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Adequate Housing for All



बी.एम.टी.पी.सी.
bmtpc

निर्माण सामग्री एवं प्रौद्योगिकी संवर्द्धन परिषद्

आवासन और शहरी कार्य मंत्रालय, भारत सरकार

BUILDING MATERIALS & TECHNOLOGY PROMOTION COUNCIL

Ministry of Housing & Urban Affairs, Government of India



“Creating Enabling Environment for Affordable Housing for All”



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From the Desk of Executive Director

A house becomes a home when it offers more than shelter, when it provides **safety, dignity, stability and a sense of belonging**. It is where aspirations take shape and families build their futures. Adequate housing, therefore, is not merely a development goal; it is a fundamental element of human wellbeing, social inclusion, and sustainable development.

The theme of this year’s World Habitat Day, “**Adequate Housing for All**”, invites us to reflect on what it truly means to create housing that meets the needs of people and communities. Adequacy must go beyond the provision of a dwelling to encompass affordability, safety, accessibility, essential services, and a healthy living environment. In a dynamically evolving world, housing must also be **disaster-resilient, climate ready and technology forward**.

For India, this challenge is particularly significant. Rapid urbanisation, demographic change, pressures on land use and infrastructure, and the growing impacts of climate change are transforming our cities and settlements. The homes of tomorrow must therefore be affordable and scalable, while also being **resilient to disasters, responsive to climate, resource-efficient and enabled by right technologies**.

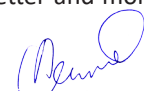
The **Building Materials & Technology Promotion Council (BMTPC)** has consistently worked towards promoting innovative building materials and construction technologies that can contribute to faster, safer, affordable, and sustainable construction. Through technology promotion, demonstration projects, knowledge dissemination, and capacity building, BMTPC continues to ease the adoption of solutions that can strengthen the housing sector and transform the way we build.

At the same time, the Council’s work towards sustainable building practices, energy efficiency, thermal comfort, and climate-responsive construction reflects the need to make our built environment prepared for the challenges ahead. Yet technology alone cannot deliver adequate housing. It requires convergence across **policy, planning, finance, infrastructure, institutional capacity and community participation**, with solutions that remains grounded in the needs and aspirations of the people they serve.

It gives me immense pleasure to present this special issue of ‘**Nirman Sarika**’, dedicated to “**Adequate Housing for All**”. This issue brings together the considered perspectives of eminent experts, practitioners, academicians and professionals from the housing and built-environment sector. Their valuable contributions enrich the discourse on housing and offer diverse insights into building more inclusive, sustainable, and resilient human settlements.

I extend my sincere appreciation to all the contributors for sharing their knowledge and perspectives, and to the BMTPC team for their dedicated efforts in bringing this issue together. As we look towards the future, our endeavour must go beyond building structures. **We must build homes that give security, communities that foster opportunity, and settlements that are resilient, climate ready and technologically forward**.

May *Nirman Sarika* continue to serve as a platform for **knowledge, dialogue, and innovation**, contributing to a future where adequate housing is accessible to all, and every home becomes a foundation for a better and more resilient life.


(Arvind Kumar)

Tracing the Trajectory of Housing Models in India – Insights for the road ahead



Sfeeti Padele ¹ Nilesh Rajadhyaksha ²

Abstr**act**
India runs the largest housing mission by volume of almost any country in the world. And yet even as housing construction (both private and public-led) accelerates, a number of households remain outside the ambit of affordable and adequate housing. This paper builds on the global evidence presented by UN-Habitat's *World Cities Report 2026: The Global Housing Crisis – Pathways to Action* (WCR 2026), which frames the housing crisis worldwide as five interlinked and mutually reinforcing challenges – affordability, displacement, informality, sustainability and liveability – rather than a single, solvable shortage of units. Against this backdrop, the paper traces the evolution of housing delivery in India across five broadly sequential, though still co-existing, models spanning nearly eight decades: direct state provision, site-and-services, slum upgradation and networking, market-led in-situ redevelopment, and the national mission architecture of the

Pradhan Mantri Awas Yojana (PMAY), tracked here from PMAY 1 through to PMAY 2.0. Based on such an analysis, the paper identifies five persistent gaps in India's housing system – in land, finance, informality, climate resilience and participation – and closes with pathways for action adapted to India's institutional and demographic context.

Keywords: *Housing Policy, PMAY, Slum Upgrading, Affordability, Informality, World Cities Report 2026, India*

1. Overview: The Housing Challenge, Global and National

Housing has become one of the defining fault lines of urban life worldwide. Globally, between 1.6 and 3.4 billion people currently lack adequate housing.¹ The global housing deficit has widened even as construction activity has grown, from 251 million units in 2010 to 288 million in 2023 – a reminder that building more housing, on its own, will not resolve the persistent

housing crisis.² By 2050, cities are projected to absorb an additional 2 billