged	High - becomes harder over time
Chemical Resistance	None to minimal	Improved resistance to acids and alkalis
UV Degradation	Yes - resin types break down	No degradation
Typical Applications	Fresh concrete curing: pavements, slabs, precast	Industrial floors, warehouses, polished concrete

Parameter	Membrane-Forming Compounds	Non-Membrane Forming (Penetrating) Compounds
ASTM Classification	ASTM C309, C1315	No specific ASTM (not traditional curing)
Effect on Subsequent Concrete Pours	Must be removed for proper bond	No interference; can improve bond
Environmental Impact	Moderate (solvent types) to low (water-based)	Very low - inorganic salts
Testing Method	Water absorption test, moisture loss test	Surface hardness, water absorption, wear resistance
Ideal Use Case	Curing newly placed concrete	Densifying and hardening mature concrete surfaces

5.4.Comparative Analysis of Curing Compounds

5.4.1.Performance Comparison Table

Curing Compound Type	Moisture Retention Efficiency (7 days)	UV Resistance	Film Durability	Compatibility with Surface Treatments	Ease of Application	Environmental Impact
Acrylic Resin (Solvent)	85-92%	Excellent	Good	Good	Easy	Moderate VOC
Acrylic Resin (Water)	80-88%	Excellent	Good	Excellent	Easy	Low VOC
Wax-Based	92-98%	Fair	Poor	Poor	Easy	Moderate VOC
Styrene-Butadiene	82-90%	Good	Good	Good	Easy	Moderate VOC
Sodium Silicate	N/A (Penetrating)	Excellent	Excellent	Excellent	Moderate	Low
Lithium Silicate	N/A (Penetrating)	Excellent	Excellent	Excellent	Moderate	Low

5.4.2.Application Conditions and Suitability

Condition/Application	Recommended Compound Type	Alternative Options	Compounds to Avoid
Hot & Windy Weather	Wax-Based, Chlorinated Rubber	Acrylic Solvent-Based	PVA, Water-Based
Cold Weather (<10°C)	Acrylic Solvent-Based	Styrene-Butadiene	Water-Based Emulsions
High Humidity Regions	Acrylic Resin, PVA	Styrene-Butadiene	Wax-Based

Condition/Application	Recommended Compound Type	Alternative Options	Compounds to Avoid
Vertical Surfaces	Acrylic Resin, PVA	Water-Based Emulsions	Wax-Based
Floors Requiring Finish	Acrylic Water-Based, PVA	Silicate-Based	Wax-Based, Chlorinated Rubber
Industrial Floors	Lithium Silicate, Wax-Based	Acrylic Solvent-Based	PVA
Pavements & Roads	Wax-Based, Acrylic Solvent	Chlorinated Rubber	PVA
Architectural Exposed Concrete	Acrylic Water-Based	Styrene-Butadiene	Wax-Based

6. Practical Application Guidelines and Best Practices

6.1. Surface Preparation and Timing

The effectiveness of curing compounds depends critically on application timing. The ideal time for application is when the concrete surface has reached initial set and free water (bleed water) has evaporated. For horizontal surfaces, the concrete should be finished before compound application.

6.2. Application Methods

- Spray Application
- Roller Application
- Brush Application

6.3. Weather Considerations

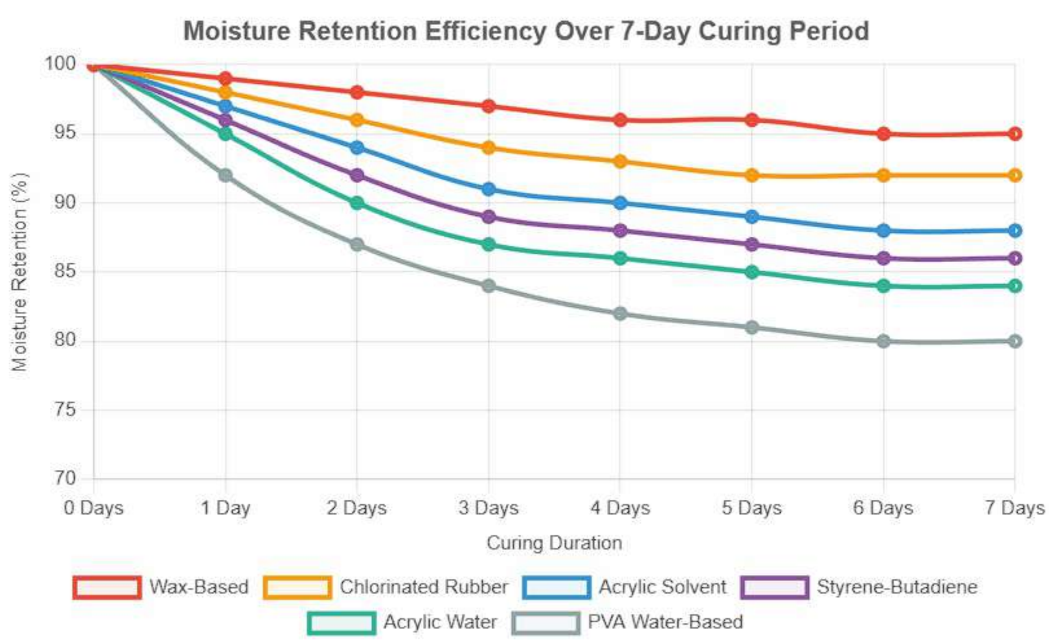
Hot Weather (>32°C):

- Apply compound immediately after finishing
- Consider white pigmented compounds for solar reflectance
- May supplement with wet covering for first 24 hours

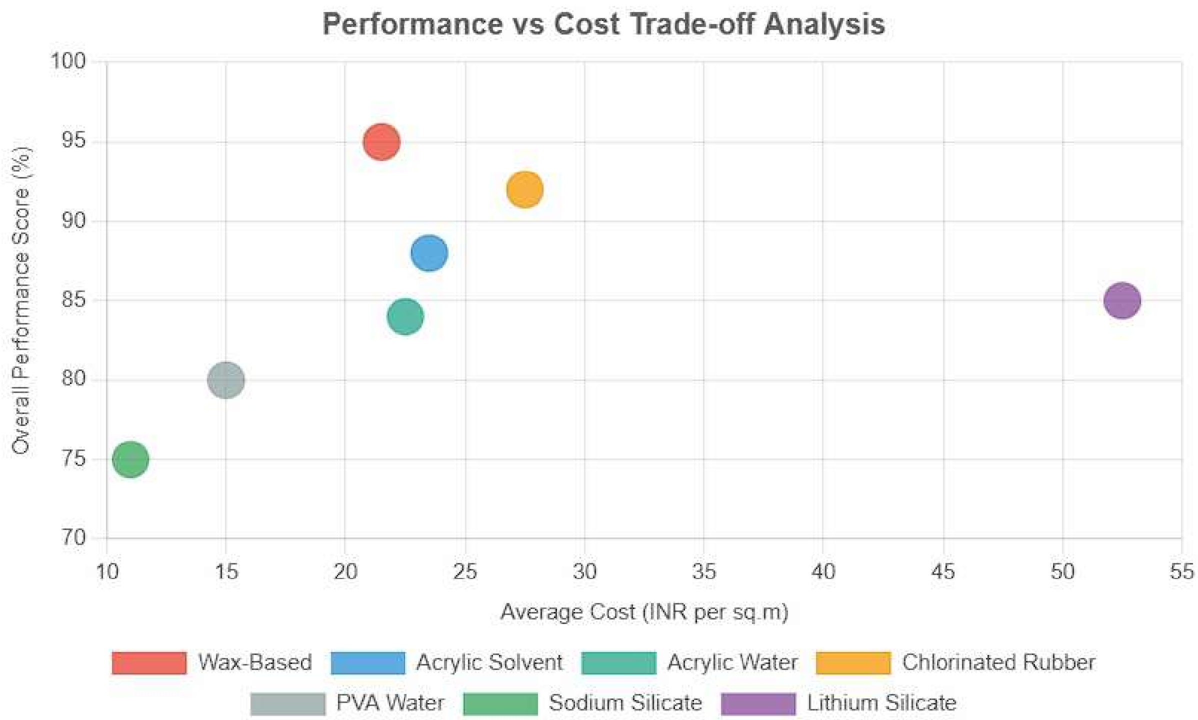
Cold Weather (<10°C):

- Use solvent-based compounds suitable for low temperatures
- Maintain concrete temperature above 10°C
- Extend curing periods proportionally

6.4. Moisture Retention Efficiency Comparison Chart



6.5.Cost-Effectiveness Analysis Chart



Prices are indicative and may vary by region and from manufacturer to manufacturer

7. Conclusion: Ensuring Concrete Quality Through Proper Curing

The curing of concrete stands as one of the most critical aspects of concrete construction. Despite representing minimal cost relative to overall project scope, often neglected, proper curing signiificantly influences concrete's ultimate performance, durability, and service life.

Investment in proper curing methodology represents not an added expense but rather an essential component of quality concrete construction. As we advance toward more sustainable and durable infrastructure, the role of proper curing will continue to be fundamental to achieving these goals.

Key Standards Referenced:

- ASTM C309: Standard Specification for Liquid Membrane-Forming Compounds
- ASTM C1315: Specification for Liquid Membrane-Forming Compounds Having Special Properties
- ASTM C156: Test Method for Water Loss
- IS 456:2000: Code of Practice for Plain and Reinforced Concrete

Quality Consciousness: A Continuous Journey of Improvement and Commitment to Excellence

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Trainer, Educator, Author

We often hear about the importance of quality in various aspects of our lives. In personal as well as professional areas, we mention quality in rather loose terms without really understanding the true meaning of quality and what that meaning represents. If we go to purchase a product and it is expensive in comparison to similar products, the salesperson justifies it as being of superior quality. Branded items often cost more than non-branded items and we happily believe that it is quality that has hiked up the price. Alternatively, we are suspicious of a similar product that is cheaper because we feel that it must be of inferior quality. Hence, the concept of quality deals with objective as well as subjective aspects.

If we look at the definitions of quality across various time frames, different management gurus have dealt with it in their own ways. Out of the many definitions, the one that I believe is the most apt is perhaps, the most succinct of them all – Fit for Use! This has been propounded by Joseph Juran, Romanian American author, management consultant and an engineer.

Any product or service, that is fit for use, is of good quality. Now, that may differ from person to person, from situation to situation and also from time to time. So, in that sense, what works today for me is quality while the same, which doesn't work for you may not be quality! Here we arrive at an important part – perception.

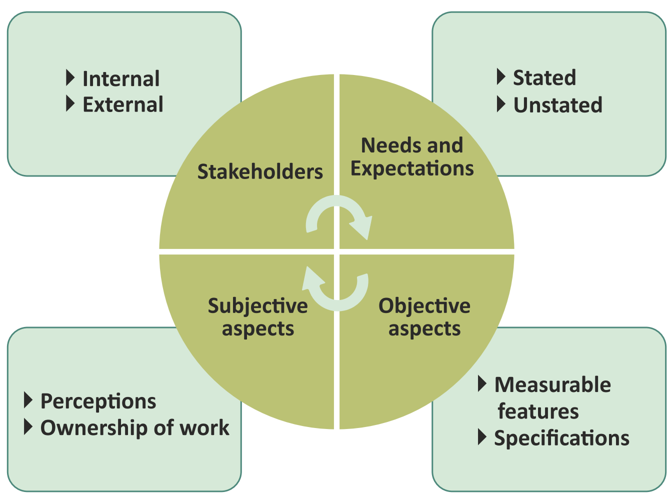
The organisation may have created a great product from their point of view; however, the customer may not perceive it to be so. Now the question is, who is right and who is wrong? And that answer, will again differ from the point of view. That is why, quality questions must be specific with scope and limitations defined clearly. It is not easy. Does it mean that it can't be done? Of course not. It certainly can be done if adequate attention is paid to all the stakeholders.

The stakeholders are varied with their own perceptions and requirements. Now, requirements are again stated and unstated. The stated are the obvious ones that may pertain to the measurables, specifications etc. The unstated needs are those are left unsaid due to many reasons. Sometimes these reasons could be cultural; sometimes, simply, wrong assumptions are made.

As a result, due to these faulty communication aspects, what suffers is quality. And, as a continued result, the brand suffers, leading to loss of customers, loss in profits, leading to perhaps in extreme conditions, loss of jobs, company shut-down.

Now, how do we address this situation? Firstly, define quality in terms that are understood by all within the organisation. This should cover not just the end product, but also the intermediate processes and their acceptance tolerances. These must be communicated in unambiguous terms to the concerned personnel like production, accounting etc. This will bring most of the internal stakeholders on the same page. External stakeholders must also contribute to the process as they will be involved in areas like marketing, legal etc.

Once all the stakeholders are clear about what is expected from them, and what they may expect in return, questions will be asked and suitable responses will be given. This clarity will help to define the quality and enhance the sense of confidence in the products offered by the organisation and purchased by the customer.



Quality culture should be inculcated in a top-down approach. When the Top Management sets the goals that focus on quality, and then it puts into practice, the rest of the organisation also starts believing in the importance of quality.

Then, we have the sense of ownership and pride about one's work, that helps to perform towards excellence.

The external stakeholders like the material suppliers and other service vendors are also very important in the journey of quality. It is critical to define the Objective aspects very clearly and in unambiguous terms as to what is required and the acceptance criteria. In case there are deviations which outside the acceptance range, strong action should be initiated right in the beginning to ensure that a subsequent error does not take place. This message of quality reinforcement will ensure that production work flow is not hampered in future.

The top-down approach percolates across different levels within the organisation – the internal stakeholders, till it reaches the last point, where the worker feels strongly about his importance of his contribution to the organisation. As a result, the first time right and zero-error do not remain just slogans, but translate into actual work, that is for all practical purposes, perfect. Which means, less or no re-work, which means improved productivity, which means improved resource deployment, which means, better productivity and better products and service! Now, what does all of this result into? A happy customer! This happy customer is the best advertisement for the organisation. This happy customer gives more business and causes more business to come to the organisation – and all of this translates into improved profits!

The profits may be distributed among the organisation members and staff. In addition, in a listed organisation, the improved profits if shared among the shareholders, will make them happy, result in a higher share price, which is good for the economy.

■ Saket Devkare

Understanding UHPFRC: A High-Strength Material for Next-Generation Infrastructure

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A. R. Engineers & Consultants

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Introduction

Advancements in cementitious materials have continuously shaped modern civil engineering. From ancient lime mortars to Roman pozzolanic concrete, material innovation laid the foundation for today's construction technologies. The real breakthrough occurred with the invention of Portland cement in the 19th century, enabling the development of modern materials such as PCC, RCC, and HPC.

- PCC is widely used for pavements and small structures.
- RCC, with steel reinforcement, revolutionized high-rise buildings, bridges, and hydraulic structures.
- HPC introduced higher durability and mechanical performance for demanding applications.

As the need for stronger, durable, and long-lasting materials grew, concrete technology evolved towards Fiber-Reinforced Concrete (FRC) and eventually to advanced materials such as UHPC and UHPFRC. These next-generation composites are redefining modern infrastructure due to their exceptional mechanical and durability properties.

What is UHPFRC?

Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) is a cement-based composite characterized by:

- Compressive strength >150 MPa
- Tensile strength of 8–12 MPa
- Strain-hardening behavior
- Very low permeability and superior durability

Unlike conventional concrete, UHPFRC contains no coarse aggregates. Instead, it uses fine powders, optimized particle packing, and steel fibers to create a dense, high-strength matrix.

Core Principles of UHPFRC

1. Optimized particle packing - Maximizes density and minimizes voids through carefully selected powders and fine aggregates.
2. Low water-to-binder ratio - Achieves minimal porosity and high strength.
3. High fiber content for ductility - Steel fibers (13–20 mm) or synthetic fibers enable tensile capacity, crack bridging, and ductility.

Material Composition - A typical UHPFRC mix incorporates:

- **Portland cement:** High-grade cement with controlled particle distribution.
- **Fine Aggregates:** Quartz or silica sand for better compaction.
- **Silica Fume:** A highly reactive pozzolano that enhances strength and reduces permeability.
- **Superplasticizers:** High-range water reducers for workability at extremely low water content.
- **Steel Fibers**: Typically 2–3% by volume, providing cracking resistance and post-crack load capacity.

Steel Fibers : length=13 mm, Dia =0.15m

Mechanical Properties of UHPFRC

- Compressive Strength - UHPFRC can routinely achieve 150–200 MPa, far exceeding conventional concrete (20–40 MPa) and even HPC (60–100 MPa). This is due to its dense microstructure, reduced porosity, and optimized particle packing.

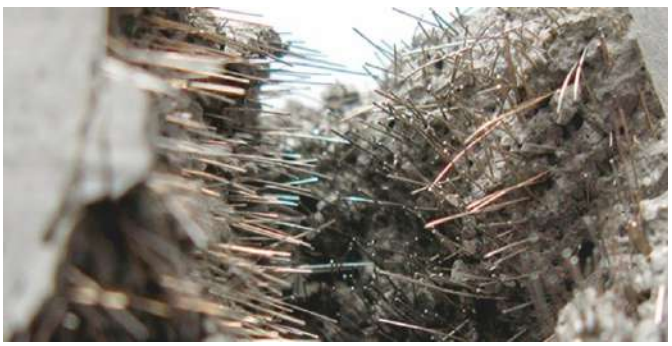
- Tensile Behavior - With fiber reinforcement, UHPFRC exhibits strain-hardening behavior and tensile strengths of 8–12 MPa. Fibers delay crack initiation and control propagation, enabling multiple fine cracks instead of a sudden failure.

- Flexural Strength - Flexural strength ranges from 20–30 MPa, depending on fiber dosage and distribution. Post-cracking strength is significantly superior to that of FRC.

- Modulus of Elasticity - Typically ranges between 40–50 GPa, influenced by mix design and fiber type.

Table T.1 — Indicative values for UHPFRC characteristics

Young's modulus E_{cm}	45 - 65 GPa
Characteristic compressive strength f_{ck}	150 - 200 MPa
Mean compressive strength f_{ck}	160 - 230 MPa
Characteristic tensile limit of elasticity $f_{ctk,el}$	7.0 - 10.0 MPa
Mean tensile limit of elasticity $f_{ctk,el}$	8.0 - 12.0 MPa
Characteristic post-cracking strength f_{ctfk}	6.0 - 10.0 MPa
Mean post-cracking strength f_{ctfk}	7.0 - 12.0 MPa
Global fibre orientation factor K_{global}	1.25
Local fibre orientation factor K_{local}	1.75
Linear coefficient of thermal expansion	11 µm/m/°C
Length L_f	12 - 20 mm



UHPFRC in India: A Growing Opportunity

India is gradually adopting UHPC/UHPFRC technology in national infrastructure. A notable milestone is India's first major UHPFRC Bridge on NH-752 K (Latur–Nilanga–Aurad section) at KM 42+050, commissioned by NHAI with a project value of ₹359 lakh.

This project demonstrates the growing confidence in UHPFRC for enhanced durability and faster construction.

Latur–Nilanga–Aurad section

Conclusion

UHPFRC marks a significant advancement in concrete technology, offering exceptional strength, durability, and crack resistance that make it ideal for bridges, high-rise buildings, seismic zones, tunnels, precast elements, and marine structures. Its ability to reduce reinforcement, enable slender components, and extend service life makes it highly suitable for sustainable and future-ready infrastructure. However, challenges such as higher material costs, the need for controlled production, workability issues, and limited field experience must be addressed through research, training, and localized mix development. Establishing India-specific standards—covering mix design, structural guidelines, durability models, and quality control—will be crucial for safe and widespread adoption. With proper codification and industry readiness, UHPFRC has the potential to reshape India's infrastructure by enabling faster, safer, and more resilient construction.

■ Shree Gogawale

Connecting Elements: Engineering Smarter Innovation in Precast Construction Technology

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Precast India Connections Pvt. Ltd.

We began with a simple, persistent question that many in the precast community ask in one form or another: can horizontal continuity between precast elements be achieved in a way that is both structurally reliable and operationally efficient? Over years of working on our internal projects, at Precast India Infrastructures Pvt. Ltd., watching site sequences, and talking with execution teams and structural consultants, we observed a repeating pattern. Two familiar solutions were being used — wire loops and cast in situ stitch joints — and each solved a piece of the problem while introducing other, often significant, complications. The invention of the Precast India Connector (PIC) manifested from that observation. It was not conceived as an abstract engineering novelty but as a practical response to everyday trade-offs: move difficult, error prone work into the factory; give site teams a reliable, verifiable sequence; and provide designers a connection they can accept for emulative continuity where it makes sense.

To understand why we developed PIC, it helps to start with the practical realities that shaped our thinking. Wire loop connections remain common for good reasons. They are simple to cast, inexpensive in material, and convenient where panels are not relied upon to act together for lateral resistance, often being termed as a non-structural connection. In many buildings — especially where walls are not primary lateral elements — wire loops function adequately to align panels and to provide a basic mechanical link while keeping production and erection straightforward. However, wire loops are inherently flexible. Designers often model such walls as discrete units with deliberate small gaps, because the connection does not reliably provide the stiffness or shear transfer a continuous shear wall would require. In areas with higher lateral demand, seismic sensitivity, or where cores and stair walls must act as a single unit, the limited contribution of wire loops becomes a design constraint.


Photo 2


Photo 3

The alternative used in such situations has traditionally been the cast in situ stitch joint: overlapping U bars or starter bars with a small in situ pour to achieve continuity. On paper this is an effective way to make panels act monolithically, but on site the method introduces repeated, small, and time sensitive tasks. Each stitch requires local shuttering, careful positioning of overlapping reinforcement, precise grout or concrete mixing with attention to flow and compaction, and a curing period before subsequent work can proceed. These operations multiply across every joint in a precast run and, cumulatively, occupy significant labour, time and inspection resources. Tiny volumes of concrete are particularly difficult to place and cure consistently; quality control and aesthetic matching become issues; and the presence of projecting starter bars during transport and erection adds handling risk and an exposure point for corrosion. Needless to mention, providing for the protruding bars in the production stage, require slits in the moulds, where leakage of concrete slurry may take place, leading to honeycombs, irregular quality standard, inefficient form removal methods, often leading to hammering them out leading to touch ups and re-works. Put simply, stitch joints tend to create recurring micro activities that sit on the project's critical path and invite quality variation.

The pattern of trade offs made us question ourselves whether it would be possible to keep the structural advantages of an emulative connection while removing the repeated on site wet works and their attendant risks. The Precast India Connector is the product of that practical inquiry: a factory installed dowel in sleeve system intended to provide predictable shear transfer and ductile behaviour, with a simple, verifiable on site completion sequence.

Photo 4: PIC for Wall to Wall

The system is straightforward to describe in operational terms. At the factory, donor and receptor sleeves are located and fixed within the reinforcement cage and mould. Where the connecting bar must pass through one element to the other, often via an intermediate precast element, if applicable. At erection, the donor element, any intermediate member, and the receptor element are aligned so that the sleeves are collinear. The dowel is actuated from donor to receptor by rope pull or drill pull, the external gap between elements is sealed with backer rod, MS or PVC pipe or mortar, and grout is placed either by gravity or pressure pumping until the indicator confirms fill. The dowel bar sits in the donor; small features such as front mount, ensure the bar is surrounded by grout on all sides; grout vents and a visual grout indicator (the GIW) provide a clear signal when the grout has been filled in the tubes entirely.

The practical value of that sequence became clear in our early trials and mock ups. By shifting sleeve installation and alignment into the factory, where processes are repeatable and conditions are controllable, many of the variables that make stitch joints challenging were addressed before the elements left the yard. Sleeves are fixed using holders, grout vents are routed and protected, and pulling wires attached to the dowel bars are readily available at erection. On site the operation is far less dependent on transient conditions: there is no ad hoc shuttering for a tiny stitch, no small complicated pour to manage for local curing, and there are fewer opportunities for the sort of workmanship errors that later require rework. The GIW provides an immediate, visible confirmation of grout flow, reducing uncertainty and the need for intrusive verification.

Photo 5

Photo 6

Structural performance was a central focus for us, and it remained a concern for many of the consultants we worked with. To address that, an independent experimental programme was conducted by IIT Madras. The tests compared PIC joints with looped wire ropes and conventional U bar stitch joints under monotonic and cyclic loading. The test series covered typical panel and grout strengths and examined dowel diameters, spacing and embedment lengths. The results were informative. PIC specimens exhibited ductile behaviour: after interface cracking they demonstrated significant slip capacity with retained load, and many tests ended in dowel rupture rather than pull out or joint failure. U bar stitch specimens often reached higher peak loads in monotonic tests, yet their failures involved crushing of joint concrete and less favourable post peak retention. Looped wire systems, as expected from their geometry and flexibility, exhibited lower cracking capacity and little residual strength after cracking. Importantly, cyclic testing showed that configurations with higher dowel density and appropriate confinement — for example using four dowels or providing collars around grouted regions — improved hysteretic stability, an observation that informs conservative detailing for seismic or high cyclic demand situations.

On the basis of these results, conservative design guidance was developed for early adoption. It was suggested that dowel diameters in most wall applications remain in the 16–25 mm range, that spacing be initially limited to 250 mm unless analysis supports wider centres, and that embedment length remain within a range of 250mm to 350mm in case of wall to wall application of PIC. Surface preparation was also discussed in the test programme: moderate roughening of panel faces increases early stiffness and cracking load, but excessive roughening may induce brittle behaviour, so preparation should follow measured industry practice. In short, the tests confirmed that PIC can provide predictable shear transfer and ductile failure modes when detailed and executed in line with test based recommendations.

Field experience complemented the laboratory evidence. PIC was applied in a variety of projects — cores, stair and lift shafts, retaining walls, an underground water tank, and beam continuity runs in multi storey work. Feedback from precast contractors, developers and consulting engineers shared common themes. On site the sequence was generally faster and required fewer crews for joint works when compared with repeated stitch operations. Finish quality at joints was notably better in many cases, reducing remedial patching and aesthetic correction. Transport and handling incidents related to protruding starter bars decreased because donor sleeves obviated the need for exposed starters. Contractors repeatedly noted the practical value of on site support during early installations: factory mock ups, supervised initial erecting, and clear QA checklists materially shortened the learning curve. Consultants asked for a cautious, measured rollout: pilot mock ups, documented grout quality checks, and retained conservative detailing until multiple pilot successes provided broader confidence.


Photo 7


Photo 8

Adapting the same approach to beam to beam continuity required attention to scale but not to principle. Where walls commonly use dowel diameters in the 16–25 mm range, beam continuity often requires larger bars. For beam work we offer M, L and XL models sized for rebars of diameters 32 and 40mm. Mid receptors become useful to pass bars through columns or primary beams without disturbing intermediate reinforcement. Practical differences appear in actuation method and tolerance control. Beam bars are longer, so rope pull methods are typically preferred over drill pull. Over longer travel distances a small misalignment becomes more likely to block insertion, so shop coordinate checks and tighter tolerance controls are emphasised. The grout and verification principles remain the same: seal the gap, grout through the vents, and confirm fill visually. The operational benefit — avoiding many small in situ pours. The coordination required is slightly higher, though, and the shop drawings and erection checks must be followed more rigorously.


Photo 9:
PIC for Beam to
Beam/Beam to Column


Photo 10


Photo 11

If a team is considering PIC for the first time, our recommendation is to adopt a measured pilot approach. Start with two or three factory mock ups to validate sleeve placement, pulling procedures and grout accessibility, and to confirm grout cube strengths from the batches used in the yard. Follow this with a single representative site pilot — a wall run or beam continuity sequence that typifies the project's most frequent joint type. Capture simple metrics during the pilot: man hours spent on joint activities, grout volumes used, time from erection to topping readiness. Compare those observations with matched stitch based sequences to quantify the practical trade offs in labour and time. Use the pilot data to inform any design changes, particularly where designers plan to treat adjacent panels as continuous and consider modifying vertical reinforcement accordingly.

The system is a practical tool intended to be used where its attributes align with project objectives: improved site productivity, verifiable grouting, and the desire to consider emulative continuity in design. Where wire loops are sufficient and preferred, they remain an economical and simple choice. Where stitch joints are chosen, our intent has been to provide an alternative that reduces recurring wet work risk and gives both production and design teams an additional option when continuity and productivity are priorities.

From the team at Precast India Connections, the journey with PIC has been both technical and practical. Laboratory evidence, proper detailing guidelines, conservative product tolerances, correct factory procedures while installing the products and initial field experience during installation and grouting have informed a straightforward adoption path: mock ups, a controlled pilot, documented QA and then scale up informed by measured outcomes. For teams that wish to evaluate PIC we can supply shop drawing blocks, factory and site QC method statements, and a pilot plan with acceptance criteria with training and supervision from our teams experienced in PIC usage. The connector was developed to address everyday operational challenges while maintaining a conservative, test informed approach to structural performance. Our experience to date suggests the approach is useful and practical; with measured, data driven adoption it can be integrated into broader precast workflows while providing predictable execution and structural performance.

We do mention with humility and pride that our innovation has been Patented in more than 25 countries and technically approved in Singapore already. It is in process of Technical approvals in other countries like Thailand, Germany and soon Japan. Due to the above advantages, tremendous market interest is generated in our product which will be compliant to Make in India vision of our country and hopefully shall earn invaluable foreign reserves for the country when the exports begin. Till date, we were mostly importing technology from the world however, today India is poised to export patented technology in the precast field for the very first time, via PIC -

Bamboo beyond Gazebos and Pergolas: Architectural Innovation for Sustainable Living.

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Abstract

Bamboo-the "green steel" of the 21st century, remains largely confined to gazebos, pergolas and decorative structures, despite its immense potential as a renewable, high-performance building material. In an age defined by climate crisis and resource depletion, the paper challenges conventional material hierarchies by exploring bamboo's scientific, ecological, and socio-cultural strengths. It traces the work of Manasaram Architects, led by Ar. Neelam Manjunath, whose decades-long research and architectural practice have pushed bamboo beyond ornamentation into the realms of urban architecture, policy, and sustainable innovation. The article reframes bamboo as a structural, climate-responsive, and culturally rooted material, advocating for its mainstream integration through design, education, and policy frameworks.

Keywords: Bamboo architecture, sustainability, Manasaram Architects, circular materials, ecological construction, regenerative design.

1. Introduction

In the Anthropocene, human activity has become the dominant force reshaping the Earth's ecosystems and material cycles (Crutzen , 2002). Architecture and construction-though vital to human progress are now major contributors to environmental degradation. The built environment accounts for over 40% of global carbon emissions, with materials like concrete and steel responsible for nearly 8% of total CO_2 emissions (AGENCY, 2022; Hafez, et al.).This reliance on high-carbon materials poses a fundamental challenge: How do we continue to build, yet remain within planetary limits?

This question leads us to bamboo, a material both ancient and futuristic. Once dismissed as "poor man's timber," bamboo is now emerging as a biogenic, high-performance material capable of meeting modern construction demands (Sharma, Gatóo , Bock, & Ramage, 2015). Despite its structural capabilities comparable tensile strength to steel and compressive strength similar to concrete bamboo's mainstream potential remains underutilized, largely due to entrenched misconceptions about its fragility, durability, and permanence (Janssen, 2000).

Manasaram Architects, under Ar. Neelam Manjunath, have been at the forefront of mainstreaming bamboo architecture in India and beyond. Through decades of experimentation, policy advocacy, and built projects, they have demonstrated bamboo's viability as a structural, aesthetic, and sustainable building material. This paper builds upon their practice to explore how bamboo can anchor a new architectural paradigm one that unites climate responsibility, material innovation, and social equity.

2. Bamboo As A Sustainable Material

2.1 Botanical and Structural Properties

Bamboo is a fast-growing grass, not a tree, capable of reaching full maturity in 3–5 years, compared to 50–70 years for hardwoods. Its natural geometry hollow cylindrical culms with vascular bundles aligned along the length provides exceptional strength-to-weight ratio. Bamboo exhibits tensile strength up to 370 MPa, often comparable to mild steel (Zhang et al., 2024). Its elasticity and resilience make it ideal for seismic regions, where flexibility prevents catastrophic failure.

Furthermore, advancements in engineered bamboo composites laminated panels, trusses, and beams have enhanced consistency, fire resistance, and dimensional stability. This innovation bridges the gap between craft and modern manufacturing, positioning bamboo as a legitimate structural material for 21st-century architecture (Sharma, Gatóo , Bock, & Ramage, 2015).

2.2 Ecological Benefits

Bamboo is a carbon-negative material. It sequesters up to 17 tonnes of CO_2 per hectare per year, while simultaneously releasing 35% more oxygen than equivalent tree stands (Negin & Shirzad, 2025). Its rhizomatic root network prevents soil erosion and aids in land restoration and slope stabilization critical in monsoon-prone and deforested regions. With low embodied energy from harvesting to processing, bamboo outperforms conventional materials in lifecycle assessments (Hafez, et al., 2024).

2.3 Cultural Heritage and Traditional Craft

Across India, bamboo is deeply embedded in vernacular and tribal architecture-from the stilt houses of the Northeast to the mat-walled dwellings of Kerala. These traditional typologies, developed through empirical knowledge systems, reveal an intuitive understanding of material behaviour, climate adaptation, and local resource cycles (Janssen, 2000). In contemporary practice, reviving this heritage connects design to cultural continuity and community resilience.

3. Limitations in Mainstream Adoption

Despite its promise, bamboo's mainstream adoption faces significant challenges. The most persistent is perceptual bias-its association with low-cost, rural, or temporary structures. This stigma often leads clients and professionals to overlook its technical advantages.

3.1 Policy and Code Gaps

India currently lacks a fully standardized National Bamboo Building Code. While efforts are underway through agencies like BIS, BSI, and INBAR, the absence of codified guidelines hampers large-scale acceptance. Without certification standards for grading, preservation, and joinery, bamboo remains outside conventional structural design frameworks.

3.2 Institutional and Skill Barriers

Educational curricula in architecture and civil engineering rarely integrate bamboo design and construction training. Consequently, professionals lack both technical confidence and design vocabulary to employ bamboo effectively. Institutions like CGBMT are addressing this gap by conducting workshops, certification programs, and hands-on training sessions.

3.3 Market and Economic Limitations

Fragmented supply chains, inconsistent quality control, and limited access to treated bamboo further restrict scalability. Moreover, cost misconceptions persist-while raw bamboo may seem inexpensive, treated and engineered bamboo products require processing that ensures longevity. However, lifecycle analyses consistently show bamboo to be cost-efficient over time due to its durability and renewability.

4. Bamboo Beyond Gazebos And Pergolas: Reframing Possibilities

4.1 Engineered Bamboo and Material Innovation

Modern innovation has moved bamboo far beyond its rustic image. Engineered bamboo-through processes of lamination, densification and adhesive bonding-achieves uniformity and structural reliability. Laminated bamboo beams and boards can rival glulam timber in strength and aesthetics (Sharma, Gatóo , Bock, & Ramage, 2015). Treatments such as boric acid-borax preservation, thermal modification and resin coatings improve fire resistance and pest durability, addressing concerns about longevity.

4.2 Modular, Prefabricated, and Scalable Systems

Bamboo's lightweight nature and ease of assembly make it suitable for prefabrication. Modular bamboo units can be used for mass housing, classrooms, eco-resorts or emergency shelters. Projects by Manasaram Architects demonstrate this potential-where pre-engineered bamboo components enable rapid construction while maintaining cultural identity.

[Figure 1: Prefabricated Bamboo Modules for Rural Housing]

4.3 Interior Systems and Furniture

In interiors, bamboo offers both aesthetic warmth and functional efficiency. From structural flooring to acoustic panels and modular furniture, its design versatility supports a circular approach. The tactile, sensory quality of bamboo interiors reconnects occupants with nature-a critical aspect of biophilic design (Verma, & Chariar, 2012).

4.4 Bamboo in Public Architecture and Infrastructure

Bamboo's potential extends far beyond gazebos and pergolas, proving its viability at the urban scale through bridges, bus stops, amphitheatres, and community halls. Projects like the Bamboo Museum in Palampur India's only Bamboo Museum demonstrates how museums can sustainably protect natural and cultural environments while shaping meaningful visitor experiences. The project showcases bamboo in multiple architectural and interior applications. A glazed central dome anchors the structure, while the exhibition hall and passages use Bamboo Mat Corrugated Sheets (BMCS) for roofing. Floors are finished in

Figure 1- Bamboo Museum in Palampur (Source- Manasaram Architects)

red-and-black cement oxide, and walls use Bamboo Crete with interior surfaces in plaster, round bamboo, or Bamboo Mat Board. Doors combine Bamboo Mat Board with glazing, framed in neem and other locally sourced seasoned wood-highlighting bamboo's versatility in contemporary museum design.(Refer figure-1)

The Yamuna Biodiversity Park structures by Manasaram Architects demonstrate how bamboo can shape civic identity through ecological aesthetics. Their 15 m × 13 m arched-truss bamboo bridge assembled in just 20 days-meets IRC-6-2000 load standards, supporting up to 400 kg/sq.m. The deck uses 2"–2.5" hollow and solid bamboo, with 1.5"–2" bamboo railings, a corrugated bamboo-mat roof, and truss ends bolted to 16 mm MS plates. Wooden brackets at 10-foot intervals support both deck and roof, showcasing bamboo's strength, efficiency, and architectural elegance. (refer figure - 2)

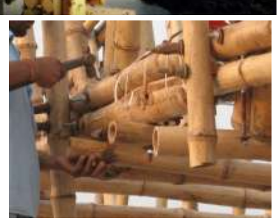

Figure 2-
The Yamuna Biodiversity Park Bridge and its details
(Source- Manasaram Architects)

5. Case Studies From Manasaram Architects

5.1 Bamboo Symphony, Bangalore (Refer Figure-3 and 4)

An architectural milestone, the Bamboo Symphony serves as both office and laboratory for Manasaram Architects. The structure explores bamboo in multiple dimensions-structural, acoustic, and climatic. Its triple-curved shell showcases the material's flexibility, while the double-layered bamboo facade enhances passive cooling.

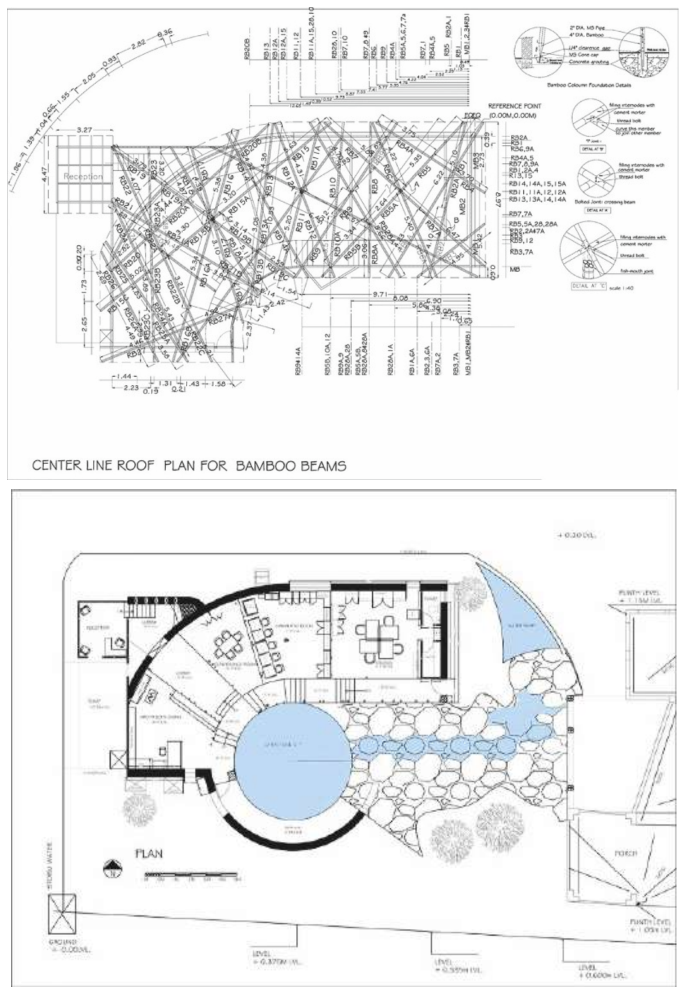

Figure 3-
Bamboo Symphony, Bangalore centre line plan of roof and floor plan. (Source- Manasaram Architects)

Figure 4-
View of Bamboo symphony (Source- Manasaram Architects)

5.2 House of Five Elements, Bangalore (Refer Figure -5 and 6)

This residence embodies the philosophy of Pancha Mahabhuta-earth, water, fire, air, and space-interpreted through bamboo. The hybrid structure integrates bamboo with concrete cores, demonstrating material synergy rather than competition.

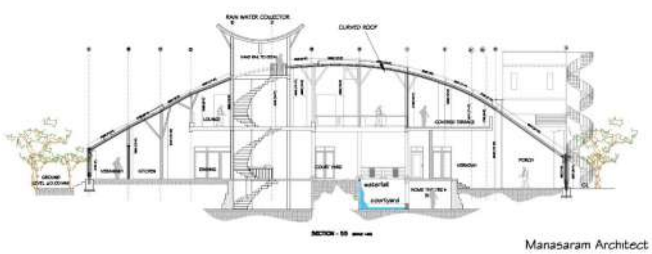

Figure 5-
Section of house of five elements (Source -Manasaram Architects)

Figure 6-
Construction Details house of five elements (Source -Manasaram Architects)

5.3 CGBMT Headquarters (Figure -7)

The Centre for Green Building Materials and Technology is both an institution and experiment--a living example of circular construction. The building integrates bamboo-reinforced composites, lime plasters, and recycled materials, serving as a hub for research, advocacy, and training.

Figure 7-CGBMT Headquarters, Bangalore
(Source -Ar.Ayush Prakash Hazare)

5.4 Lunardi Residence, Rome

A transcontinental collaboration that demonstrates bamboo's global adaptability, the Lunardi Residence (Figure-8) merges Indian sustainable expertise with European minimalism, symbolizing bamboo's international design language.

Figure 8-
Lunardi Residence, Rome view and elevation (Source -Manasaram Architects)

6. SOCIAL, ECONOMIC & COMMUNITY IMPACT

Bamboo architecture transcends material boundaries, it catalyses social transformation. The adoption of bamboo construction revitalizes local economies, especially in rural and tribal communities. Craft clusters and women-led enterprises associated with CGBMT demonstrate how material innovation can foster economic inclusion and skill empowerment.

By creating local employment and reducing the need for imported materials, bamboo contributes to rural stabilization and curbs urban migration. Furthermore, it fosters knowledge revival, reconnecting artisans to sustainable livelihoods.

Bamboo-based economies also align with India's Atmanirbhar Bharat mission-emphasizing local materials, circular value chains, and self-reliance.

7. POLICY, EDUCATION & SCALING FRAMEWORKS

7.1 Policy Integration

The absence of a National Bamboo Building Code has long hindered adoption. However, through the advocacy of experts like Ar. Neelam Manjunath, committees under NITI Aayog, BIS, and INBAR are developing standards for bamboo grading, joinery, and fire safety. Once codified, these will open avenues for bamboo in public infrastructure and housing missions.

7.2 Educational and Institutional Role

CGBMT plays a vital role in bridging academic and practical knowledge. Its training modules equip architects, engineers, and artisans with scientific understanding and hands-on skills. Partnerships with universities, CSR programs, and design schools expand research and innovation capacity.

7.3 Public and Private Sector Collaboration

Integration into eco-tourism, affordable housing, and school infrastructure projects can drive scale. Bamboo's circular economy potential positions it as a key component in India's net-zero and green building goals.

8. CONCLUSION

Bamboo is not an ornamental afterthought-it is a material philosophy for the future. In the face of ecological breakdown, it offers a pathway toward carbon-neutral, culturally connected, and economically inclusive architecture.

Through the pioneering work of Manasaram Architects, bamboo has evolved from gazebos and pergolas into a structural and societal force-a living symbol of how tradition and innovation can coexist.

As the Anthropocene demands a redesign of our material culture, bamboo stands as both heritage and horizon-rooted in the soil, yet reaching for a sustainable future.

Acknowledgment

We extend our sincere gratitude to Team Manasaram Architects and the Centre for Green Building Materials & Technology (CGBMT) for their invaluable support and insights. We also thank Ar. Pranjali Karnik for generously providing detailed project data that strengthened the technical depth of this work.

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Shivam Sutar

Circular Economy in Construction: Paving the Way for a Regenerative Built Environment

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The construction industry is at a critical juncture where embracing circular economy principles can fundamentally transform resource use, waste management, carbon emissions. This article addresses core aspects, innovations, case studies, benefits of circular economy in construction, revealing a path toward sustainable and economically viable building practices.

Breaking the Mould: Why Construction Needs a Circular Revolution

The construction industry is a major consumer of raw materials and a significant generator of waste; therefore, switching from the conventional linear "take-make-dispose" model to a circular economy approach is vital. In order to minimize waste, reduce environmental effects, and create economic value over a number of lifespan stages, the circular economy in construction places a strong emphasis on designing infrastructure and structures such that materials may be recovered, repurposed, or reused. This change is crucial since, in nations like the UK, around 62% of national garbage is produced and roughly 40% of the world's basic materials are extracted. The conventional take-make-dispose approach is unsustainable given that 3.4 billion tons of construction waste are predicted to be produced worldwide by 2050. The circular economy in construction breaks this mould and offers a transformative approach by redesigning waste out of the system and keeping materials in continuous use. Circular construction could cut embodied carbon by 30-50% and unlock $122 billion in material value by 2050, representing both environmental and economic imperatives.

Circular Economy Unpacked: The Blueprint for Sustainable Construction

This approach champions closed-loop systems—from designing adaptable buildings to material tracking and waste minimization. The fundamental shift is from disposable to reusable. It's not just waste management but a holistic redesign philosophy, engaging all stakeholders like architects, engineers, manufacturers, and demolition specialists.

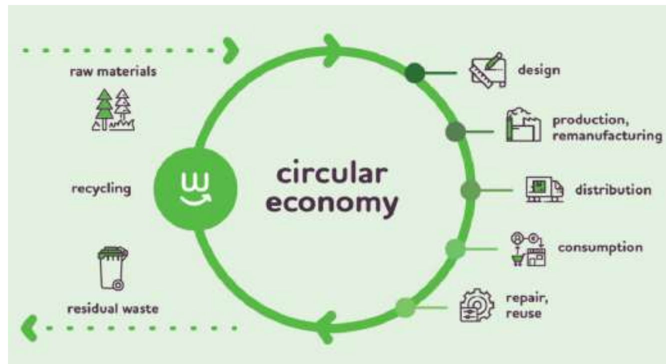

Fig 1: Circular Economy for Sustainable Construction

The Five Pillars of Circular Building Design

1. **Design for Longevity and Adaptability**

   Buildings constructed to last longer and adapt to new uses prevent premature demolition, conserving materials and embodied energy over multiple generations.

2. **Design for Disassembly (DfD)**

   Using reversible connections (bolts, screws) enables components to be dismantled without damage, transforming demolition into valuable deconstruction.

3. **Prioritizing Reuse and Recycling**

   Reclaimed steel, bricks, and recycled aggregates reduce demand for virgin materials and embodied carbon—often at lower costs.

4. **Material Tracking and Transparency**

   Digital material passports ensure every component's data is recorded for future recovery, turning buildings into resource banks.

5. **Waste Minimization via Precision Construction**

   Off-site prefabrication and modular methods reduce waste by up to 74%, increasing both efficiency and sustainability.

   "Circular construction treats buildings not as endpoints, but as living systems of reusable resources."

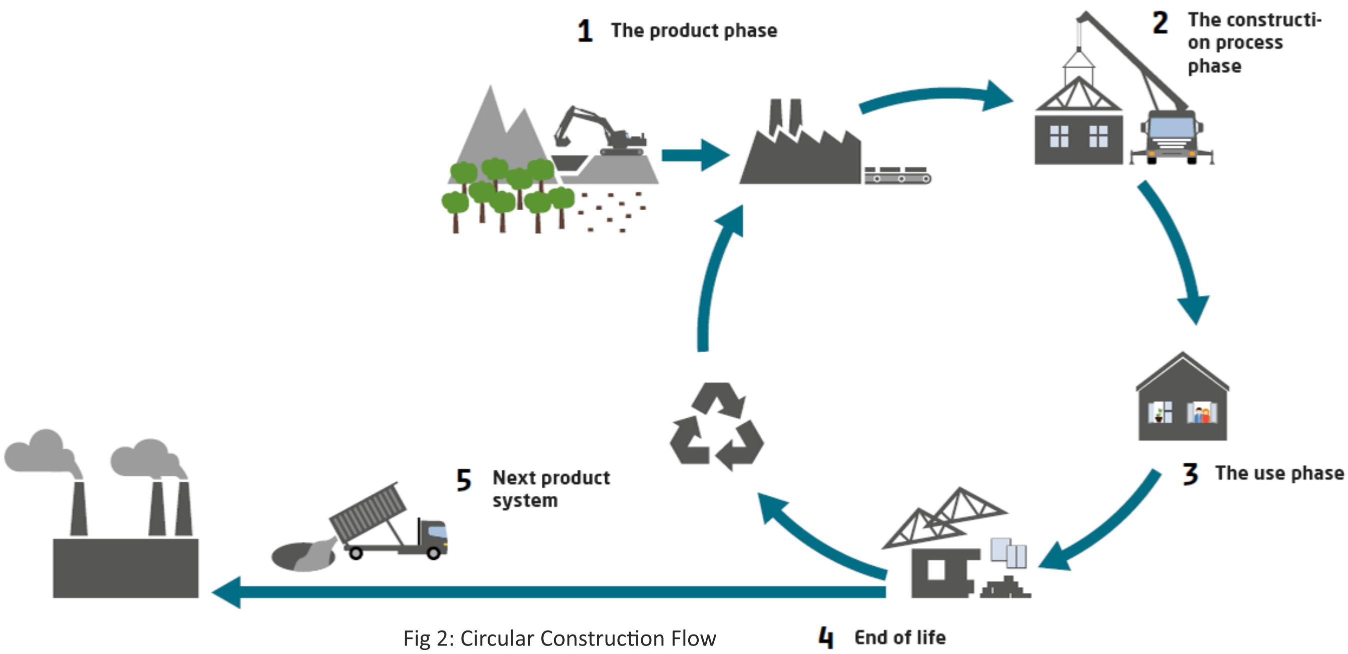

Fig 2: Circular Construction Flow

Innovation in Material Recovery: Engineering Waste into Wealth

Technologies are emerging to revolutionize material recovery, including:

- **Recycled Concrete Aggregates (RCA):** Wet processing and CO_2 curing improve quality and sequester carbon.
- **Steel Recycling:** Saves 95% of production energy, with over 98% recovery of structural steel from demolition.
- **AI Sorting Systems:** Robotics enhance separation of mixed materials like wood, plastics, and glass.
- **Waste to Resource:** Materials like Gypsum, wood, glass, asphalt, and insulation are now recycled into new products-demonstrating how "waste" becomes a resource.
- **Mobile On-site Processors and Centralized Facilities:** Work synergistically to reduce emissions and improve material purity.

Fig 3: Circular Economy through Material Recovery

Designing with the End in Mind: Exemplary Deconstruction Projects

Design for Disassembly (DfD) starts at the drawing board. It emphasizes reversible connections, material separation, and clear documentation for future recovery. Projects like Denmark's Circle House demonstrate scalable design for disassembly with 90% of materials designed for reuse. Arup's Circular Building Prototype also exemplifies full recovery feasibility, proving economic viability and practical application.

Building Block by Block: The Power of Modular Construction

Modular and prefabricated construction intensifies circular advantages:

- Reduces material waste by up to 74% through 'Precision and Efficiency'.
- Offers flexible modules for reconfiguration or relocation extends building lifespans.
- Cuts carbon emissions by 30-50% due to reduced transport and site activity
- Ensures higher durability and quality control and longer life cycles.

UK modular student housing projects highlight significant time savings (~50%) alongside embodied carbon reductions.

Digital Material Passports: Tracking Circularity Efficiently

Material passports digitize the lifecycle of building components including type, origin, carbon footprint, and recycling potential. Integration with BIM and QR codes allows quick access for deconstruction and reuse planning. Increasingly adopted in Europe and the UK, these are set to become regulatory standards.

Economic and Environmental Rewards of Going Circular

Circular construction delivers substantial returns:

- Reduces procurement and landfill costs
- Offsets deconstruction costs through resale of recovered materials
- Protects against raw material price volatility
- Projected global market exceeding $232 billion by 2024, growing 5.2% annually

Environmentally, it achieves embodied carbon reductions of 30-50%, significantly cuts virgin resource extraction, potentially lowers CO_2 emissions from materials by up to 38% by 2050.

Leading by Example: Global and Indian Case Studies Paving the Circular Path

- **Circle House, Denmark:** A pioneering social housing project designed for 90% material reuse using bolted timber frames and demountable systems, proving circularity at scale.
- **Amsterdam Circular Action Plan:** City-wide initiative integrating reuse mandates, recycling platforms, and zero-waste targets with the aim for complete circularity by 2050.
- **Cape Brick, South Africa:** A venture that transforms demolition waste into concrete bricks, saving 95% of energy and preventing one tonne of CO_2 emissions per 2,000 bricks produced.
- **Industrial Symbiosis, Aalborg, Denmark:** A network of 25 companies exchanging residual materials and energy, turning waste into resources and significantly cutting emissions and costs.
- **Swan Childcare Centre, Denmark:** Renovated using reused materials from a demolished school, earning the Nordic Swan Ecolabel and setting a precedent for sustainable renovation.

Indian Case Studies

- **Ahmedabad Circular Economy Pilot Project:** This pioneering project in Ahmedabad focuses on circular approaches in urban housing redevelopment. It emphasizes reuse of construction debris and salvaged materials, significantly reducing landfill pressure and raw material demand while creating affordable homes.
- **Mumbai Demolition Waste Recycling Initiative:** A large-scale initiative in Mumbai's redevelopment zones where 80% of demolition waste is processed and recycled into aggregates for road construction and concrete production, reducing virgin material extraction and urban waste challenges.
- **TERI's Sustainable Building Demonstration:** The Energy and Resources Institute (TERI) in India developed a model green building using recycled steel, fly ash concrete, and reclaimed wood. The project demonstrated a 45% reduction in embodied carbon compared to conventional construction practices.
- **Green Building Materials Incubator, Bengaluru:** A startup incubated in Bengaluru promotes recycled and low-embodied-carbon materials such as recycled plastic composites and agricultural waste-based bricks. These innovations are cutting material costs and CO_2 footprints in local construction projects.
- **Delhi Metro Circular Material Strategy:** The Delhi Metro Rail Corporation has adopted circular principles by strategically using recycled steel and concrete, incorporating modular station design for ease of future disassembly and material recovery, and optimizing construction waste recycling.

Overcoming Barriers: The Roadblocks and Remedies

Despite success stories, circular construction faces several barriers:

- Economic: Deconstruction costs more upfront, and recycled materials are often undervalued without carbon pricing.
- Infrastructure: Few recycling facilities, material marketplaces hinder large-scale reuse.
- Regulatory: Building codes still favour virgin materials.
- Knowledge: Limited training in circular design and material recovery.
- Cultural Resistance: Industry conservatism toward "new" materials persist.
- Coordination: Circular projects demand collaboration across all value-chain actors-something traditional procurement rarely encourages.

These challenges require policy reform, education, incentives, and infrastructure investment.

Tomorrow's Vision: The Future of Circular Construction

Looking forward, several forces are aligning to accelerate circular transformation:

- Policy Drivers: Landfill bans, carbon taxes, and mandatory recycled-content requirements will make circularity economically advantageous.
- Technological Innovation: AI, robotics, and blockchain will enable smarter waste sorting and material tracking.
- Market Development: Emerging material exchanges and digital marketplaces will connect supply with demand efficiently.
- Financial Instruments: Green bonds and sustainability-linked loans will increasingly fund circular projects.
- Education and Collaboration: Universities, industries are embedding circular design in curricula, while partnerships foster shared standards, material recovery networks.

By 2050, buildings will function as material banks, with demolition replaced by deconstruction and recycling fully integrated into design and construction.

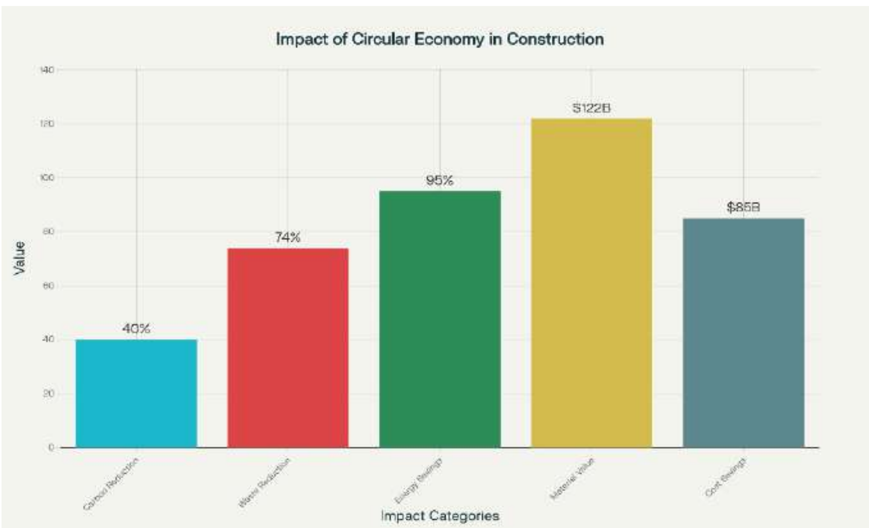

Fig 4: Impact of Circular Economy in Construction highlighting environmental and economic benefits.

Fig 5: Waste Generation and Material Use percentages in construction industry.

Conclusion: Building the Circular Foundation for a Sustainable Tomorrow

The circular economy in construction is far more than a sustainability trend-it's a systemic transformation of how humanity builds. It aligns economic opportunity with environmental necessity, turning waste into wealth and structures into material ecosystems.

From modular buildings and material passports to advanced recycling and digital innovation, circular practices are proving not just possible but profitable. The question is no longer whether the transition will happen-but how fast.

As resource limits tighten and climate goals become urgent, circular construction stands as the blueprint for a regenerative built environment-where every material has a purpose, every building has a second life, and the future is built

An Integrated Coastal Engineering Framework: Field Data Acquisition, Analytical Processing, Numerical Modelling, and Coastal Structure Design: A Case Study

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Abstract

Coastal engineering relies on a comprehensive understanding of hydrodynamic, sedimentological, and morphodynamic processes that govern coastal system behaviour. This article presents an expanded technical framework that integrates four core components of coastal engineering practice: field data acquisition, data analysis, mathematical and numerical modelling, and the design of coastal protection and harbour infrastructure. Each component is described in detail with emphasis on methodological rigor, interdependency of datasets, and application in real-world coastal management and infrastructure development. The proposed framework contributes to improved accuracy in predicting coastal responses, optimizing structural configurations, and enhancing climate resilience in coastal zones. The article comprises of application of mathematical modelling for design of coastal structures.

1. Introduction

Coastal engineering is a specialized branch of civil and ocean engineering that focuses on understanding, managing, and modifying coastal environments through the application of hydrodynamics, sediment transport processes, numerical modelling, and structural design. It involves the study of waves, tides, currents, coastal morphology, and shoreline dynamics to develop engineering solutions that protect coastlines from erosion and flooding, enhance navigation, support coastal infrastructure, and ensure sustainable and climate-resilient coastal development.

Coastal zones constitute complex, highly dynamic environments shaped by wave action, tidal oscillations, storm surges, sediment transport, and long-term morphodynamic evolution. The growing pressures of climate change, sea-level rise, rapid coastal urbanization, and port expansion necessitate scientifically robust engineering solutions. Modern coastal engineering therefore adopts a systems-based approach integrating in-situ measurements, analytical characterization of processes, advanced numerical modelling, and the design of hard and soft coastal protection interventions.

This article elaborates a structured methodology applicable to coastal and ocean engineering studies, highlighting the critical role of field data, statistical interpretation, process-based modelling, and structural design. The objective is to provide a technically rigorous framework that supports informed decision-making and sustainable coastal zone management.

2. Field Data Acquisition

Field data collection is the primary determinant of reliability in coastal engineering assessments. High-resolution, site-specific datasets provide the essential basis for model calibration, validation, and engineering design. The accuracy and temporal coverage of field measurements directly influence the fidelity of downstream analyses.

2.1 Bathymetric and Hydrographic Surveys

Bathymetric mapping using multibeam echosounders coupled with RTK-GPS allows the generation of high-resolution digital terrain models (DTMs) of nearshore and offshore zones. Hydrographic surveys capture depth variations, seabed slopes, and channel morphology, forming the basis for wave transformation studies, sediment transport calculations, and navigational channel design.

2.2 Hydrodynamic Measurements

Hydrodynamic data—including wave height, spectral energy distribution, tidal levels, and current velocities—are acquired using Advanced Doppler Current Profilers (ADCPs), wave rider buoys, tide gauges, and high-frequency radar. These datasets define the energetic conditions of the coastal region and establish boundary conditions for mathematical models.

2.3 Sedimentological and Geomorphological Data

Sediment sampling (grab samples, vibro-corers) and laboratory grain-size analysis (sieving, laser diffraction) provide sedimentological parameters such as d50, σg, settling velocity, and critical shear stress. Geomorphological mapping using UAV-based photogrammetry and satellite-derived dataset allows quantification of shoreline migration and dune dynamics.

2.4 Environmental and Ancillary Data

Data on water quality, turbidity, biological habitats, and coastal vegetation are collected for environmental impact assessments and for designing nature-based coastal solutions. Meteorological data—wind fields, pressure systems, cyclonic tracks—support extreme event analysis.

3. Data Analysis

Data analysis transforms raw field measurements into coherent datasets suitable for engineering interpretation, model parameterization, and design input derivation.

3.1 Wave, Tide and Water Level Analysis

Wave spectral analysis using Fast Fourier Transform (FFT), directional wave roses, and long-term wave statistics provides insight into predominant wave climate. Extreme wave and storm surge conditions are estimated using probabilistic methods such as Gumbel, Generalized Extreme Value (GEV), and Peaks Over Threshold (POT) approaches. Tidal harmonic analysis using tools like T_TIDE helps decompose tidal constituents and predict tidal elevations with high accuracy.

3.2 Current Field Interpretation

Measured current data are processed to identify residual currents, tidal asymmetry, stratification effects, and circulation patterns. These insights help in understanding sediment pathways, port siltation potential, and pollutant transport.

3.3 Sediment Transport and Morphological Assessment

Empirical and semi-empirical formulas (e.g., CERC, Engelund–Hansen, Van Rijn) are applied to estimate longshore and cross-shore sediment transport rates. Historical shoreline change analysis using DSAS or GIS-based tools reveals long-term accretion–erosion trends, seasonal cycles, and anthropogenic impacts.

3.4 Statistical and Uncertainty Analysis

Sensitivity analysis, error quantification, and uncertainty assessments ensure that engineering decisions reflect process variability and data accuracy constraints.

4. Mathematical and Numerical Modelling

Numerical modelling constitutes the predictive core of modern coastal engineering. It provides scenario-based insights into hydrodynamics, sediment transport, and morphodynamics under natural conditions and engineered configurations.

4.1 Hydrodynamic Modelling

Depth-averaged or 3D hydrodynamic models - MIKE21/MIKE3, Delft3D-FLOW, ADCIRC - simulate tides, currents, storm surges, and density-driven circulation. Model calibration employs iterative tuning of bottom roughness, eddy viscosity, and boundary conditions to achieve agreement with observed data.

4.2 Wave Transformation Modelling

Spectral wave models such as SWAN and MIKE21 SW compute wave propagation, refraction, shoaling, diffraction, breaking, and harbour tranquillity. Boussinesq models (e.g., FUNWAVE) may be used for surf-zone analysis and wave-structure interaction.

4.3 Sediment Transport and Morphodynamics Modelling

Coupled hydrodynamic–sediment transport models (Delft3D, MIKE21 FM) simulate erosion–deposition patterns, bed shear stress, and long-term seabed evolution. These models inform the design of beach nourishment, dredging schedules, and shoreline stabilization measures.

4.4 Climate Change and Scenario Modelling

Sea-level rise projections, cyclonic intensification scenarios, and changes in wave climate are incorporated into design sensitivity studies. These projections support the development of climate-resilient coastal structures and adaptive management strategies.

5. Design of Coastal Structures

Designing coastal structures requires a synthesis of empirical knowledge, model outputs, hydrodynamic loads, material characteristics, and geotechnical properties. Failure modes such as sliding, overturning, toe scour, and armour layer instability must be evaluated comprehensively.

5.1 Breakwater Design

Breakwater layout and cross-section design follow stability criteria such as Hudson, Van der Meer, or Goda formulations. Numerical and physical models support optimization of armour stone size, crest elevation, overtopping limits, and trunk-head transitions.

5.2 Seawalls, Revetments, and Bulkheads

These structures protect landward areas from wave attack, flooding, and coastal erosion. Their design considers wave pressure distribution, dynamic loading, uplift forces, foundation stability, and scour protection using toe aprons and filter layers.

5.3 Groynes, Jetties, and Training Walls

These structures regulate sediment transport, stabilize navigation channels, and control inlet morphology. Their geometry is optimized through shoreline evolution modelling to minimize downdrift erosion.

5.4 Soft and Hybrid Engineering Solutions

Beach nourishment, dune restoration, mangrove belts, and artificial reefs serve as low-impact alternatives or supplements to hard structures. Their design depends on sediment supply, wave climate, ecological compatibility, and maintenance requirements.

5.5 Integrated Coastal Zone Management (ICZM)

Engineered interventions must align with ICZM principles by integrating technical, environmental, socio-economic, and governance considerations.

6. Case Study

Project Name: MATHEMATICAL MODELLING STUDIES FOR HYDRODYNAMICS, SEDIMENT TRANSPORT AND EROSION – ACCRETION AT ROHINI SHIPYARD

Project Proponent: M/S. DAS Offshore Ltd.

Introduction:

M/s DAS Offshore Ltd (DOL) (previously known as M/s DAS Offshore Engineering Pvt. Ltd.) established in 1987 is engaged in fabrication of offshore structures, transport and installation in Indian Ocean. The company has its fabrication unit at Trans-Thane Industrial Area of Navi Mumbai. Project proponent have proposed to develop shipyard facilities near village Rohini in Raigad district. The site is located at Latitude 18° 14' 35" N and Longitude 73° 00' 55" E.

Figure 1: Location of Project site

6.1 Scope:

M/s DAS Offshore Ltd (DOL) has a jetty and fabrication yard at Rohini in the Rajpuri Creek. It was previously proposed to develop a ship building and ship repairing facility at Rohini. According to MoEFCC, it is essential to assess the effect of the existing facility of fabrication yard on the surrounding region of Rajpuri creek. It is proposed by DOL to undertake development of shipyard adjacent to the existing fabrication yard as a part of expansion of business. Along with the above studies it is essential to study the possible effect of the development of shipyard on the surrounding region of Rajpuri Creek.

DAS Offshore Ltd has approached M/s Aditya Environmental Services Pvt. Ltd. and Coastal Power Services for undertaking the further Hydrodynamic and sediment transport studies for the development of Shipyard on the southern bank of Rajpuri Creek.

In view of the above, it is proposed to undertake studies as follows

1. Review of Studies already completed and submitted
2. Assessment of Effect of Project Activities on the surrounding region of Rajpuri Creek

- In order to assess the effect on the surrounding region i.e. Shore line, prevailing water depths etc, it is essential to obtain old survey charts of this area and also to undertake the hydrographic survey of the entire region of Rajpuri Creek.
- To understand the source of sediment and its corresponding movement, it is essential to collect the water samples and bed material samples from atleast 6

locations in the proximity of project. These samples will be analyzed at the NABL accredited laboratory to determine the sediment characteristics.

- Comparison of the old hydrographic and latest charts will also to be carried out to determine the changes in the shoreline subsequent to construction and operation of fabrication yard.
- Identifying the location of erosion and accretion resulted in the surrounding region
- In order to exactly decide the sediment accretion / erosion dredging activity carried out by the agencies in the surrounding region, need to be explored and the quantum will be appropriately added to the total quantity of sediment.

6.2 Proposed Layout

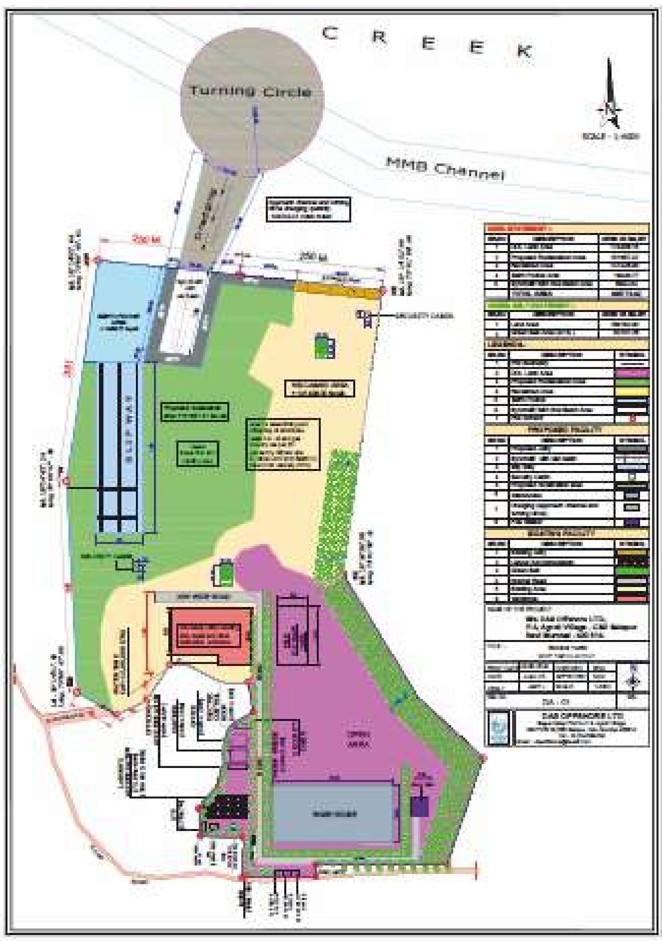


Figure 2: Proposed Layout of Rohini Shipyard

6.3 Data Collection and analysis

Coastal Power Services, Pune (CPS) visited site and started survey work on 5th November 2024 acquired bathymetry data, tide and tidal current data for three days.

Bathymetry data: Collected on site by using single beam echo sounder (USV) for three days 5th to 8th November 2025. It was observed the depth of water is ranging from 0 m to -15.0 m.

Tide data: Tide collected by using USV and GNSS technology and the tide data for period of 10 years 2014 to 2024 also collected from tide table published by MMB. In addition, the tide data collected by the project proponent in 2022 has also been incorporated into this study. The values of high water varied from 4.02 m to 4.82 m while the values of low water varied from 1.02 m to 3.0 m. Observations confirm that the tides are semi-diurnal in nature with diurnal distinct inequality in low waters.

Tidal current: Tidal current data collected on site by propeller type current meter for the period 5th to 8th November 2024 and also the data collected by project proponent during the year 2022 was also used. The tidal currents in the main stream are of the order of 0.75 m/s to 1.50 m/s.

Wave Data: The wave data collected for INCOIS for the period of 2014 to 2024. The maximum significant waves of 3.5 m to 4.5 m are seen to propagate from the deep water with a wave period of 10 to 14 seconds from westerly direction. The following wave rose diagram were plotted based on the wave data analysis for years 2024 to 2014. The overall observed significant wave height in this region is 4.375 m and the predominant wave direction from South West (SW), South of South West (SSW) and West (W).

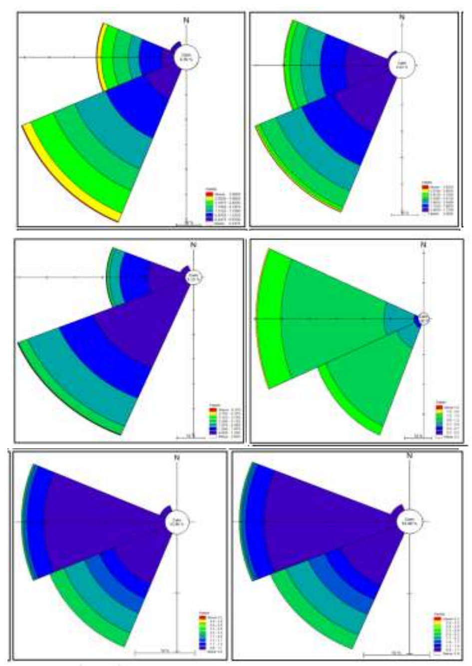


Figure 3: Wave Rose Diagrams for various months and years

Rainfall Data: The daily rainfall data collected from IMD for stations namely Alibag, Murud and Mhasala. In general the land in the vicinity of the shoreline is fairly plain while the region further inside is hilly. As such, though the annual rainfall is of the order of 3000 mm, the natural conditions do not help in storing the freshet discharge by way of construction of a bund, a dam or a reservoir.

Sediment Properties: Sediment and water samples collected from site and tested in the laboratory for the bed load and suspended sediment properties. The sediment is silty clay with mean diameter of 0.5 mm. The average suspended material concentration is almost the same during the flood phase of the tide (0.039 to 0.046 gm/lit) as well as during the ebb phase of the tide (gm/lit).

Other climatic parameters such as wind, temperature, water temperature, storms, and relative humidity were also considered while studying the project.

6.4 Mathematical Modelling:

Coastal Hydrodynamics (HD) is to be used for simulation of flow field and Coastal sediment transport modelling is to be used for bed level change and rate of bed level changes and spectral wave modelling used for simulation of significant wave height. Though the Rohini shipyard is situated 10 km away from the Rajpuri creek mouth, there will not be reached sea wave in this location. The software developed by Danish Hydraulics Institute (DHI), Denmark is widely used commercial software for solving coastal engineering problems. Brief description of these models is given below.

The hydrodynamic model MIKE 21 –HD (FM) (DHI, 2023) would be used for simulation of water levels and flows in coastal areas and creek region. It simulates unsteady two-dimensional flows in coastal area and is based on the non-linear vertically integrated 2-D equations of conservation of mass and momentum. The Sediment Transport model MIKE 21 –ST (FM) (DHI, 2023) would be used for simulation of sediment load and bed load in coastal and adjacent river areas. It simulates unsteady two-dimensional sediment movement in coastal and adjacent river area and is based on the non-linear vertically integrated 2-D equations of conservation of mass and momentum.

The simulation of wave transformation from deep to shallow waters was carried out using MIKE 21 SW model. This model is a spectral wind-wave model based on unstructured mesh, which takes into account all the important phenomena like wave growth by influence of wind, nonlinear wave-wave interaction, dissipation due to white capping, bottom friction and depth induced breaking.

6.5 Preparation of Boundary Conditions:

The tidal boundary condition for the present study obtained from MIKE Global tide sources and extracted from there and survey data from Project proponent with phase lag of 5 minutes. Figure No. 60 shows the boundary condition prepared for the simulation. The tidal level ranges from -1.7 to 1.4 m during the period of this simulation.

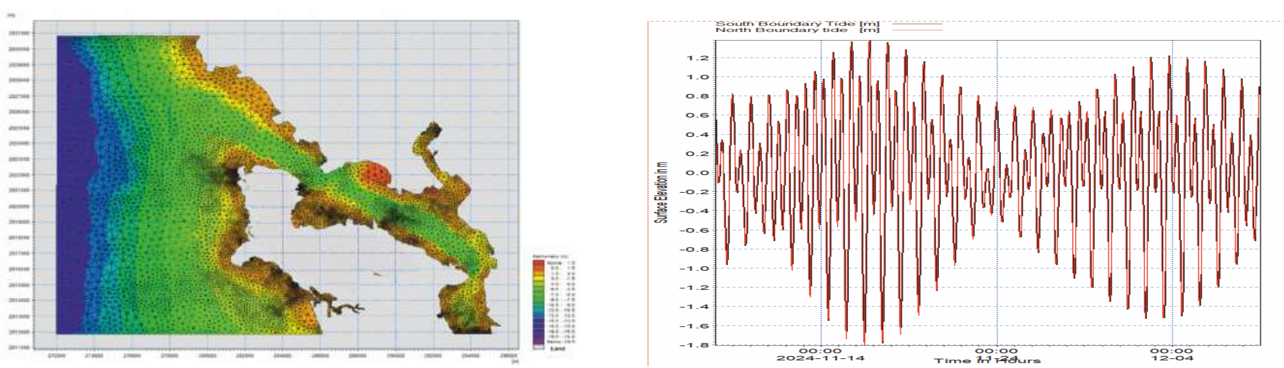


Figure 4: Bathymetry with mesh and boundary condition

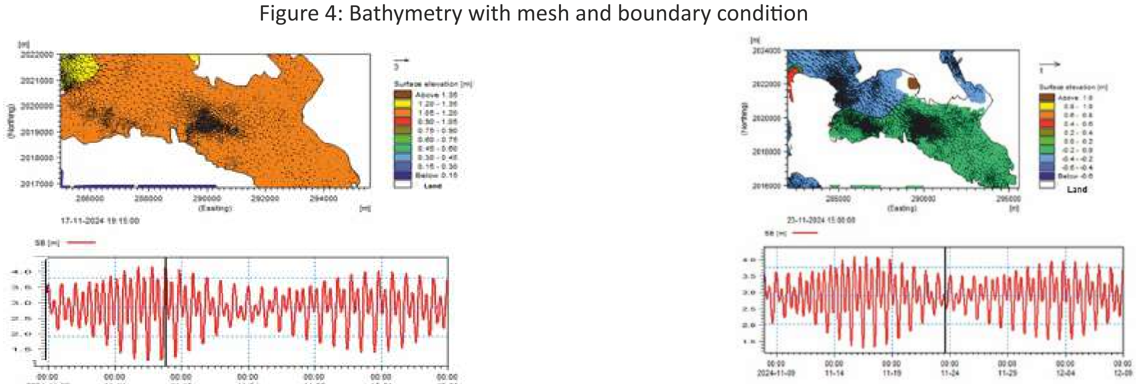


Figure 5: Results obtained for Hydrodynamic Model for Spring and neap tide (Existing)

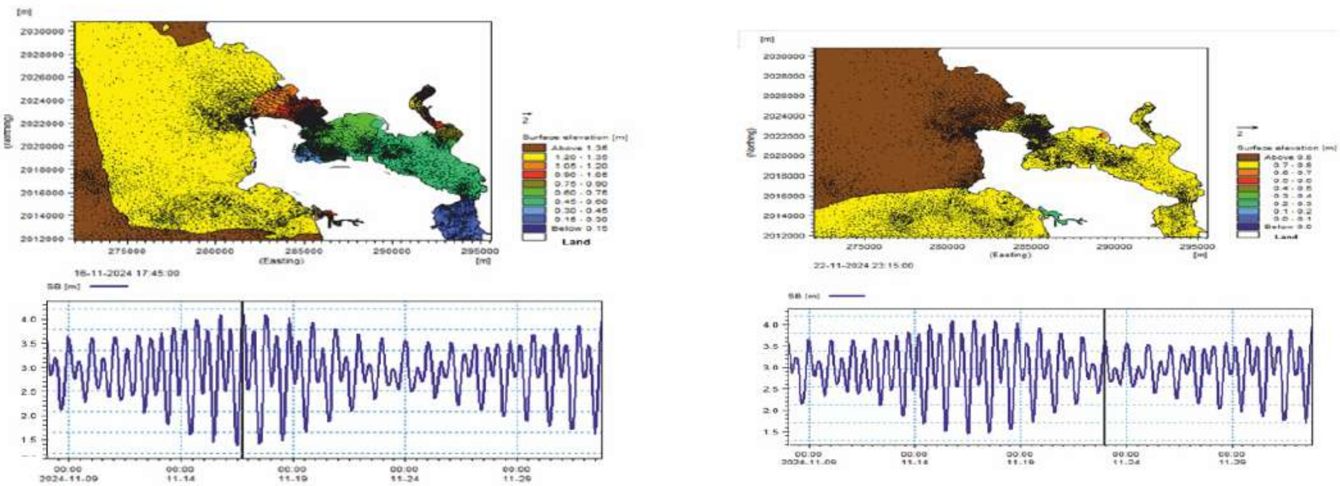


Figure 6: Results obtained for Hydrodynamic Model for Spring and Neap tide (Proposed)

6.6 Results:

The tidal hydrodynamics flow field of existing condition and proposed development are compared and circulations and velocities in the coastal region and Rajpuri creek region are not observed any significant variations and harmful impact on the development of reclamation at west side of the existing Rohini yard. It is concluded that the hydrodynamic modelling studies shown normal flooding and ebbing at Rohini shipyard and from the river mouth and river discharges.

The simulation of sediment transport modelling carried out with Proposed developmental conditions. The results show the rate of bed level change in the Rajpuri creek region also observed as 0.1 to 0.8 m/d. The results show the bed level change in the Rajpuri creek region also observed as -0.15 m. At the end of simulation the overall sediment transport in the Rajpuri creek region, the bed level change is of the order of 2 m.

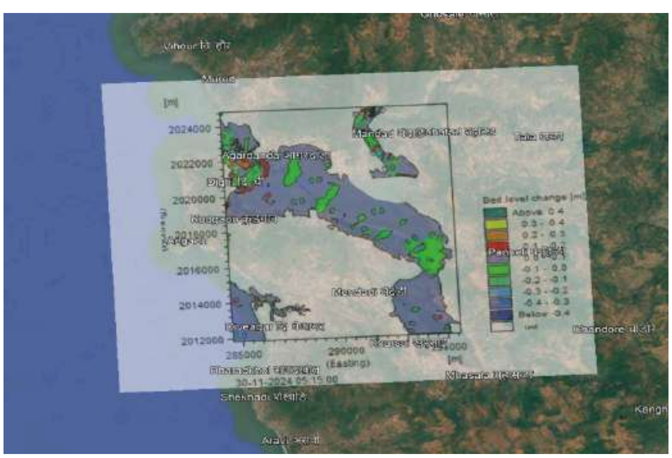
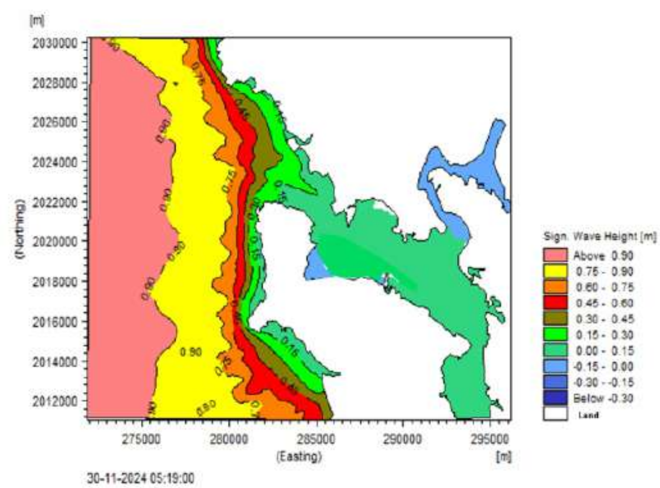


Figure 7: Results showing Sediment Transport at the end of simulation for proposed layout

The spectral wave modelling studies for existing condition and proposed development are compared and significant wave height in the coastal region and Rajpuri creek region are not observed any significant variations in the wave impact on the development of reclamation at west side of the existing Rohini shipyard. It is concluded that the spectral wave modelling studies shown normal movement of wave action from the river mouth and not in front of Rohini shipyard. It is evident that wave action near the Rohini shipyard observed that the Rohini shipyard is located 15 km from the river mouth of Rajpuri creek. Hence Rohini shipyard is well protected region of any storm and normal wave action.



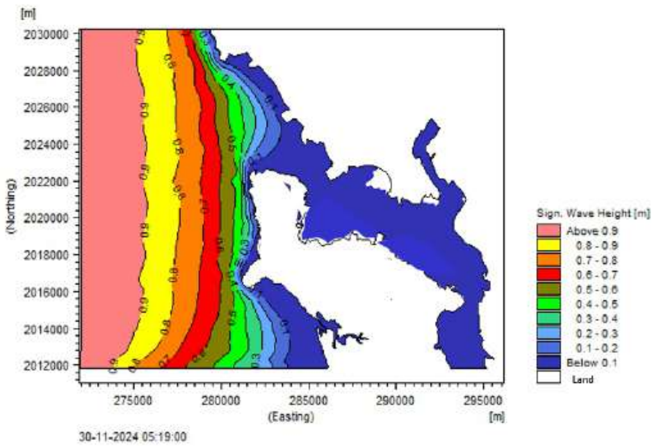


Figure 8: Spectral Wave Modelling: Existing and Proposed

7. Conclusion

Coastal engineering demands a multi-layered, technically rigorous approach to address the complexities of coastal systems and the increasing impact of climate change. High-quality field measurements, detailed analytical processing, robust numerical modelling, and sound engineering design form an integrated workflow essential for delivering reliable, sustainable, and climate-resilient coastal infrastructure. The framework presented in this article enhances predictive capability, supports optimized intervention strategies, and contributes significantly to sustainable coastal zone management.

It is concluded that the hydrodynamic modelling studies shown normal flooding and ebbing at Rohini shipyard and from the river mouth and river discharges. It is concluded that the sediment transport modelling studies shown normal movement of sediment during flooding and ebbing at Rohini shipyard and from the river mouth and river discharges.

It is evident that wave action near the Rohini shipyard observed as 0.15 m that the Rohini shipyard is located 15 km from the river mouth of Rajpuri creek. Hence Rohini shipyard is well protected region for normal wave action and Rohini yard is not in the wave breaking zone.

Acknowledgment :

Er. Vasant Vaze

Proprietor,

Coastal Power Services Pune

■ Yash Fatale

■ Hrutik Dhanawade

Concrete Reimagined
Building a Greener & Carbon-Smart Future

Prof. Ar. Mahesh Bangad
Chairman - Architects Engineers & Surveyors Association (AESA)

Janhavi Dudhane
BNCA's SDG Officer (2025–2026)

Figure 1: Sustainable concrete future.

Concrete is a composite material made up of coarse aggregates held together by a fluid cement paste that hardens and strengthens over time. Most commonly, lime-based concretes such as Portland cement or other hydraulic cements (e.g., cement fondu) are used.

However, the most desirable properties of concrete — workability in its fresh state and strength and durability in its hardened state — cannot always be achieved with regular constituents alone. Concrete, by definition, is a composite consisting of a binding medium and aggregate particles, and it can take many forms. Concrete production is a blend of scientific precision and artistic skill.

In addition to normal concrete, other types include high-strength and high-performance concrete, self-compacting concrete, lightweight concrete, high-density concrete, fibre-reinforced concrete, polymer concrete, coloured concrete, and others. Special types of concrete are characterized by out-of-the-ordinary properties or are produced by unconventional techniques.

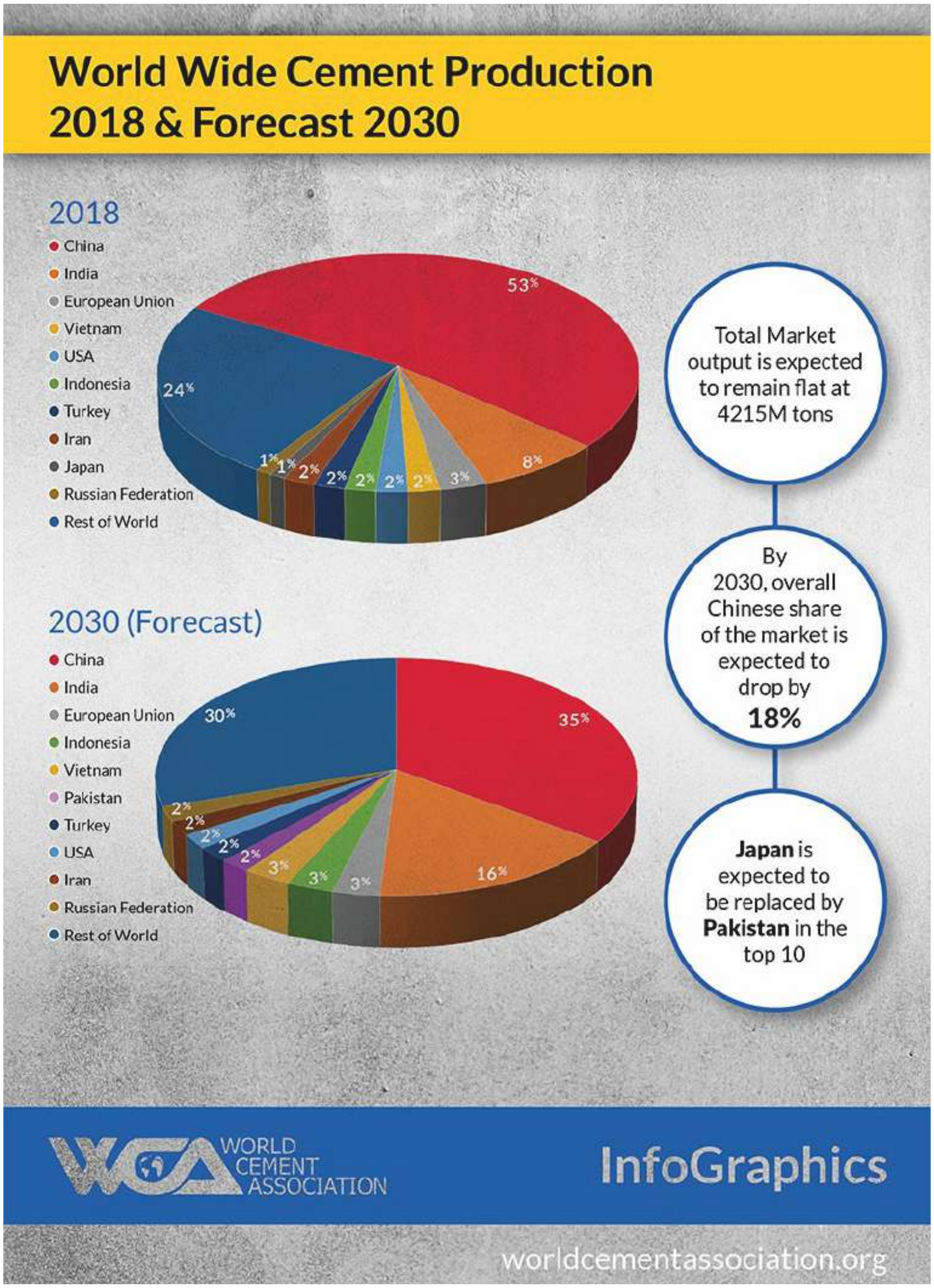
Introduction

An ever-evolving world demands ever-evolving construction methods. Concrete stands as one of the most essential and extensively used materials in modern construction practices. This is due not only to its wide range of applications, but also its strength, affordability, durability, and versatility. Concrete stands out as the only major construction material that can be transported to the site while still in a workable, plastic state. This flexibility makes it highly versatile, allowing it to be shaped or cast into nearly any desired form. It is also designed to permit reliable and high-quality fast-track construction. Structures built with concrete are more durable and can be engineered to withstand earthquakes, hurricanes, typhoons, and tornadoes.

Concrete is regarded as the backbone of modern construction due to its qualities. Its consumption is around 20 billion tonnes annually — roughly two tonnes per person on Earth. The reasons for its widespread use include adaptability, strength, durability, availability, and cost-effectiveness.

Why Green Concrete Matters Now ?

In the face of escalating climate change, the construction industry is under increasing pressure to adopt sustainable practices. Globally, the built environment accounts for nearly 40% of annual CO_2 emissions, with cement production alone responsible for approximately 8% of total global emissions (IEA, 2023). As the world urbanizes rapidly, there is a critical need to develop and deploy low-carbon alternatives to conventional construction materials. Among them, green concrete emerges as a promising solution — not only reducing carbon emissions but also improving material performance, resource efficiency, and long-term resilience. Transitioning to green concrete is no longer optional but essential for achieving net-zero climate goals and resilient infrastructure.



Due to its mass and density, concrete resists fire, reduces sound transmission, and minimizes floor vibration. It is readily available and affordable. For these reasons, concrete plays a role in nearly every major structure built in the world today. Given the growing awareness of sustainability in the construction industry — and beyond — it is essential to examine how this ubiquitous material can meet "greener" standards.

Concrete consists of Portland cement, coarse aggregates and fine aggregates, and water. While this may sound simple, batching (mixing) concrete for various applications and climates is complex. Portland cement and aggregates vary greatly, and most concrete mixes also contain at least one chemical admixture, such as water-reducing or air-entraining admixtures. The most consistent ingredient in concrete is the solvent — good old H_2O.

What is 'green' concrete ?

How can we make concrete more sustainable?

Here comes into picture green concrete, which refers to environmentally friendly concrete produced using sustainable materials and processes, aimed at minimizing the ecological footprint of construction.

It involves:

- Supplementary Cementitious Materials (SCMs): These are industrial by-products like fly ash, ground granulated blast-furnace slag (GGBS), and silica fume that partially replace Portland cement to lower embodied carbon.
- Recycled Aggregates: Crushed concrete or construction and demolition waste reused in new concrete mixes, reducing raw material demand
- Geopolymer Binders: Alkali-activated materials derived from industrial waste (e.g., fly ash, metakaolin) offering superior durability and significantly reduced CO_2 emissions compared to OPC-based concrete.

Green concrete combines these innovations to offer enhanced environmental performance without compromising strength, workability, or durability.

Source: Mehta & Monteiro, "Concrete: Microstructure, Properties, and Materials," 2014; Ghosh et al., 2020, Journal of Cleaner Production.

Feature	Ordinary Portland Cement (OPC)	Fly Ash Concrete	Geopolymer Concrete
Binder Type	Portland cement	Partial replacement of cement with fly ash	Alkali-activated industrial waste (e.g., fly ash, metakaolin)
CO_2 Emissions	High (approx. 1:1 ratio of cement to CO_2)	Up to 30-60% reduction compared to OPC	Significantly lower than OPC and fly ash
Durability	Good	Improved resistance to sulfate attack and ASR	Superior durability and chemical resistance
Workability	Standard	Comparable, sometimes better due to finer particles	Good, but mix design may be complex
Sustainability	Low (high embodied carbon)	Utilizes industrial by-products, reduces waste ,	Uses industrial waste lowers embodied carbon significantly
Thermal Performance	High thermal mass	Similar thermal mass	Similar or improved thermal properties
Water Usage	Standard	Often reduced in mixing and curing	Varies; can be optimized
Cost Implications	Baseline cost	Reduced cost due to use of industrial by-products	Can be cost-effective but depends on raw materials and processing
Common Applications	Widespread use in all construction types	Infrastructure, mass concrete, precast elements	Specialized applications requiring high durability and sustainability

Table 1: Concrete Mix Comparison Chart.

Advantages of Green Concrete

Environmental Benefits

- Up to **60% reduction in CO_2 emissions** by replacing cement with SCMs.
- **Reduces industrial waste** by repurposing fly ash, slag, and other by-products.
- **Lower water usage** during mixing and curing in many green formulations.

Performance Benefits

- **Higher durability and lower permeability**, resulting in longer service life.
- **Improved resistance** to sulphate attack and alkali-silica reaction (ASR).
- Thermal mass helps **lower energy consumption** in buildings by naturally regulating indoor temperatures through passive heating and cooling.

Economic Benefits

- **Reduced material cost** due to use of industrial by-products.
- **Lower lifecycle maintenance costs** due to increased durability.
- **Faster curing and ease of placement** in high-performance mixes.

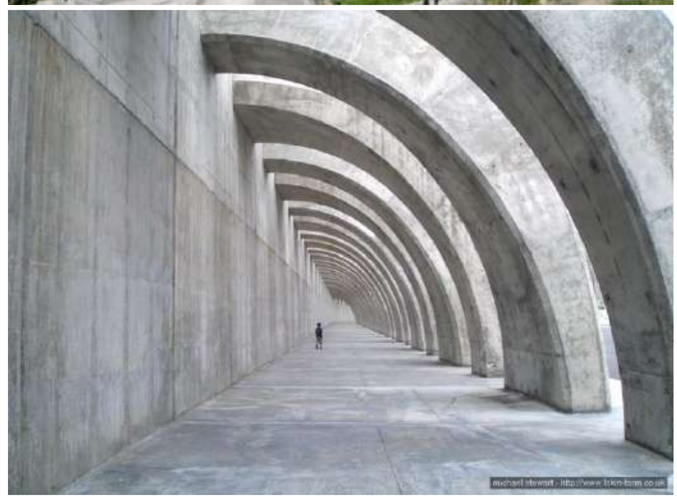


Figure 3,4,5: Scenic example of a concrete hydroelectric dam integrated within a mountainous landscape, illustrating concrete's critical role in large-scale infrastructure. Such structures demonstrate the material's exceptional durability, water resistance, and ability to withstand environmental stressors, while contributing to energy efficiency and climate resilience.

Current scenario

Today, the Portland cement industry is working to reduce its emissions, as producing one pound of Portland cement releases nearly one pound of CO_2 into the atmosphere. Regardless of one's stance on global warming, responsible stewardship of our planet demands minimizing greenhouse gas emissions.

Specifying the partial replacement of Portland cement with recycled pozzolans is an important step toward a more sustainable future. In addition, another way to reduce the consumption of Portland cement is to lower the total amount of cementitious material used in concrete mixes — especially for daily batched applications like slabs-on-grade and slabs-on-metal deck.

Several alternative pozzolanic materials, such as metakaolin, calcined paper sludge, and metro waste burner ash, are being researched as potential partial replacements. The future of concrete remains bright, but we must prioritize reducing greenhouse gas emissions and preserving natural resources.

Energy efficiency in buildings

Concrete can buffer a large portion of heat gains. Its high thermal mass helps optimize passive solar heating and can reduce fuel consumption for heating by 2–15% compared to lightweight buildings. Its passive cooling properties can also limit the need for air conditioning in summer.

An intelligent combination of heating, natural ventilation, solar shading, and structural strategies can reduce energy used for cooling — and the associated CO_2 emissions — by up to 50%. Concrete plays a crucial role in minimizing heat buildup in warmer climates, helping to maintain comfortable indoor temperatures even as the environment grows hotter. Additionally, exposed concrete surfaces can reflect light deeper into building interiors, reducing the need for artificial lighting.

Experts predict an increase in extreme weather events such as flooding, sea-level rise, and natural disasters, which will place unprecedented demands on infrastructure. This calls for the urgent construction of secure and resilient buildings. Concrete, being robust and versatile, offers the durability and climate-proofing required by updated building codes in response to these changing conditions.

Well-designed and built concrete structures—such as homes, schools, hospitals, and dams—are built to last, providing benefits for both present and future generations. Furthermore, concrete structures recover quickly after events like water damage, reducing repair times.

Extreme weather & climate change mitigation

- Extreme Weather Events: Concrete infrastructure provides stability and safety during natural disasters.
- Floods & Rising Sea Levels: Concrete is key to flood defences, coastal protection, water management, and hydraulic works. It safeguards people, animals, property, and the environment.
- Rainwater Management: Sustainable urban drainage systems (SUDs) made of concrete help filter water into the ground and reduce the burden on drainage networks,

mitigating flash floods.

- Rising Temperatures & Heat Waves: Concrete ensures thermal stability and comfort while enhancing energy efficiency. Its airtightness contributes to healthier indoor conditions, crucial during heatwaves.
- Spread of Diseases: Concrete structures are pest-resistant and help guarantee a safe supply of clean water.

Concrete can play a pivotal role in addressing the consequences of climate change by protecting both people and ecosystems. As a cement-based material, it offers an affordable and durable path toward climate adaptation and resilience

Figure 6,7,8: Architectural examples illustrating the versatility and climate-resilient properties of concrete.

Applications & Project Examples (Case Studies)

Delhi Metro Rail Corporation (DMRC), India

The DMRC incorporated fly ash concrete in several station and tunnel segments to reduce its carbon footprint. This move reportedly cut CO_2 emissions by over 30% per cubic meter of concrete used, making it one of India's early adopters of green concrete technology. [Source: DMRC Sustainability Report, 2018]

Figure 9,10: Illustration and project reference showing the Delhi Metro Rail Corporation's use of fly ash–based green concrete across stations and tunnel segments.
Credit: Delhi Metro Rail Corporation

San Francisco–Oakland Bay Bridge, USA

This large-scale infrastructure project used slag cement and silica fume blends to improve durability and reduce chloride-induced corrosion in a marine environment. The improved mix design greatly increased the durability and environmental sustainability of the bridge components.

[**Source:** Federal Highway Administration (FHWA) Case Studies, 2016; SIKA Construction of San Francisco - Oakland Bay Bridge]

Figure 11,12: Documentation from the San Francisco–Oakland Bay Bridge reconstruction project, where high-performance mixes incorporating slag cement and silica fume were used to enhance corrosion resistance, durability, and environmental sustainability, especially in harsh marine conditions.

Partanna Homes, Bahamas

This startup has developed carbon-negative concrete using brine from desalination and other natural binders. Their pilot housing project in the Bahamas is helping build climate-resilient homes that actively sequester CO_2 during curing. [Source: Partanna Global, 2024 Press Release; World Economic Forum, 2023]

Figure 13,14: Project reference of Partanna's carbon-negative concrete homes developed in the Bahamas. These structures use desalination brine and natural binders, actively sequestering CO_2 during curing and demonstrating a scalable model for climate-resilient, low-carbon housing.

Conclusion: Building Tomorrow with Responsibility

As one of the most indispensable materials in modern construction, concrete has shaped skylines, supported infrastructure, and empowered progress. But with growing concerns about climate change, it's clear that the way we use and produce concrete needs to change. Through alternatives like green concrete and sustainable construction methods, we have a real chance to reduce the environmental impact of our buildings without compromising on performance.

As designers, we're taught to design not just for today, but for the future. Green concrete is one such step — helping us balance design, durability, and environmental responsibility. By reimagining our construction methods, we have the opportunity to transform the way we live — and this change begins with the materials we select. Green concrete is not just an innovation — it is an essential component for sustainable construction. Embracing these low-carbon alternatives is how we build not only for today, but for generations to come.

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Property Valuation with Technology

Mandaar Gadre
Registered Valuer of Land & Building with Income Tax Dept. and IBBI.
Certified Independent Director

Property valuation in India has traditionally relied on manual site visits, paper-based documentation, and subjective judgment. But with the rapid growth of technology now valuators / appraisers now have access to powerful apps and software that streamline the entire process—from field data collection to report generation.

After struggling for many years we came up with an idea of collecting data on site using application and post processing in the office.

The conventional method of valuation involved

1. Collecting data at site.
2. Noting down the facts and data on site on a sheet of paper and photographs etc.
3. Return to office and submit the data in the office to staff.
4. The office staff collates the data and inputs it in required formats of the banks, NBFC's etc and the calculation by manual process.
5. Preparation of draft report then checking by the valuator and issue of draft report to client.
6. The client /banks request for changes, then again working on the report changing values in the report and resubmission of draft and then finally issue of final report.

In the conventional data collection method, the data used to be available for processing only after the surveyor/appraiser would return to office and then enter the information collected on sheets into electronic format. This was very time consuming and error prone since the user who would enter the data would make mistakes in proper reading and interpretation and filling up in the report.

Then the era of WhatsApp began by which the photographs and information collected at site started coming to valuator s office quickly which no doubt reduced the TOT but the process later on remained the same.

The data coming over WhatsApp would create confusion if more than one user would transmit the data at the same time. The collected data would be processed using known software's like word and excel.

As mentioned earlier any changes to report would be time consuming and again error prone.

The new process involves different stages like

1. Job creation and allocation to a particular surveyor/appraiser
2. Data collection
3. Transfer of data to portal
4. Post processing and preparation of draft and final reports.

Mobile Apps for On-Site Data Collection

The data collection application has to be designed keeping in mind the requirement of the job. Like

1. Collecting data from exterior to interior of the property.

a. At the time of the site visit the app collects the data step by step.

b. More than 100 data points are collected which are used as

Login into the app and portal is similar.

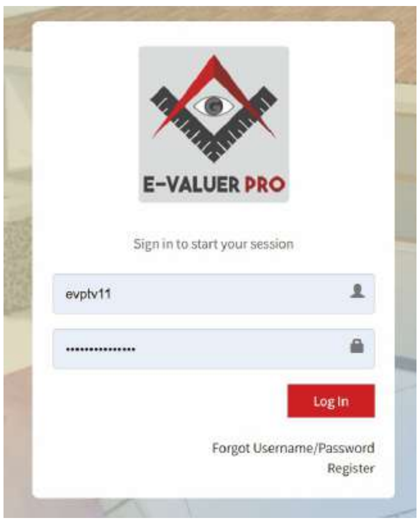
required in different formats.

c. For ease of operation the job allocated to the surveyor is downloaded on the android phone and then the data is captured step by step.

d. For ease of data collection drop down options area provided.

e. After the data is collected the photographs are collected through the app. The collected photographs get the time stamp and GPS coordinates automatically.

f. The data is saved on the device and then transferred to the portal for further processing. Like shown below.



Login into the app and portal is similar.

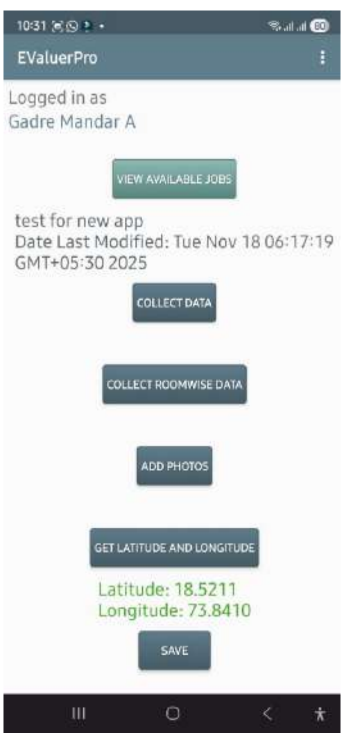
Post Processing

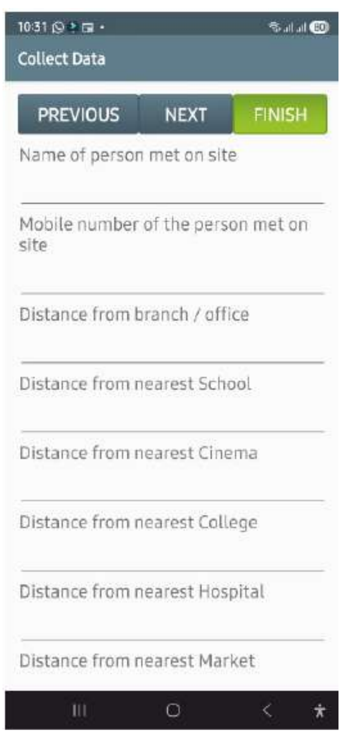
Post processing involves compilation of data received from the app collected.

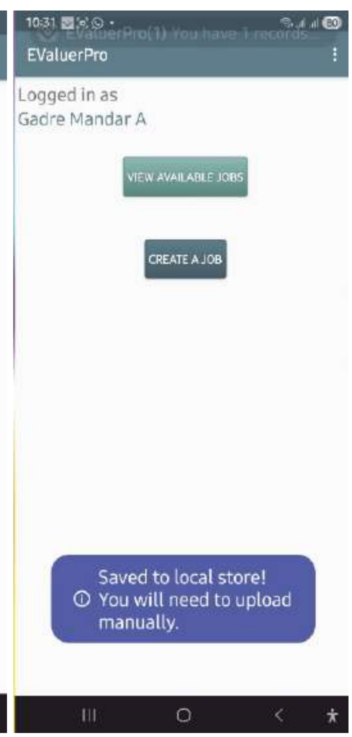
1. The data collected is available in the job created.
2. A particular template of the bank / NBFC is assigned to the particular job and then the data is further processed.
3. The information of documents available is entered into the text box provided and similarly under valuation note the detailed valuation approach can be jotted down.
4. The calculation part is dynamic in the sense that if one value is changed the entire calculation changes and revised valuation figures are available.
5. The option to change the inputs like useful life of the property and age of the property are available.
6. The % between fair market value and realizable and distress value can be changed accordingly.
7. % of Carpet to BUA can be changed too.
8. For land and building cases the calculation is in two part viz.

a. Assessment of land value in simple sense land area x rate

b. For calculation of constructed area, a dynamic computation table is provided in the application which allows you to calculate the depreciated value of the structure with respect to the reference year of your choice.







9. Comparable sale instance table is part of the report which helps the financer know the reference rates easily.
10. After the data is processed and valuation is ready the report is tagged with "To be revised status". The valuator then Reviews and locks it so that only he can edit and change the content of the report.

Advantages

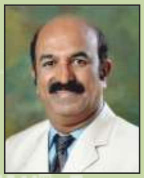
1. Turnaround time TOT reduces drastically.
2. Hierarchy of users can be set like surveyor and officer who can enter data make report and Appraiser who finalises the report.
3. Human errors in calculations are eliminated since the calculation is automatic.
4. Audit trial for each user. It means with a click you will come know who worked on which report and which values were changed by the user.
5. Removal of users who have left the company and addition of new users etc.
6. Maker and checker facility.
7. Appraiser has the complete control over the assignment.
8. Outside photographs not entertained in the application except for the valuator.
9. Data being collected at site it cannot be manipulation of data is possible.
10. The photographs collected are water marked with time and date.
11. The external documents in the A4 format can be inserted into report which can be printed with the report.
12. Data is secured over cloud.
13. Users can work from anywhere and log into their portal and process the reports.
14. A PDF is created which can be digitally signed.
15. As the PDF's is created from the application no editing in the data can be done.
16. Every report has a footer line which mentions the number of the report date etc.
17. No need of separate letter head which results in saving of cost.
18. Old report can be cloned into a new job wherein the inputted information like list of documents valuation note etc is available except the photographs. Once the photographs are collected at site the report can be completed quickly.
19. Alternative used of dual units like sq.mt and sq.ft

To conclude the applications will make life of the valuator easy provided the appraiser is prudent and clear in his assessment of the rate and different parameter which change from case to case.

■ Kshitij Jambhale

■ Anjali Sawant

जगातील सर्वात उंच रेल्वे पूल - चिनाब



प्रकाश मेढेकर
स्थापत्य सल्लागार, पुणे

भारताचे नंदनवन असणारे काश्मीर आता रेल्वे सेवेने देशाच्या इतर भागांशी जोडले गेले आहे. हे साध्य झाले , काश्मीर खोऱ्यातील एका रेल्वे लिंक प्रकल्पाने. युएसबीआरएल म्हणजेच उधमपुर श्रीनगर बारामुल्ला रेल्वे लिंक प्रकल्प २७२ किलोमीटरचा असून, त्याची चार प्रमुख भागांमध्ये विभागणी झाली आहे . यामध्ये बारामुल्ला ते काझीगुंड ११८ किलोमीटर, काझीगुंड ते बनिहाल १८ किलोमीटर, बनिहाल ते कटरा १११ किलोमीटर आणि कटरा ते उधमपूर २५ किलोमीटर असा रेल्वे मार्ग आहे. देशातील अभियांत्रिकीच्या विविध प्रकल्पांमध्ये या आव्हानात्मक प्रकल्पाने मानाचा तुरा रोवला आहे. कारण याच मार्गावर आहे जगातील सर्वात उंच चिनाब रेल्वे पूल. या पुलावरील रेल्वे लाईन ब्रॉडगेज असून त्यासाठी सिंगल ट्रॅक बनवला आहे. प्रकल्पाचा खर्च अंदाजे १४८६ कोटी आला असून पुलाची आयुष्य मर्यादा १२० वर्ष असणार आहे. या पुलाने स्थिरता, टिकाऊपणा आणि सुरक्षिततेच्या सर्व चाचण्या पूर्ण केल्या आहेत .

पुलाची वैशिष्ट्ये

या पुलाचे स्थान हिमालयाच्या पर्वतरांगांमधील आव्हानात्मक भूप्रदेशात आणि प्रतिकूल हवामानात येते. काश्मीर खोऱ्यातील रियासी जिल्ह्यातील कौरी आणि बक्कल गावांच्या दरम्यान हा पूल येतो. हा पूल चिनाब नदीच्या पात्रापासून ३५९ मीटर उंचीवर असून, आयफेल टॉवर पेक्षा ३५ मीटर अधिक उंच, तर कुतुबमिनार पेक्षा ५ पटीने उंच आहे. पुलाची लांबी १३१५ मीटर असून रुंदी १३.५ मीटर आहे. पुलाला एकूण १७ स्पॅन असून सर्वात मोठा आर्च स्पॅन ४६७

मीटर लांबीचा आहे. आर्च स्पॅनचे वजन १०,६१९ टन भरते. पुलाच्या आधारासाठी स्टीलचे कॉलम आहेत. पुलाची स्लॅब बनवण्यासाठी ८ मीटर लांबी आणि ८ मिलिमीटर जाडीच्या १६१ गर्डर प्लेट्स एकमेकांना जोडण्यात आल्या आहेत. पुलावर तीन ठिकाणी एस्कपांन्शन जॉईट असल्याने वेगवान रेल्वे धावताना पुलाच्या डेक स्लॅबला कोणताही धोका उत्पन्न होत नाही. डेक स्लॅब आणि स्टील कॉलम यांच्या मधील स्पेरीकल बेअरिंग मुळे पुलावर येणारे संपूर्ण वजन कॉलम द्वारे जमीनीपर्यंत नेले जाते.

प्रकल्पाची मुहूर्तमेढ

या प्रकल्पाची मुहूर्तमेढ सन २००२ मध्ये भारत सरकारने योजली. पुलाची अलाईनमेंट अंबरबर्ग इंजिनिअरिंग कंपनीने केली. प्रकल्पाची प्रत्यक्ष सुरुवात २००४ मध्ये होऊन आर्चचे काम २०२१ मध्ये पूर्ण झाले. २००८ ते २०१० मध्ये सुरक्षितेसाठी पुलाचे काम बंद ठेवण्यात आले होते. ॲफकॉन, अल्ट्रा कन्स्ट्रक्शन, व्हीएसल इंडिया कंपन्यांनी प्रकल्पामध्ये भाग घेतला. कोकण रेल्वे कार्पोरेशनने प्रकल्पाचे नियोजन केले. फिनलँड, जर्मनी, स्विस देशातील सल्लागार प्रकल्पावर नेमण्यात आले होते. अंदाजे ३०० अभियंते आणि १३०० कामगारांनी अहोरात्र काम करून हा प्रकल्प पूर्ण केला.

प्रकल्पातील आव्हाने

नियोजित प्रकल्पाची जागा अति दुर्गम भागात होती. पुलाच्या पायापर्यंत मशिनरी, बांधकाम साहित्य, कामगार यांना नेण्यासाठी ५ किलोमीटर लांबीचे रस्ते सर्वप्रथम बांधावे लागले. कोणत्याही पुलाचे बांधकाम करताना त्याचा पाया मजबूत असावा लागतो. पुलाच्या जागी असणारा डोलोमाईट खडक हा मृदू असून आणि त्यामध्ये तडे आढळले. दरीचा उतार ४३° अंशापासून ७७° पर्यंत असुरक्षित होता. या तीव्र आणि धोकादायक उताराला टप्पाटप्प्याने स्थिर करावे लागले. स्फोटके वापरून जमिनीची लेवल करण्यात आली. पोकळ खडक दूर करण्यात आला. हायड्रॉलिक, केमिकल आणि मेकॅनिकल पद्धतीने रॉकबोल्टिंग, ग्राऊटिंग, शॉर्टक्रीटचा वापर करून खडकाचे मजबुतीकरण करण्यात आले आहे. कमानीचा मुख्य स्टील कॉलम १३७ मीटर उंचीचा आहे. त्यासाठी ५० मीटर लांब, ३६ मीटर रुंदीचे काँक्रीट फाउंडेशन करावे लागले. मुख्य आर्चसाठी स्टील आणि त्यामध्ये काँक्रीट भरलेले सीलबंद बॉक्स तयार करण्यात आले. नटबोल्टच्या साह्याने बॉक्सचे विविध भाग एकमेकांना जोडण्यात आले.

त्याचप्रमाणे संरचनेच्या विविध भागांना जोडण्यासाठी अंदाजे ५८४ किलोमीटर वेल्डिंग करावे लागले. त्याचे अंतर जम्मू तवी ते नवी दिल्ली दरम्यानच्या अंतराइतके भरेल. पुलाच्या उभारणीसाठी जगातील सर्वात मोठी ९१५ मीटर लांबीची केबल क्रेन वापरण्यात आली. संपूर्ण पुलाला गंज प्रतिरोधक रंग दिला असून त्याचा टिकाऊपणा १५ वर्ष कालावधीचा असेल. पुलाच्या उभारणीसाठी २८,६६० टन स्टील, ४००० टन रीन्फोर्सड स्टील, ६६००० घन मीटर काँक्रीट, ८४ किलोमीटर लांबीची केबल आणि ८ दशलक्ष घनमीटर उत्खनन करण्यात आले.

प्रकल्पाची संरचना

हा पूल देशाच्या भूकंपप्रवण क्षेत्रातील झोन ४ मध्ये येतो. परंतु संरचना करताना झोन ५ मधील भूकंप शक्तींचा विचार करण्यात आला. दहशतवादी हल्ला रोखण्यासाठी संरक्षण संशोधन आणि विकास संघटनेचा सल्ला घेऊन पुलाला स्फोट प्रतिरोधक बनवला आहे. पुलावरून रेल्वे १०० किलोमीटर प्रति वेगाने धाऊ शकते. पूल २६६ किलोमीटर प्रती /तास पर्यंतच्या वाऱ्याच्या वेगांना तोंड देण्यासाठी डिझाईन केला आहे. पुलामध्ये ८ रिश्टर स्केलचा भूकंप आणि ४० टनाच्या समतुल्य उच्चतीव्रतेच्या स्फोटकांच्या हल्ल्याचा विरोध करण्याची ताकद आहे. उणे २० अंश ते अधिक ४० अंश तापमानाला तोंड देण्याची क्षमता या पुलामध्ये आहे. पुलाच्या डिझाईन आणि बांधकामासाठी बीएस : ५४०० हा मूलभूत मार्गदर्शक तत्त्व म्हणून वापरण्यात आला. आर्च कमानी मध्ये ३६ मीटर लांबीचे २ ॲप्रोच स्पॅन असून दोन्ही बाजूला दरी पूल आहेत. पुलाच्या दोन टोकाला १३० मीटर आणि १०० मीटर उंचीचे मनोरे असून त्यांना केबल्सच्या सहाय्याने एकमेकांना आधार दिला आहे. पुलाच्या कामाचे फॅब्रिकेशन जास्तीत जास्त साइटवर करण्यात आले. पूल उभारणीमध्ये गुणवत्ता आणि अभियांत्रिकी तंत्रज्ञान यामध्ये कोठेही तडजोड करण्यात आली नाही. जम्मू ते काश्मीर या भागात पूर्वीच्या काळात रेल्वे नव्हती. या प्रकल्पामुळे उधमपूर, श्रीनगर, बारामुल्ला हे रस्त्याने होणारे १५ तासाचे अंतर रेल्वेमुळे फक्त ५ ते ६ तासात पार करण्यात आपण यशस्वी झालो आहोत.

The Intelligent Construction Enterprise: The Shift That Changes How We Build Forever

Mitesh K. Bhatt
Director - Shree Tirupati Construction and Technologies (STC&T) Pvt. Ltd.

Executive Summary

A fundamental shift is reshaping construction. Agentic AI autonomous systems that reason, coordinate, and execute across entire project ecosystems is enabling performance previously unattainable through conventional methods.

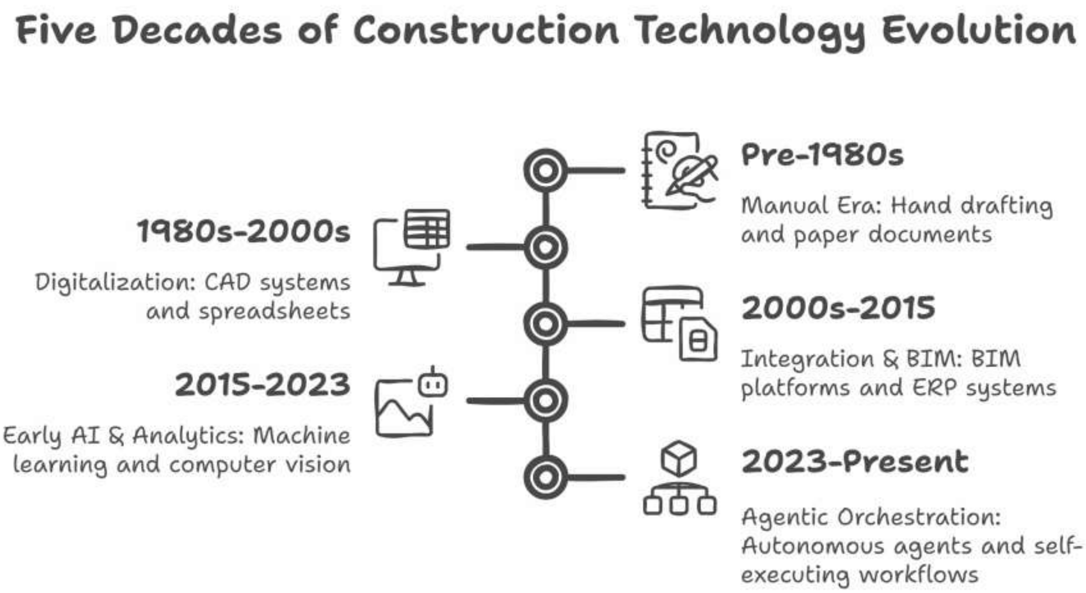
Leading construction firms are deploying these systems now. They coordinate design workflows, optimize procurement timing, predict project trajectories, and manage facility operations at speeds that create measurable advantage. The performance gap between early adopters and traditional operators widens with each project cycle.

Three insights define this transformation. First, agentic AI operates as an orchestration layer above existing platforms, unifying fragmented systems without requiring wholesale replacement. Second, the technology has reached operational maturity, this represents deployment reality across global markets. Third, early adoption creates compounding advantages as systems learn organizational patterns and accumulate project intelligence.

This article maps construction's intelligence evolution, explains how agentic systems transform core functions, and provides a clear implementation roadmap for organizations ready to capture this opportunity

The 50-Year Evolution of Construction Intelligence

Construction technology has progressed through five distinct phases, each building the foundation for today's autonomous orchestration.



Foundations of Intelligence

Construction professionals encounter artificial intelligence in familiar applications: defect detection in photographs, cost forecasting from historical data, schedule risk analysis. These tools analyse and recommend, but humans must execute.

Three distinct intelligence levels exist today, each representing a different performance threshold. Recent advances in generative AI and autonomous coordination have accelerated movement across these levels, enabling faster and more consistent decision-making across project environments.

Artificial Intelligence performs specific cognitive tasks at expert-level competence. A quality control model analyses structural images for defects. A forecasting system processes historical data and market inputs to estimate costs. A safety system reviews site video to detect hazardous conditions. These systems operate within defined analytical boundaries and depend on humans for further action.

Generative AI (GenAI) expanded capability by enabling systems to understand and generate engineering information. GenAI can interpret drawings, specifications, BOQs, method statements, contracts, and schedules, and produce summaries, RFIs, checklists, and inspection notes. It reduces documentation effort and makes information easier to access, but still relies on human-driven execution across tools.

AI Agents move beyond analysis and content generation into autonomous execution. Agents monitor their environment, evaluate available options, and complete defined workflows independently. A procurement agent may adjust delivery dates, reallocate material, update suppliers, and revise logistics when schedules shift tasks traditionally requiring multiple coordinators.

Agentic AI introduces the ability to coordinate entire project workflows end-to-end. These systems operate across multiple digital environments, interpret changes in real time, evaluate engineering and commercial implications, and update connected processes without requiring manual intervention. They understand organizational rules, approval pathways, dependencies, and technical standards, enabling them to execute multi-step actions that traditionally depended on numerous human handoffs.

A clear demonstration of this capability is the emerging agentic browsing approach, where the system operates across departmental applications through a single interface. Instead of teams navigating multiple isolated systems design, planning, procurement, contracts, finance, quality, or operations. the agent can access each functional layer directly, interpret the underlying data structures, and maintain continuity between them. It can review design information, trace linked activities, reference procurement commitments, verify contract conditions, and align cost and schedule impacts within one consistent environment. The result is a unified digital ecosystem where every department works on the same synchronized layer, eliminating manual consolidation and ensuring that decisions reflect current, organization-wide information.

The progression is clear: traditional software automates tasks, AI automates analysis, GenAI automates understanding and documentation, AI agents automate contained workflows, and agentic AI orchestrates complete processes across systems, disciplines, and project phases.

Intelligence Capability Progression

Characteristic	Traditional Software	AI Systems	AI Agents	Agentic AI
Rules	Fixed	Learns from Data	Autonomous Actions	Cross-Platform Orchestration
Logic	If-Then	Adapts & Improves	Perceives & Decides	Navigates tools
Commands	Waits for Commands	Analyzes & Recommends	Initiates Workflows	Synthesizes data
Actions	No autonomous actions	No autonomous actions	No autonomous actions	Coordinates work
Context	No context learning	No context learning	No context learning	Learns context
Autonomy	No autonomy	No autonomy	No autonomy	Acts autonomously

Operational Transformation: Eight Core Functions

Design and Building Information Modelling

Agentic systems maintain persistent awareness of model evolution across all disciplines. When conflicts emerge, they assess constructability, query material databases for alternatives, calculate cost differentials, evaluate schedule impacts, and deliver prioritized recommendations with quantified trade-offs. Design teams receive actionable intelligence that accelerates decisions while improving quality.

Planning and Scheduling

Agentic planning systems continuously monitor execution through sensor networks and progress platforms. They maintain probabilistic project models, simulating outcomes under varying conditions. When deviations emerge from equipment performance, weather, or productivity changes systems trace impacts, evaluate recovery scenarios, and implement optimal adjustments automatically. Teams manage by exception, focusing expertise on strategic decisions.

Procurement and Supply Chain

Agentic procurement systems synchronize ordering dynamically with project execution. As activities accelerate or delay, they automatically adjust delivery schedules, redirect materials between sites, communicate revised requirements to suppliers, and continuously optimize inventory levels. The result is reduced carrying costs alongside improved material readiness.

Contracts and Billing

Agentic contract systems synthesize progress data, cross-reference scope, identify completed quantities, flag variances indicating potential change orders, and prepare payment applications with supporting documentation automatically. This significantly decreases administrative overhead while accelerating payment cycles.

Project Execution and Site Management

On site, progress reporting becomes intuitive. A site engineer simply speaks an update, and the agentic system records it automatically, categorizes it, tracks labour and equipment, and notifies every relevant stakeholder. Each department sees live data without duplication or delay.

This autonomous Daily Progress Report capability transforms site management. Real-time data from crew logs, equipment sensors, material deliveries, and weather flows continuously.

Systems identify resource conflicts, propose efficient task sequences, and alert field leadership to emerging constraints with actionable lead time. Site management thus evolves into proactive orchestration rather than reactive firefighting.

Quality and Safety

Agentic systems continuously analyse site imagery, identifying compliance deviations and quality issues as they occur. They systematically verify inspection completion, track corrective actions, and maintain comprehensive documentation automatically. This early detection enables prevention, improving outcomes while reducing rework.

Finance and Cost Control

Agentic financial systems continuously monitor spending, comparing actuals against estimates in real-time. They identify trends, forecast outcomes under different scenarios, and alert teams with sufficient lead time for an effective response. Cost management thereby becomes predictive rather than merely retrospective.

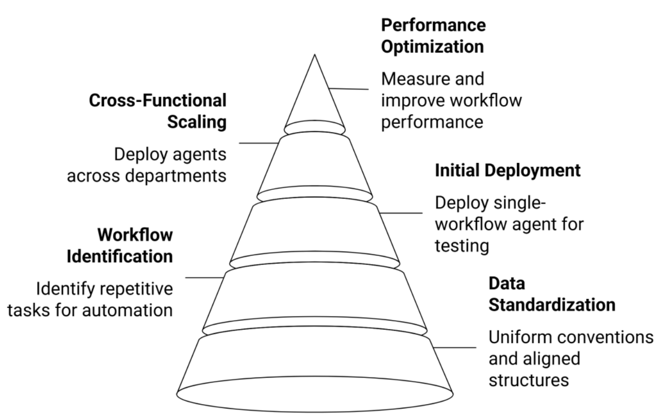
Facility and Asset Management

Agentic operational systems continuously monitor building systems and equipment, analysing performance patterns to detect anomalies preceding failures. They automatically schedule preventive maintenance, optimize energy consumption dynamically, and maintain comprehensive lifecycle records. This improves asset performance while decreasing operating costs.

How Firms Can Begin the Agentic Transition

Organizations can build capability progressively while demonstrating value at each stage.

Agentic Workflow Implementation Pyramid



Stage One: Data Standardization

Organizations establish consistent information foundations. Uniform naming conventions for projects, activities, cost codes, and materials enable automated data transfer across systems. Standard document templates and aligned data structures create the conditions for autonomous orchestration. This foundational work proceeds in parallel with current operations and unlocks subsequent automation capabilities.

Stage Two: Workflow Identification

Teams map processes consuming significant time while requiring information transfer between multiple systems. Design clash resolution, schedule-driven material ordering, progress-based invoice processing, and RFI tracking represent common high-value candidates. These repetitive, multi-step workflows deliver immediate returns when automated.

Stage Three: Initial Deployment

Implementation begins with a single workflow. Organizations deploy an agent automating the complete process end-to-end across relevant platforms. They measure time savings, error reduction, and user adoption. Refinements incorporate feedback before expanding to additional workflows. Each successful deployment builds organizational confidence and technical capability.

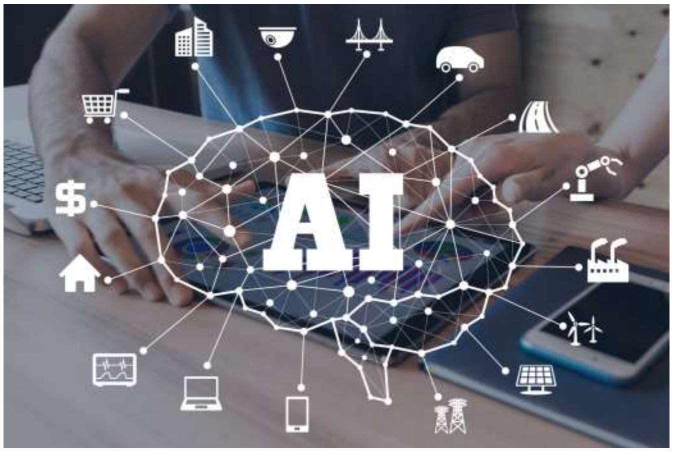
Stage Four: Cross-Functional Scaling

As individual workflows mature, organizations introduce agents coordinating across multiple functions. A project orchestration agent monitors design changes, adjusts procurement timing, updates schedules, revises cost forecasts, and communicates with stakeholders managing cascading impacts that traditionally require extensive manual coordination across departments. Cross-functional agents create compounding value by eliminating handoffs and accelerating information flow.

Stage Five: Performance Optimization

Organizations track clear indicators demonstrating impact: time from design change to resolution, procurement lead time consistency, schedule update frequency, cost forecast accuracy, and response time for information requests. Quantified improvements justify expanded investment and guide capability scaling across project portfolios.

The compounding effect: As agentic systems accumulate



organizational knowledge—standards, preferences, successful patterns—their effectiveness increases. Early adopters build advantages that strengthen over time.

Leadership Imperatives

Construction has reached a performance threshold. Autonomous intelligence now orchestrates work across project ecosystems at speeds and scales that redefine operational capability.

Three strategic priorities guide successful adoption:

First, build foundational discipline before deploying automation. Data standardization, workflow documentation, and process clarity determine system effectiveness. Organizations establishing these foundations create infrastructure that amplifies every subsequent capability deployment. This represents capability investment, where each implementation strengthens organizational performance across all future projects.

Second, validate value through contained deployment. Begin with single-workflow automation. Measure time reduction. Quantify error elimination. Document productivity gains. Visible success in controlled environments builds executive confidence and secures stakeholder commitment for expanded scope. Proof precedes scale.

Third, recognize that competitive advantage accumulates through system learning. Each project cycle teaches agentic systems organizational patterns, supplier behaviours, and process efficiencies. This accumulated intelligence becomes proprietary capability. Organizations beginning implementation today build knowledge assets that enhance decision quality, execution speed, and cost precision across every subsequent project.

The strategic value extends across entire project portfolios. Organizations mastering autonomous coordination demonstrate measurably superior delivery speed, cost certainty, and operational efficiency. These capabilities compound as systems learn, creating performance advantages that strengthen with each completed project.

For construction leaders, the imperative is execution. Build data foundations. Deploy initial automation. Measure outcomes. Scale systematically. The firms defining next-generation delivery are implementing these capabilities now.

▪ Shree Gogawale

▪ Sakshi Patil

BIM: A Peek into the Future of Intelligent Construction

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Introduction: The Evolving Language of Construction

Building Information Modeling (BIM) has revolutionized how we imagine, design, and manage the built environment. Once limited to creating 3D digital representations of physical spaces, BIM has evolved into an intelligent ecosystem that connects every stakeholder in a project—from architects and engineers to contractors, facility managers, and even occupants. It is no longer just a tool for visualization or documentation; it is a dynamic language that drives collaboration, decision-making, and innovation across the entire lifecycle of a building.

The BIM of tomorrow extends beyond geometry and data. It is becoming intelligent, predictive, and autonomous. The fusion of Artificial Intelligence (AI), cloud computing, the Internet of Things (IoT), and extended reality (XR) technologies is transforming BIM into the central nervous system of modern construction. Together, these technologies are redefining how buildings are conceived, delivered, and operated—ushering in an era where the built environment is as smart as the people who design and inhabit it.

This article explores the evolving future of BIM through the three critical phases of a project's lifecycle—Design, Build, and Operate—and highlights the emerging technologies reshaping each stage.

1. The Future of Design: Intelligent, Generative, and Sustainable

1.1 Generative Design: The Co-Creator of Tomorrow's Architect

Generative design represents one of the most profound transformations in architectural practice. Traditionally, architects and engineers rely on experience, creativity, and iterative refinement to arrive at design solutions. This process, while artistic, can be time-intensive and limited by human capacity to test every possible variation. Generative design changes that paradigm entirely.

By defining a set of goals, constraints, and performance criteria—such as spatial efficiency, daylighting, structural stability, cost, and sustainability—designers can delegate the process of exploration to algorithms. The system automatically generates thousands of design permutations in minutes, analysing and ranking them based on performance outcomes. This approach allows for design discovery rather than mere design creation.

In the near future, generative design will become deeply integrated into BIM platforms, making it a native feature rather than an add-on. Architects will act as curators, guiding the creative direction and applying human judgment to select the best outcomes produced by AI systems. The process will balance machine precision with human sensibility—leading to optimized, sustainable, and aesthetically compelling results.

1.2 Sustainable Design and Environmental Analysis at the Click of a Button

Sustainability has moved from being a moral imperative to an operational necessity in construction. Governments, clients, and end-users are demanding environmentally responsible solutions that minimize energy consumption, reduce carbon footprints, and promote resource efficiency. In this evolving landscape, BIM is becoming the primary vehicle for embedding sustainability into the design process.

Future BIM systems will offer real-time sustainability analysis directly within the modelling environment. Designers will be able to assess building performance—energy use, thermal comfort, water efficiency, and embodied carbon—without leaving their primary design workspace. AI-driven analysis tools will simulate different material options, structural systems, and orientations to predict life-cycle environmental impacts. This shift will allow decisions about materials, mechanical systems, and construction methods to be made early, when they are most cost-effective and impactful.

Moreover, AI will enable BIM systems to recommend alternatives automatically. If a designer specifies a material with high embodied carbon, the system could suggest more sustainable substitutes or warn about regulatory noncompliance. The integration of environmental intelligence ensures that sustainability is not an afterthought but an inherent property of every design.

1.3 Instant Realism: AI-Powered Rendering and Visualization

Visualization has always been an essential communication bridge between designers and clients. Traditionally, high-quality renderings required hours of processing and expertise in specialized software. However, AI and GPU acceleration have redefined this process entirely.

AI-driven rendering engines can now produce photorealistic images and animations in seconds. Through deep learning, these systems understand material properties, lighting behaviour, and environmental conditions to simulate reality with astonishing accuracy. The near future holds even greater possibilities: designers may soon use natural language prompts—describing scenes or moods—to generate immersive visualizations instantly.

This advancement democratizes visualization, allowing every stakeholder to experience a project in realistic detail from the earliest stages. It improves communication, accelerates approval processes, and enhances creative iteration. As visualization merges with extended reality, stakeholders will not only see the design but inhabit it—making BIM models truly immersive and experiential.

2. The Future of Build: Connected, Automated, and Augmented

2.1 Cloud Collaboration: The Single Source of Truth

The construction phase is historically plagued by fragmentation—disconnected teams, inconsistent documentation, and communication breakdowns. The future of BIM in construction seeks to eliminate these inefficiencies through cloud-based collaboration.

Cloud platforms will serve as the single source of truth, synchronizing data between design offices, construction sites, and supply chains. Every stakeholder—from structural engineers to on-site supervisors—will work on the same live model, ensuring that updates, RFIs, and change orders are reflected in real time. This connected workflow not only minimizes errors but also improves accountability and transparency.

The integration of blockchain technology could take this one step further. Blockchain-enabled BIM would provide an immutable record of design changes, material origins, and compliance certifications. This would enhance trust between contractors, clients, and regulators, reducing disputes and ensuring data integrity across the project's lifecycle.

2.2 AI and Reality Capture: Monitoring Sites with Vision

Reality capture is revolutionizing construction monitoring. Using drones, laser scanners, and photogrammetry, site conditions can now be digitized in three dimensions with millimetre accuracy. These digital scans are then compared with BIM models to assess progress, detect deviations, and ensure quality control.

The next leap lies in AI-powered analysis of this captured data. Computer vision algorithms can automatically detect discrepancies—whether a wall is misaligned, a duct is missing, or rebar placement is incorrect. These systems can generate automated reports highlighting potential issues long before they escalate into costly rework.

Over time, such systems will become self-learning. By analysing patterns from previous projects, AI will anticipate potential conflicts before they occur. This proactive intelligence feeds back into the BIM ecosystem, improving future design and construction processes through continuous feedback.

2.3 AI for Quality Control and Safety

The fusion of AI and IoT is redefining quality and safety management on-site. Machine learning models can process live video feeds and images from cameras, drones, or smart helmets to identify hazards or non-compliance issues instantly. For instance, AI can detect missing safety gear, improper scaffolding, or potential structural inconsistencies.

Connected wearable devices further enhance safety by monitoring worker health metrics, environmental conditions, and proximity to dangerous zones. Predictive analytics can warn supervisors before an accident occurs, ushering in a new era of zero-defect and zero-incident construction.

By integrating safety analytics directly into BIM, every model becomes a safety map—linking design elements to risk factors and suggesting preventive measures automatically.

2.4 Augmented and Virtual Reality: Immersive Construction

Extended reality (XR)—a fusion of augmented reality (AR), virtual reality (VR), and mixed reality (MR)—is bridging the gap between the digital and physical worlds. AR-enabled devices allow field workers to overlay BIM models onto real-world construction environments. This visual alignment enhances precision during installation, enables real-time clash detection, and facilitates rapid issue resolution. Meanwhile, VR provides immersive virtual walkthroughs of projects before ground is even broken. Clients, designers, and contractors can experience and modify spaces collaboratively, identifying potential design conflicts early in the process.

The future lies in mixed-reality BIM coordination, where digital and physical data converge seamlessly. Designers, engineers, and on-site teams will interact with live BIM data simultaneously—measuring, annotating, and verifying in real time within a shared, spatially accurate environment.

3. The Future of Operate: Smart, Predictive, and Self-Learning Buildings

3.1 Digital Twins: From Models to Living Ecosystems

While BIM provides a static representation of design intent, digital twins transform that model into a living, breathing replica of the real asset. A digital twin integrates live data from sensors, control systems, and operational databases, creating a continuous feedback loop between the virtual and physical environments.

Facility managers can use digital twins to visualize real-time building performance—tracking energy consumption, indoor air quality, occupancy, and system health. By connecting BIM data with IoT networks, the building becomes self-aware, capable of adjusting its operations dynamically.

When combined with AI, digital twins move from descriptive to predictive and prescriptive intelligence. They can forecast equipment failures, optimize energy distribution, and automatically trigger maintenance requests. On a city-wide scale, interconnected digital twins could simulate urban systems—traffic flow, power usage, and climate resilience—allowing planners to design smarter, more sustainable cities.

3.2 Predictive Maintenance: Proactive Asset Management

Traditional maintenance operates on fixed schedules or reactive repair, often leading to inefficiency or downtime. Predictive maintenance, powered by AI analytics and IoT integration, transforms this reactive approach into a proactive strategy.

Sensors embedded in building systems—HVAC units, elevators, lighting, and pumps—collect continuous data on performance parameters such as vibration, temperature, and power consumption. AI models analyse this data to predict when a component is likely to fail, allowing maintenance teams to intervene just in time.

This approach not only minimizes disruptions but also extends the lifespan of assets, reduces costs, and ensures consistent comfort and safety for occupants. By linking predictive maintenance directly with BIM, facility managers gain a comprehensive view of both physical components and their operational history—creating a truly intelligent maintenance ecosystem.

3.3 Smart Buildings and the Human Experience

The ultimate goal of BIM evolution is not just operational efficiency—it is enhancing human experience. Smart buildings of the future will dynamically adapt to their occupants' needs, preferences, and habits. By linking BIM with Building Management Systems (BMS) and AI-driven analytics, spaces will automatically adjust lighting, temperature, and air quality in response to real-time occupancy patterns.

Occupant feedback systems—through mobile apps or voice interfaces—will feed into the digital twin, allowing the environment to learn and refine itself continually. Over time, each building will develop a unique "personality," tuned to the behaviours of its users. Such spaces will not only optimize comfort but also improve productivity, health, and well-being.

The next generation of BIM will therefore serve as the foundation of human-centric design and operation, blending environmental intelligence with emotional intelligence.

4. Emerging Technologies Enhancing the BIM Future

Beyond today's frontier, several cutting-edge technologies are poised to amplify BIM's capabilities and influence the construction industry profoundly:

- **Quantum Computing:**

  Future BIM simulations may harness quantum processing to model highly complex systems—such as fluid dynamics, energy flows, or material microstructures—in seconds. This could revolutionize building physics analysis and sustainability modeling.

- **Robotics Integration:**

  Autonomous robots linked directly to BIM data will handle repetitive or precision-based tasks on-site. From layout marking and rebar tying to large-scale 3D printing, robots will execute instructions derived directly from digital models, reducing waste and improving accuracy.

- **AI Co-Pilots:**

  Embedded AI assistants within BIM software will guide users, automate documentation, and ensure compliance with codes and standards. These co-pilots will act as intelligent collaborators, freeing designers and engineers to focus on creativity and problem-solving.

- **Blockchain-Enabled BIM:**

  Secure, traceable project data exchange could revolutionize contracts, procurement, and accountability. Blockchain ensures that every design revision or material delivery has a verifiable digital record.

- **Metaverse Workflows:**

  As virtual environments mature, BIM data will populate shared metaverse spaces where project teams can meet, review, and co-create in 3D. Training, safety simulations, and stakeholder presentations will become immersive, interactive experiences.

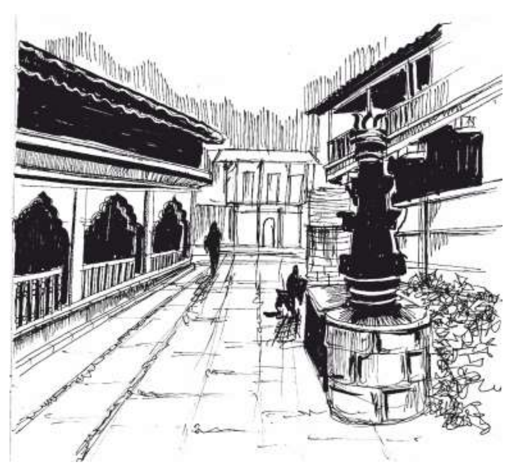
5. The Road Ahead: From Information to Intelligence

The journey of BIM reflects a larger narrative in construction—one that moves from information to intelligence. What began as a digital representation of geometry has become a living network of knowledge, prediction, and automation. The next chapter of BIM is not just about Modeling buildings but managing intelligence across their entire lifecycle.

In the coming decade, projects will no longer be defined by drawings or static models. They will exist as dynamic ecosystems powered by AI, IoT, and cloud data—learning, adapting, and optimizing continuously. BIM will act as the backbone of this intelligent infrastructure, ensuring that every decision—from concept sketches to demolition planning—is data-driven, sustainable, and human-centred.

The future of construction is not merely digital.

It is intelligent, autonomous, and profoundly human—a world where buildings think, learn, and evolve alongside us.



■ Vanshika Charmore

Integrated Thermal & Acoustic Comfort Systems for Pune's Urban Environment

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Abstract

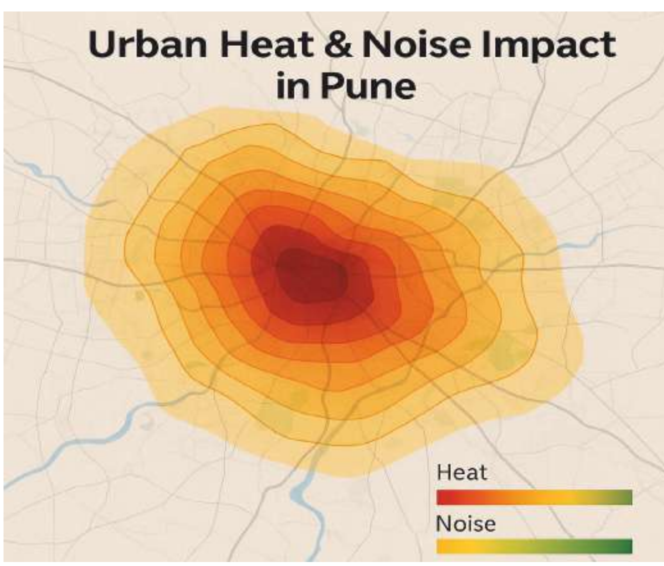
Pune's rapid urbanization has resulted in significant increases in ambient temperature, noise exposure, and energy consumption within buildings. This paper presents an integrated, engineering-driven approach that evaluates thermal and acoustic mitigation systems including Extruded Polystyrene (XPS) insulation, Double-Glazed Units (DGU), Mass Loaded Vinyl (MLV), and Polyester Fiber (PF) acoustic boards. The study synthesizes material properties, system performance metrics, and engineering design considerations relevant to Pune's climatic conditions and urban density. Diagrams and system models are included for clarity.

1. Introduction

Urban heat intensification and environmental noise are two of Pune's most critical yet under-addressed engineering challenges. Recorded field data shows temperature peaks approaching 42°C and noise exposure exceeding 75–85 dB along major corridors. These conditions impose severe discomfort, reduce productivity, degrade building performance, and increase energy consumption. To address these issues, this article presents a multi-layered engineering solution integrating thermal and acoustic technologies.

Urban Heat & Noise Zones in Pune

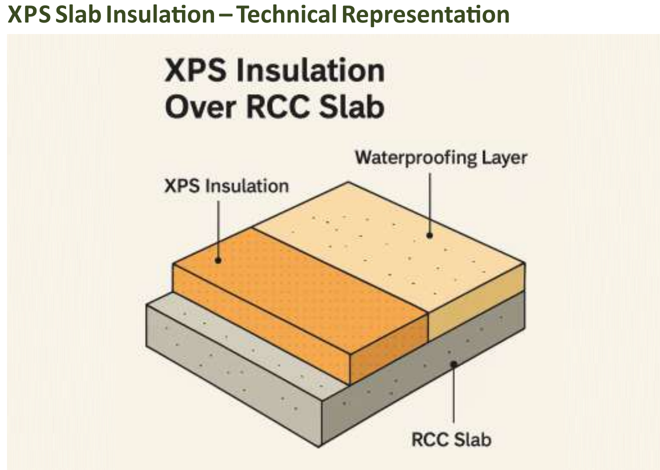
Figure 1 illustrates heat and noise intensity gradients across Pune's core.



2. Thermal Load Analysis in RCC Structures

RCC slabs typically contribute 35–40% of total heat ingress in multi-storey structures. Solar radiation, conduction, and surface temperature retention lead to delayed cooling cycles. This raises nighttime indoor temperatures and increases the load on HVAC systems. An effective engineering response requires a low-conductivity, moisture-resistant material such as XPS.

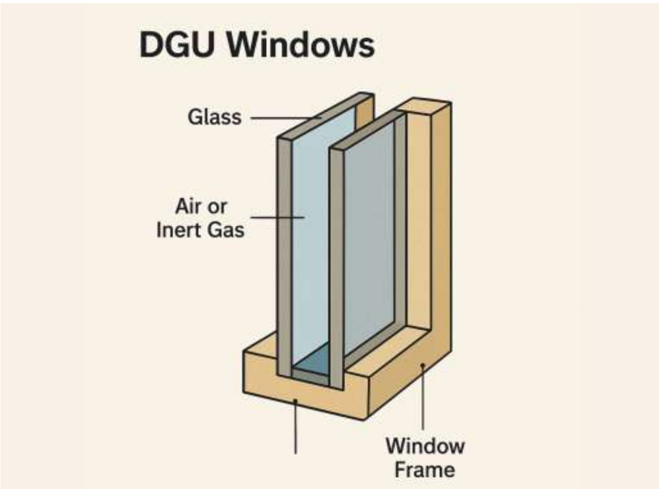
XPS Slab Insulation – Technical Representation

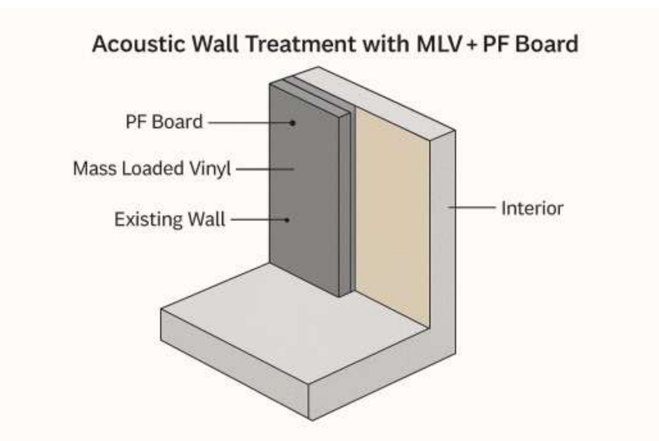


XPS boards exhibit thermal conductivity values in the range of 0.028–0.032 W/m·K, enabling significant reduction in heat transfer through slabs. Their closed-cell structure ensures negligible water absorption (<0.2%), making them ideal for Indian monsoon cycles. The boards retain compressive strength exceeding 200–300 kPa, suitable for terraces with service loads.

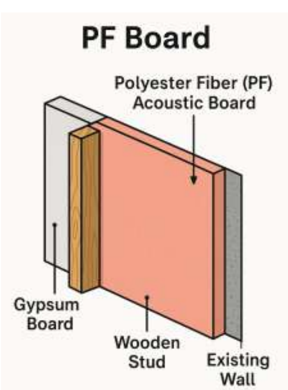
3. Acoustic Transmission & the Need for DGU Windows

Façade openings remain the weakest acoustic link in urban buildings. Conventional single-glazed windows offer STC ratings between 18–22, insufficient for high-noise environments. Double-Glazed Units (DGU), comprising two panes separated by an air or gas cavity, enhance acoustic attenuation through impedance mismatch and increased mass.

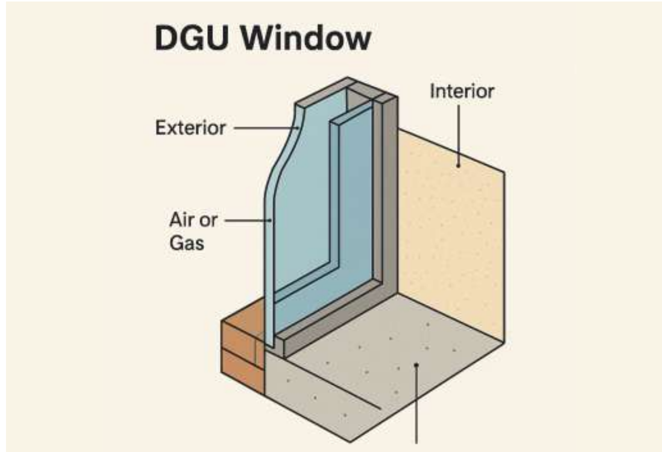




4. Interior Acoustic Isolation: MLV + PF System

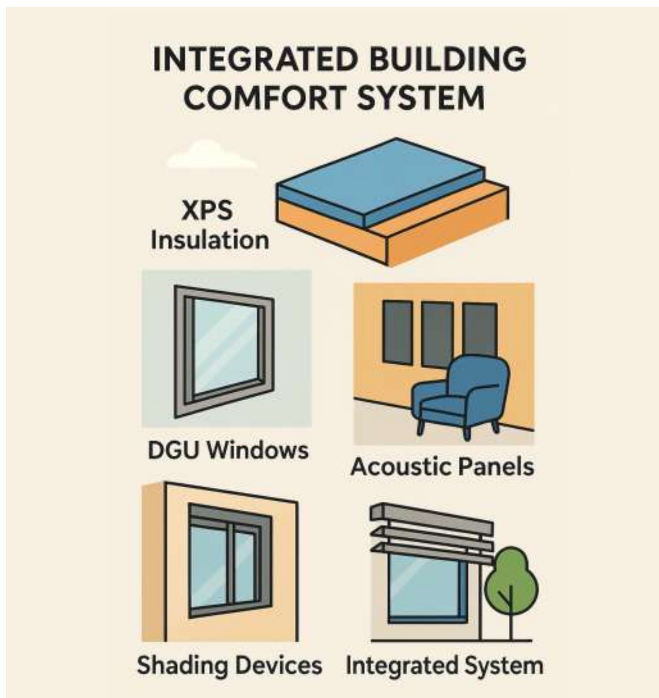


Interior noise transmission between adjacent apartments or rooms is dominated by airborne and impact noise. A hybrid system consisting of Mass Loaded Vinyl (MLV) and Polyester Fiber (PF) boards provides an effective barrier–absorber combination. MLV delivers high surface mass (3–5 kg/m²) achieving STC ratings above 55, while PF boards deliver high absorption (NRC 0.75–0.90).



5. Integrated Thermal–Acoustic System Strategy

Maximum occupant comfort is achieved when insulation systems work synergistically. Thermal insulation reduces energy load, DGUs handle façade noise, while MLV + PF systems address interior transmission. Shading devices further reduce radiant heat gain.



6. Conclusion

Pune's climatic and urban conditions demand scientifically engineered building solutions. The integration of XPS, DGU, MLV, and PF systems provides optimal thermal and acoustic comfort. These systems, when applied together, significantly improve living conditions, reduce energy dependence, and extend the lifecycle performance of buildings.

Appendix A – Material Performance Comparison Tables

Material	Thermal Conductivity (W/m·K)	Acoustic Rating (STC/NRC)	Water Resistance	Lifespan (Years)	Best Application
XPS InsuBoard	0.028–0.032	Medium	Excellent	40+	RCC slabs, terraces
Polyester Fiber (PF)	Medium	NRC 0.75–0.90	Excellent	25+	Ceilings, wall panels
Mass Loaded Vinyl (MLV)	High mass barrier	STC 50–60	Excellent	20+	Partitions, walls
Rockwool	0.037–0.040	High	Good	20	Cavity walls

Appendix B – Expected Performance Gains

System	Performance Improvement	Measurement
XPS Insulation	3–5°C reduction	Indoor temperature drop
DGU Windows	35–45 dB reduction	Street noise attenuation
MLV + PF System	20–28 dB reduction	Inter-room noise isolation
Shading Devices	12–22% reduction	Solar heat gain

■ Nachiket Tak

Swastik Witkar
Founder & CEO - Supplayr ™

Digital Transformation in Construction Material Procurement: How Intelligent Aggregator Platforms Are Reshaping the Industry

The Construction Industry's Digital Paradox

The global construction industry generates over $10 trillion annually, yet it remains one of the least digitized sectors in the world economy. While industries like retail, banking, and logistics have been revolutionized by digital platforms, construction material procurement continues to operate much as it did decades ago. This paradox represents not just an inefficiency, but a massive opportunity for transformation that could reshape how the built environment comes into existence.

Consider this: a single residential project requires coordination with an average of 15-20 different material suppliers. An architect specifying materials for a commercial complex works from catalogs that may be outdated within months. A regional manufacturer producing innovative, sustainable materials struggles to reach buyers beyond their immediate geography. These are not isolated problems—they are symptoms of a systemic failure in how construction materials move from production to project site.

The revolution in construction procurement will not come from a new wonder material, but from a new system—one that leverages digital aggregation, real-time data, and intelligent logistics to create what other industries already take for granted: transparency, efficiency, and genuine market competition. SUPPLAYR™ is pioneering this transformation, building the infrastructure for a new age of procurement guided by a powerful principle: Procure Limitless.

Section 1: The Five Critical Failures of Traditional Procurement

1.1 Fragmentation: The Archipelago Economy

The construction material supply chain today resembles a fragmented archipelago rather than an integrated network. Structural materials come from one ecosystem, finishing products from another, and specialty items from yet another. Each transaction involves separate negotiations, invoicing systems, delivery schedules, and quality standards.

The Real Cost: Project managers report spending up to 30% of their time simply managing supplier relationships and logistics rather than focusing on actual construction. For a typical mid-sized commercial project, this translates to hundreds of hours of unproductive administrative work and significant delays when orders from different suppliers fail to align.

1.2 The Information Vacuum

In an era where consumers can instantly compare specifications for a $50 smartphone, construction professionals often lack basic technical data for materials worth thousands of dollars. Critical information—load-bearing capacities, environmental certifications, chemical compositions, installation requirements—remains locked in unsearchable PDFs, scattered across supplier websites, or worse, available only through direct supplier contact.

The Real Cost: Engineers and architects make specification decisions based on incomplete information, often defaulting to familiar brands rather than optimal solutions. This information gap stifles innovation, as superior products from smaller manufacturers remain undiscovered.

1.3 Pricing Opacity and Market Inefficiency

The concept of a "market price" for construction materials is largely fictional. The same product can vary by 20-40% between suppliers in the same city. Bulk discounts are negotiated through time-consuming back-and-forth rather than transparent volume-based pricing. Hidden margins—distribution fees, marketing commissions, multiple dealer markups—inflate costs while providing no value to end users.

The Real Cost: Project budgets become exercises in guesswork rather than precision planning. Contractors either overbuy to avoid shortages or underbuy and face project delays. According to industry studies, pricing inefficiencies add 12-18% to total material costs across typical projects.

1.4 The Logistics Black Hole

Once an order is placed in the traditional system, visibility vanishes. Is the shipment delayed at the warehouse? Has it left the distributor? Will it arrive Tuesday or Thursday? These basic questions require phone calls, emails, and often go unanswered until the delivery truck (or delay notice) finally arrives.

The Real Cost: Construction schedules are built with significant buffer time to account for supply chain uncertainty. Labor crews sit idle. Project timelines extend. In fast-moving urban markets, these delays can mean missed occupancy deadlines and significant financial penalties.

1.5 Financial Rigidity in a Cash-Flow Intensive Industry

Construction is an inherently cash-flow intensive business, yet the procurement system operates with rigid payment terms better suited to stable, predictable industries. Large material orders tie up working capital for weeks. Small contractors and individual builders often cannot access bulk pricing specifically because they lack the financial capacity to place large upfront orders.

The Real Cost: Projects are delayed or scaled back not due to lack of demand or capability, but simply due to cash flow constraints. Smaller players are effectively locked out of market efficiencies available to larger competitors.

Section 2: The Digital Solution—A New Operating System for Construction Commerce

Recognizing these systemic failures, a comprehensive digital ecosystem has been engineered that treats construction material procurement as what it truly is: a data and logistics problem that technology can solve. SUPPLAYR is not a simple listing service—it's a dynamic, intelligent marketplace designed to restore power and choice to both buyers and sellers.

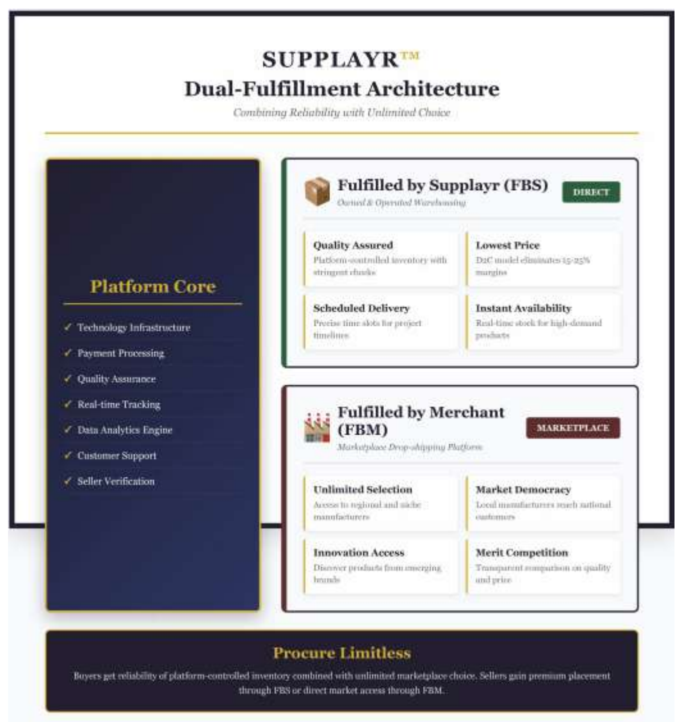
2.1 The Core Innovation: Dual-Fulfillment Architecture

At the operational heart of the platform is a revolutionary dual-fulfillment model that combines the reliability of direct inventory control with the breadth of marketplace diversity.

Fulfilled by Supplayr (FBS): For high-velocity, standardized products—cement, steel reinforcement bars, standard tiles—the platform maintains its own warehousing and logistics network. This approach delivers three critical advantages:

- Quality Assurance: Platform-controlled inventory undergoes standardized quality checks, eliminating the variability that plagues traditional multi-supplier procurement.
- Lowest Price Guarantee: By operating a true Direct-to-Consumer model for the B2B world, we eliminate multiple distributor layers, passing savings of 15-25% directly to buyers.
- Scheduled Precision: Deliveries coordinated to the hour, not just the day, allowing construction schedules to operate with manufacturing-level precision.

Fulfilled by Merchant (FBM): For specialised, low-volume, or regional products, the platform operates as a sophisticated



marketplace. Manufacturers list products and fulfill orders directly, while the platform provides the technology infrastructure, payment processing, and quality assurance framework. This model unlocks transformative benefits:

- Unprecedented Selection: Buyers access not just national brands but regional specialists and innovative newcomers who would never appear in traditional distribution channels.
- Market Democracy: A manufacturer in Kerala producing innovative bamboo composite panels can sell to a project in Chandigarh without building a national sales force—democratising access for local businesses.
- Dynamic Competition: With transparent comparison tools, competition happens on genuine merit—quality, specifications, and price—rather than just distribution muscle.

2.2 Transforming Information Asymmetry into Information Advantage

The platform wages war on information asymmetry with two world-class innovations:

The Interactive Catalogue: The traditional product catalog has been reimagined from a static list into a dynamic discovery engine. Each Product Detail Page becomes a comprehensive information hub containing:

- Structured, searchable technical specifications in clear tabulated format
- Real-world application guides and installation videos
- Compliance certifications and environmental impact data
- Verified seller information and user reviews
- Real-time availability and delivery timelines

Supplayr Explorer—The World's First Universal Construction Material Directory: This is our flagship innovation and a genuine industry first. The Supplayr Explorer is not a purchasing catalog—it's a monumental, cloud-based database of every known construction material. Think of it as "Google for building products."

The Explorer serves three revolutionary purposes:

- Research Tool: Architects, engineers, and students can research and compare materials based on technical properties—thermal conductivity, compressive strength, environmental impact—without sales pressure.
- Democratizing Knowledge: It breaks down knowledge barriers between specialists and the public. A homeowner can now understand plywood types as easily as a seasoned contractor.
- Driving Informed Choice: By providing unvarnished, comparable data, the Explorer empowers everyone to specify materials based on performance and suitability, not just brand recognition.

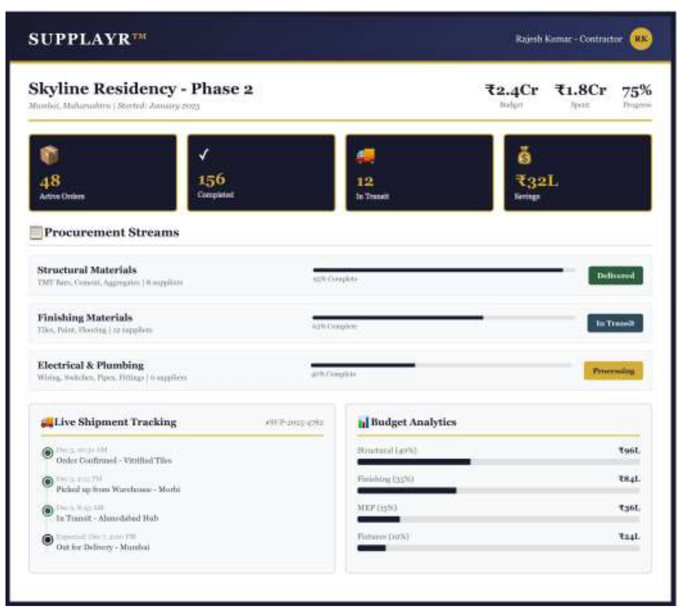
2.3 Intelligent Features That Create Competitive Advantage

The platform embeds intelligence throughout the procurement workflow:

Project-Wise Procurement Management: All procurement for a single project—from initial concrete to final light fixtures—can be organized within a single digital workspace. This revolutionary tool streamlines ordering, tracking, budgeting, and accounting, converting chaos into a managed, data-driven workflow that reduces administrative overhead by 50% or more.

Real-Time Tracking & Analytics: A unified dashboard provides GPS-enabled visibility of all shipments from both FBS and FBM partners, transforming the "logistics black hole" into transparent, manageable process.

Seamless Credit Solutions (Launching Soon): Integrated embedded finance solves the industry's cash-flow crisis. This includes Buy Now, Pay Later (BNPL) for smaller purchases and structured credit lines for businesses, providing the financial freedom to execute projects without capital constraints.



Intelligent Product Comparison: Users can select multiple products and compare them side-by-side on price, specifications, and ratings directly from the cart, ensuring optimal decision-making based on complete information.

Section 3: The Industry-Wide Impact—How Digital Platforms Change Everything

The introduction of sophisticated platforms like SUPPLAYR doesn't just improve existing processes—it fundamentally alters industry dynamics and economics.

3.1 Cost Reduction Across the Value Chain

Digital aggregator platforms compress costs at multiple levels:

- Eliminating Intermediaries: Direct manufacturer-to-user connections remove 2-3 layers of distributor margins
- Reducing Search and Transaction Costs: What once took days of calls and emails now takes minutes
- Optimizing Logistics: Consolidated deliveries and route optimization reduce transportation costs by 20-30%
- Minimizing Inventory Waste: Better demand signaling allows manufacturers to optimize production

Aggregate Industry Impact: Industry analysts estimate that widespread adoption of digital procurement platforms could reduce total material costs by 12-18% across the construction sector—representing savings of hundreds of billions of dollars globally.

3.2 Accelerating Project Timelines

When material procurement shifts from a weeks-long process to a days-long process, and when delivery certainty replaces delivery uncertainty, construction timelines compress dramatically. Projects that historically took 18 months can be completed in 14-15 months, with fewer delays and stoppages.

Platform Impact: The scheduled delivery system and unified tracking have already helped early adopters reduce material-related project delays by over 40%, directly impacting bottom-line profitability.

3.3 Democratizing Market Access

Perhaps the most profound impact is leveling the playing field:

For Small Manufacturers: The FBM model means a family business making superior ceramic tiles in Morbi no longer needs a national distribution network to compete. They need a smartphone and internet connection.

For Regional Contractors: Access to the same pricing, selection, and financial tools as major construction firms reduces the advantage of scale, allowing competitive bidding on merit.

For Individual Builders: Homeowners renovating or building can access trade pricing and professional-grade materials previously locked behind B2B relationships.

3.4 Driving Sustainable Innovation

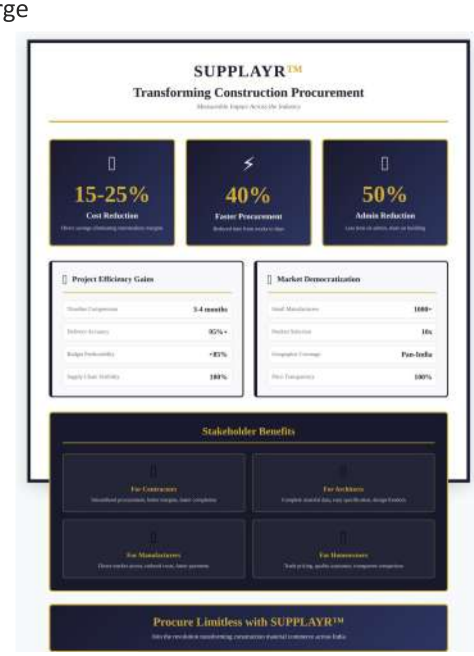
Digital platforms accelerate the adoption of sustainable materials by:

- Reducing Discovery Barriers: New eco-friendly products can reach market faster
- Enabling Comparison: Embodied carbon and lifecycle data can be standardized and compared through comprehensive databases
- Rewarding Innovation: Superior sustainable products compete on visible, verifiable metrics rather than just marketing claims

3.5 Data-Driven Decision Making

As platforms accumulate transaction data, they create unprecedented market intelligence:

- Manufacturers gain real-time demand signals
- Architects see what materials are actually specified and performing well
- Industry analysts can track trends and innovations as they emerge



Section 4: Implementation Roadmap—Building Revolution on Solid Foundation

A revolution must be built on stable foundation. SUPPLAYR's technical development is phased to ensure reliability and scalability from day one.

Phase 1: Core Commerce (The Launchpad)

The initial focus delivers a flawless core e-commerce experience:

- Frictionless Onboarding: Simple OTP for B2C; verified, GST-enabled onboarding for B2B firms
- VIP Catalogue: Launching with high-priority, deeply detailed interactive catalogue
- Intelligent Cart & Unified Checkout: Seamless, secure purchasing journey
- Integrated Delivery Tracking: Real-time visibility for all fulfilled orders
- Unified Payment Gateway: Robust system laying groundwork for future BNPL integration

Phase 2: Intelligence & Expansion (The Ascent)

Post-launch rapid deployment includes:

- Full rollout of the Supplayr Explorer
- Advanced Project Management dashboards for B2B users
- Beta launch of Seamless Credit Solutions and BNPL
- Expanded product categories and geographic coverage

Phase 3: Ecosystem Dominance (The Orbit)

Long-term vision includes:

- AI-driven predictive analytics for procurement
- Advanced supply chain finance solutions
- Deeper IoT integration for logistics and inventory management
- International expansion and cross-border procurement

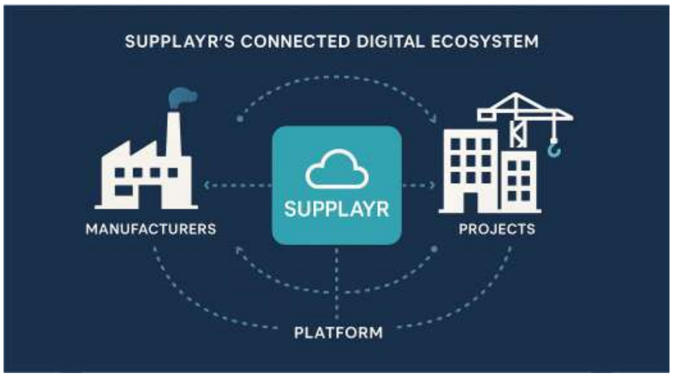
Early Adoption and Market Response

The platform is already seeing adoption in three waves:

Wave 1 - Digital-Native Builders: Younger contractors and architects, comfortable with e-commerce, are driving initial platform growth.

Wave 2 - Efficiency-Seekers: Mid-sized firms experiencing procurement pain are actively seeking digital solutions to reduce administrative burden.

Wave 3 - Institutional Interest: Large developers and government agencies are beginning to evaluate platform-based procurement for standardization and transparency.



Conclusion: Join the Revolution for a Future of Unconstrained Creation

The construction industry stands at an inflection point. The procurement systems that served the 20th century are actively holding back 21st century innovation, efficiency, and sustainability. SUPPLAYR™ represents more than incremental improvement—it represents a fundamental restructuring of how materials flow from production to project.

The platform is founded on a belief in Procure Limitless—the freedom for a builder to choose from every supplier, for an architect to specify based on perfect data, for a homeowner to access trade-grade materials, and for a local manufacturer to compete on a global stage. The old gates are being dismantled and open highways of commerce and information are being built.

The impact will be measured not just in cost savings or time reduction, but in expanded possibilities:

- Buildings completed faster and more sustainably
- Innovative materials that reach market and gain adoption
- Smaller players who can compete on merit rather than distribution muscle
- An industry that attracts top talent with modern, data-driven workflows

This transformation is already beginning. SUPPLAYR™ is being built, early adopters are seeing results, and the traditional distribution model is showing its age. The question for every industry participant is not whether to adapt, but how quickly.

The platform invites you to join in building this future—not with bricks and mortar alone, but with code, data, and a shared vision of freedom. Rising to create a more equal world by leveling the playing field. Rising to be future-ready by embedding intelligence into the very fabric of procurement.

The future of construction procurement is digital, transparent, and intelligent. SUPPLAYR™ is building that future today.

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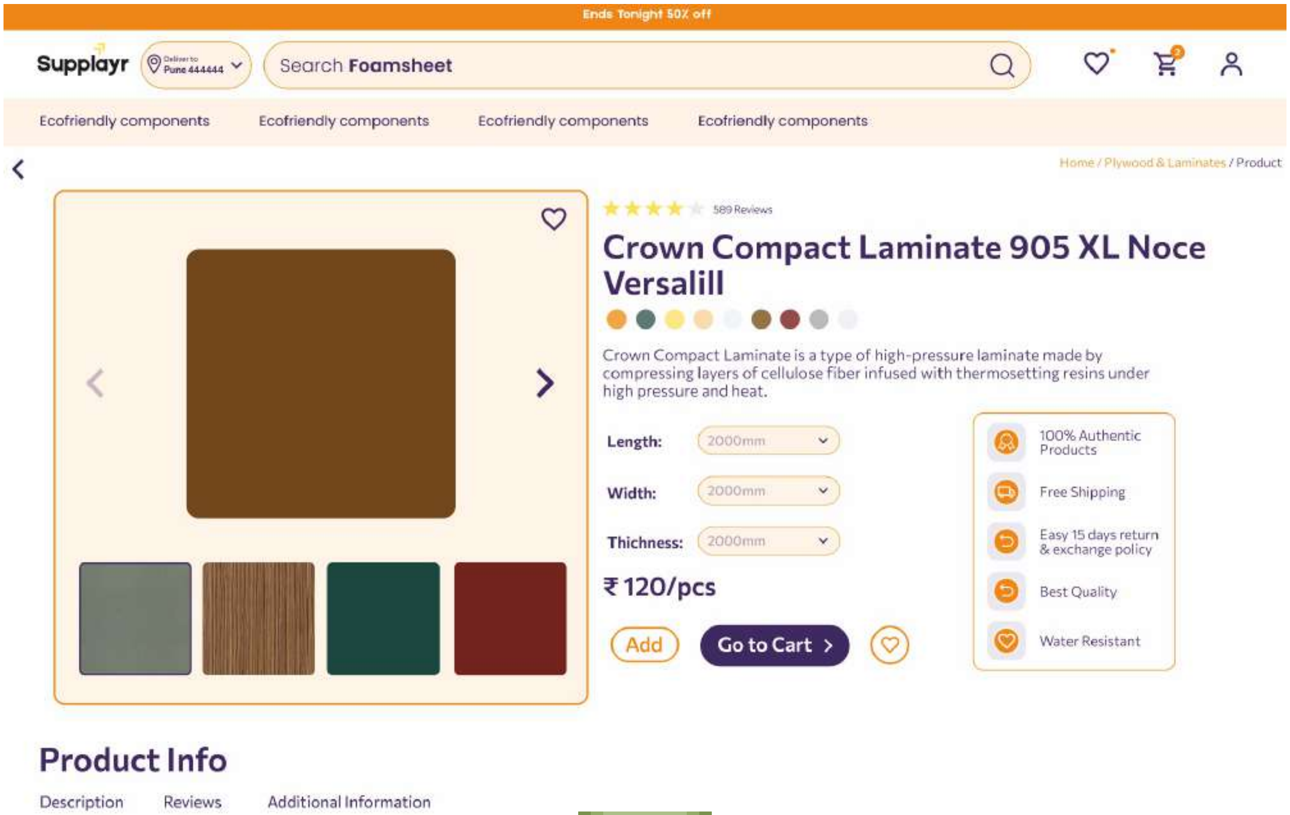
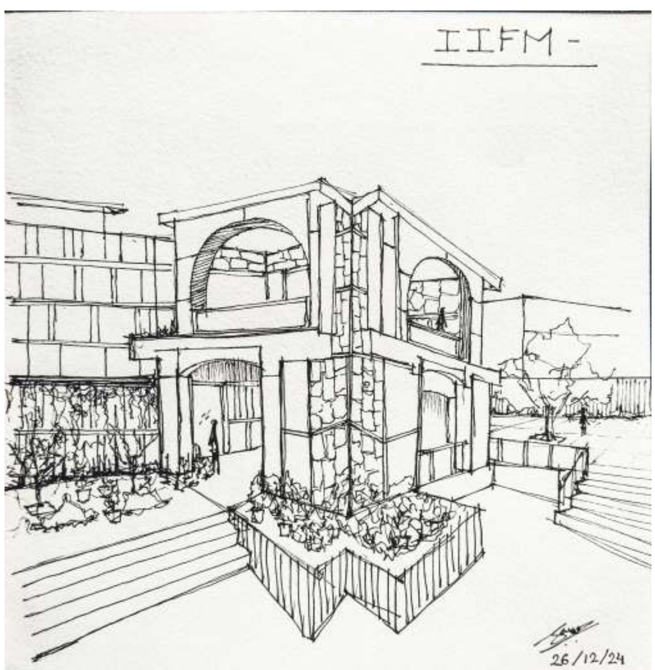




■ Swayam Patki

Chetan S Pachkhede

PUNE'S ICONIC TANPURA SHAPED BRIDGE

Project Name : Chhatrapati Sambhaji Cable Stayed Foot Over Bridge

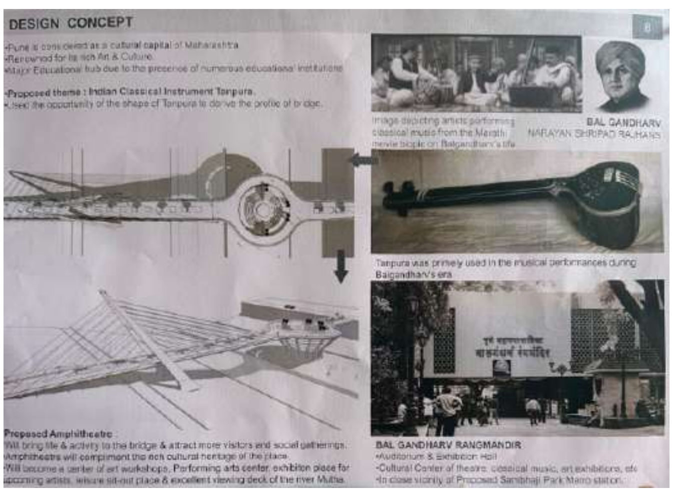
A Symbol of Engineering Excellence and Cultural Heritage

Standing tall in the heart of Pune, the Sambhaji Cable Stayed Foot Over Bridge

is a landmark of innovation, elegance, and civic pride. Executed under the most prestigious Maha Metro project, this bridge is more than a crossing—it is a

tribute to the city's cultural legacy (Image1) and its commitment to sustainable urban development.

Inspired by the Tanpura, the pylon pays homage to Padma Bhushan Bal Gandharva,blending musical symbolism with structural artistry

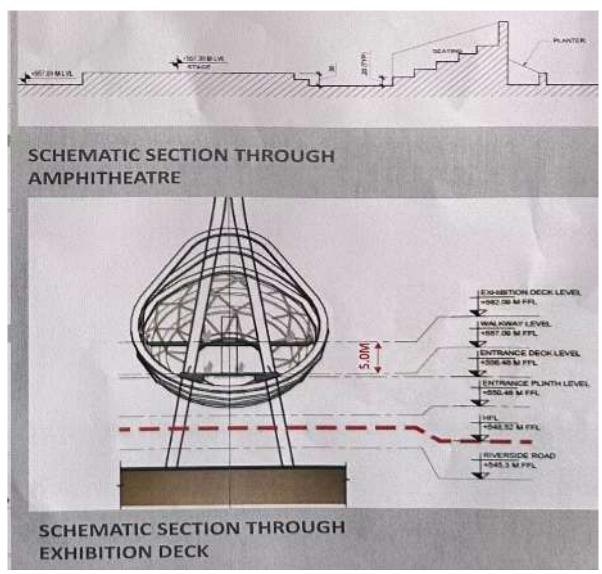


- **Key Highlights :**
- **India's First Inclined Concrete Pylon :**

India's first inclined concrete pylon stands as the defining feature of this iconic structure. Rising majestically to a height of 72.320 meters, the pylon showcases an innovative blend of architectural vision and advanced structural engineering. Unlike traditional vertical pylons, this inclined design demands exceptional precision in geometry, load management, and construction methodology. The pylon's unique inclination enhances the bridge's visual appeal while improving cable force distribution for superior stability and efficiency. Its sleek form, precise reinforcement, high-performance concrete, and careful erection sequence showcase true engineering excellence. This achievement sets new benchmarks in India's infrastructure, reflecting bold design, rigorous planning, and flawless execution.

- **Pune's First Cable Stayed Foot Over Bridge :**

Pune's first cable-stayed Foot Over Bridge introduces a new standard in pedestrian infrastructure across the Mutha River. Its cable-stayed system provides a slender, efficient structural profile, while the optimized deck geometry and balanced cable arrangement ensure stability, durability, and minimal visual obstruction. This pedestrian-only bridge combines functional performance with clean, modern aesthetics, setting a benchmark for future urban connectivity projects in Pune.



The image shows a set of architectural and structural design drawings for an amphitheatre and exhibition deck area. The sheet includes plan views and schematic sectional views with levels and structural geometry indicated.

The image shows the completed cable-stayed Foot Over Bridge with its 72.32 m inclined concrete pylon and fully tensioned stay cables. The pedestrian deck, architectural steel shell at the pylon base, and all finishing works are completed. The bridge spans across the river and integrates seamlessly with the surrounding metro and urban infrastructure.

- **Unique Structural Geometry :**

The pylon's geometry involves precise multi-directional inclinations: a 2.81° skew in plan for alignment, an 81.32° transverse inclination forming its distinctive lateral tilt, and a 70° longitudinal skew directing forces efficiently toward the foundation. These combined angles demanded advanced 3D modelling and highly accurate construction control. (Image 3)

- **Advanced Cable-Stayed Configuration :**

The bridge adopts an unsymmetrical span arrangement, relying on a balanced yet unequal cable layout. On the front side, 7 stay cables support the primary 80 m span, carrying the majority of the deck load. On the rear side, 3 stay cables stabilize the shorter 40 m span, ensuring counterweight and structural balance for the inclined pylon. All stay cables are supplied and installed by Dywidag Bridgcon, ensuring high-performance anchorage and tensioning quality

> *"Cables in harmony, geometry in motion - a bridge shaped by modern engineering and inspired by vision"*

- **Eco-Friendly Design :**

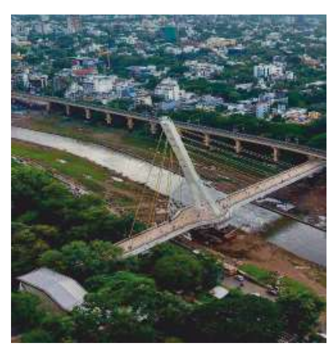
Cable-stayed structure eliminates the need for piers in the river span.

71° skew alignment across the Mutha River minimizes impact on Vartak Garden, preserving trees and valuable land.

- **Public Amenities & Aesthetic Features :**

The deck includes:

- Public seating arrangements
- A central Tanpura statue



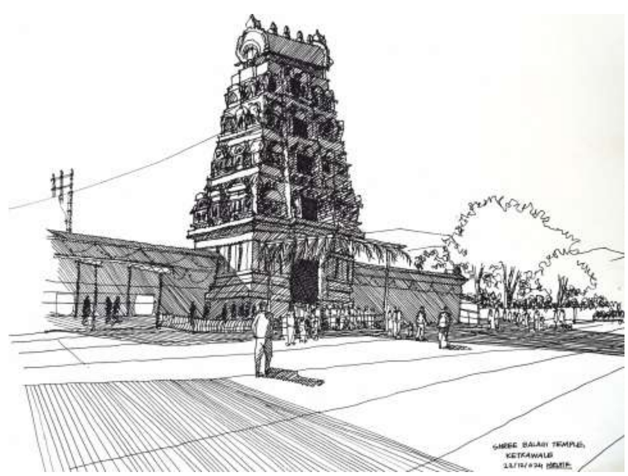
Offering citizens a tranquil space to enjoy the river view and reflect on Pune's cultural spirit

- **Superior Connectivity :**
- 11-meter wide deck
- 8-meter wide public carriageway

- Designed for safe, spacious, and comfortable pedestrian movement.

- **A New Icon for Pune**

The Sambhaji Cable Stayed FOB is not just an engineering feat—it is a symbol of progress, cultural reverence, and sustainable design. As it graces the skyline of Pune, it invites every citizen to walk across a bridge that connects not just places, but heritage and future.



■ Hrutik Dhanawade

A Research Study on Low-Cost and Sustainable Construction Techniques

Sadanand Rajgude
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PCERF YOUCONS Member)

Ar. Ayush Prakash Hazare
Practicing Architect
PCERF YOUCONS Member | Independent Researcher

1.Abstract

This research study explores four low-cost and environmentally responsible construction techniques: rat-trap bond masonry, filler slab roofing, compressed stabilised earth blocks (CEB/CSEB), and lime–earthen plaster finishes. Drawing from five research papers and two contemporary case studies, the article evaluates these systems in terms of material efficiency, cost reduction, structural performance, environmental impact, and human well-being. The findings reveal that rat-trap bond masonry reduces brick and mortar consumption by up to 30% while improving thermal insulation. Filler slabs save around 22% of roofing costs and reduce cement and steel usage. Compressed stabilised earth blocks significantly cut carbon emissions compared to fired bricks. Lime/earthen plasters enhance indoor air quality and lower finishing expenses. Case studies like the Pirouette House by Wallmakers and BC Materials' earth-block projects showcase the architectural adaptability and community benefits of these systems. The study concludes that integrating these techniques provides a scalable, climate-responsive model for affordable housing that is both cost-efficient, socially empowering, and environmentally regenerative.

Low-cost construction, sustainable building materials, rat-trap bond masonry, filler slab, compressed stabilised earth blocks (CSEB), earthen plaster, lime plaster, thermal comfort, embodied carbon reduction, affordable housing, vernacular architecture, and the circular economy are key aspects of a research study on low-cost and sustainable construction techniques.

1. Introduction

The global construction industry is under increasing pressure to reduce embodied carbon, material waste, and construction costs while simultaneously enhancing thermal comfort and human well-being. Vernacular and low-energy construction systems such as rat-trap bond masonry, filler slab roofing, compressed stabilised earth blocks (CEB/CSEB), and lime earthen plaster finishes offer practical and climate-responsive alternatives to high-carbon materials like cement plaster, fired bricks, and RCC slabs. This paper synthesises the performance, environmental impact, and socio-economic benefits of these systems for affordable housing, drawing on findings from five research papers and two built case studies.

2. Rat-Trap Bond Masonry

2.1 Definition and Construction Method

Rat-trap bond masonry involves vertically arranging bricks on edge to create a continuous hollow cavity without compromising structural integrity. Research suggests this method reduces brick and mortar consumption while enhancing thermal efficiency (Ullah, Khan & Thaheem 2018).

2.2 Material Efficiency and Cost Reduction

The internal cavity reduces the number of bricks needed by 20–30%, resulting in substantial cost savings during construction (Ullah, Khan & Thaheem 2018). Furthermore, mortar consumption decreases due to smaller bed joints (Ullah, Khan & Thaheem 2018), leading to measurable savings in cement and sand.

2.3 Structural and Thermal Performance

When executed correctly, a rat-trap bond has been found structurally adequate for load-bearing walls. (Ullah, Khan & Thaheem 2018) The air cavity within the bond acts as insulation, reducing heat transfer and enhancing indoor comfort in hot climates.

2.4 Human and Social Benefits

Rat-trap bond homes remain cooler, requiring less mechanical cooling and resulting in lower energy bills for users. Communities can adopt this technique with minimal training for masons, promoting local employment and skill transfer. (Ullah, Khan & Thaheem 2018)

3. Filler Slab Construction

3.1 Structural Principle

Filler slabs eliminate unnecessary concrete in the tension zone of the slab and replace it with low-weight fillers like earthen pots or tiles. This reduces cement and steel usage without compromising structural performance.

3.2 Cost and Material Savings

Filler slabs lead to cost and material savings.

Studies conducted in Bihar reveal a cost savings of 22.68% in roofing using filler slabs. (Sinha et al. 2020) Reduction in dead load also lowers foundation cost.

3.3 Thermal and Environmental Performance

Hollow fillers reduce solar heat gain, moderating indoor temperatures. (Sinha et al. 2020) Hollow fillers also enhance sustainability by reducing the consumption of cement and steel two of the most carbon-intensive construction materials.

3.4 Human Comfort and Livability

Filler slab buildings create cooler interiors, improving occupant comfort and reducing air conditioning reliance, particularly in low-income housing.

4. Compressed Stabilised Earth Blocks (CEB / CSEB / SCSEB)

4.1 Material Composition

CSEBs are made by compacting soil with 0–7.5% cement or lime stabiliser. Research conducted in Malawi soils has shown improved durability and mechanical performance (Eires et al. 2012).

4.2 Strength and Performance

Tests show that compressive strength increases with stabilisation, reaching 2.84 N/mm² after 28 days with 7.5% cement (Waziri et al. 2013) .This strength is adequate for low-rise construction.

4.3 Environmental Advantages

Since CEBs are unfired, they prevent deforestation and kiln emissions. Stabilised earth blocks emit only 22 kg of CO_2 per tonne, compared to 143 kg for concrete blocks and 200 kg for fired bricks (Waziri et al. 2013).

4.4 Economic and Social Benefits

CSEBs can be produced on-site using manual presses, which reduces transport costs and creates employment opportunities for rural communities. This localised production strengthens community resilience and supports sustainable development.

5. Lime and Earthen Plaster Finishes

5.1 Material Properties

Lime plaster has historically been valued for its breathability, flexibility, and durability (Paul, Girirajan & Changali 2024). Earthen plaster is also considered one of the "lowest-carbon finishing materials" as it requires no industrial processing (Paul, Girirajan & Changali 2024).

5.2 Environmental Performance

"Lime mortar production requires significantly lower energy than Portland cement" (Paul, Girirajan & Changali 2024). Earthen and lime plasters also regulate humidity, improving thermal comfort (Paul, Girirajan & Changali 2024)

5.3 Cost and Durability Advantages

Earthen finishes reduce finishing costs by eliminating the need for tiles or cement-based plaster (Paul, Girirajan & Changali 2024). Lime's flexibility resists cracking during structural movement (Paul, Girirajan & Changali 2024)

5.4 Health and Human Comfort

Lime and earth allow walls to "breathe," reducing mould growth and improving indoor air quality. This contributes to healthier living environments.

6. Case Studies from ArchDaily

6.1 Pirouette House by Wallmakers (India)

The Pirouette House showcases modern applications of rat-trap bond masonry, inspired by Laurie Baker (Figure -1). Vertical brick placement creates cavity walls that reduce materials and improve thermal comfort. Waste materials like scrap scaffolding and reclaimed wood were used for staircases and flooring, further lowering embodied energy. This project demonstrates how rat-trap bond can be expressive, economical, and ecologically responsible.

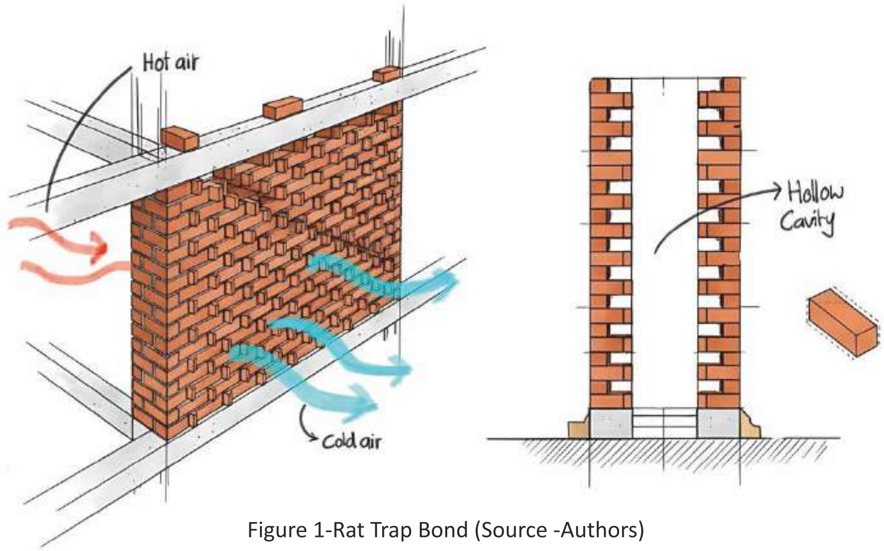

Figure 1-Rat Trap Bond (Source -Authors)

6.2 Building with Waste -BC Architects and BC Materials

This project exemplifies circular economy principles by using CEBs made from locally excavated soil(Figure -2). Through participatory workshops, local communities were trained and empowered. It confirmed that unfired earth blocks can be economically competitive, structurally reliable, and environmentally regenerative. Using "waste" soil reduces emissions, minimises transportation, and enhances community ownership-perfectly aligning with research on CSEB sustainability and affordability.

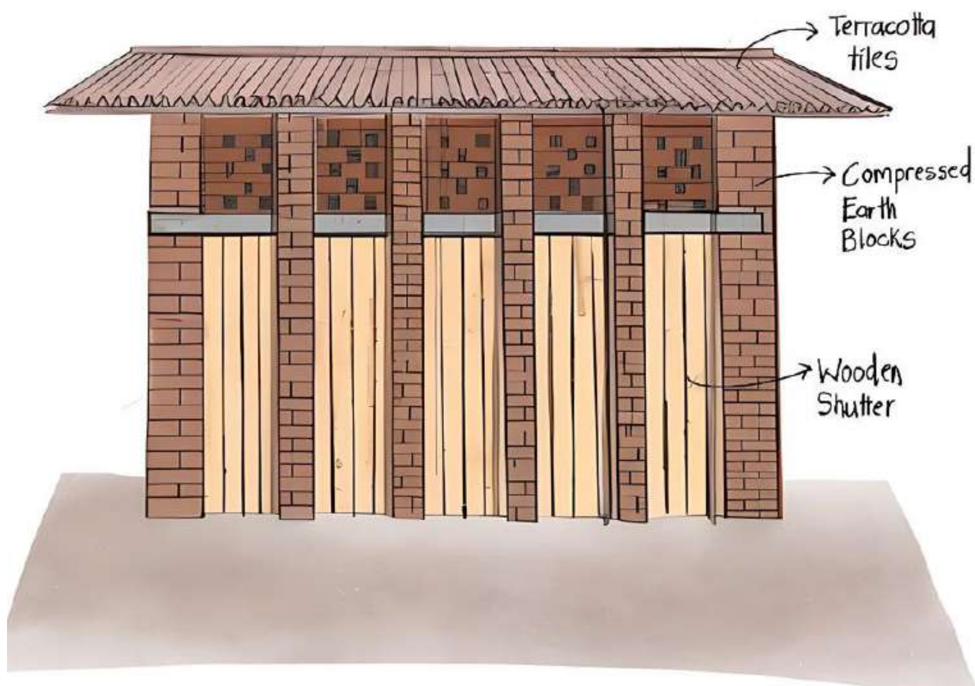

Figure 2-CSEB Composite Design (Source -Authors)

7. Synthesis of Findings

Across all research and case studies, several clear patterns emerge:

Material Efficiency:

- Rat-trap bond reduces material use by up to 30%.
- Filler slabs save approximately 22% of concrete and steel.

Thermal and Operational Energy Benefits:

- Cavity walls, insulated slabs, and breathable plasters enhance thermal comfort, thereby reducing cooling energy demand.

Environmental Responsibility:

- CSEBs significantly decrease CO_2 emissions.
- Lime and earthen plasters eliminate industrial processes and regulate indoor humidity.

Socio-Economic Empowerment:

- Techniques like CSEB production and rat-trap masonry create local employment and reduce reliance on external supply chains.

Architectural Adaptability:

- Case studies demonstrate that these methods support innovative, expressive, and contemporary design.

  Collectively, these strategies present a scalable construction model that is economically viable, environmentally responsible, and socially impactful.

8. Conclusion

By incorporating rat-trap bond masonry, filler slabs, stabilised earth blocks, and lime/earthen finishes, architects can create affordable, comfortable, and low-carbon buildings. These case studies demonstrate that these techniques are technically feasible, architecturally expressive, and community-empowering. This holistic approach harmonises contemporary design with ecological sensitivity and human wellbeing.

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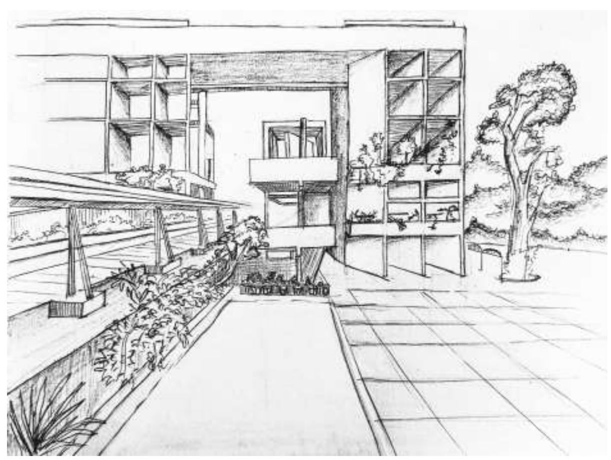

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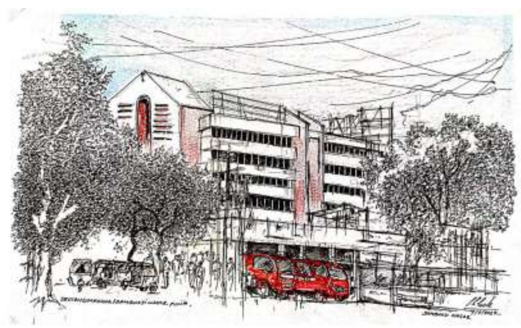

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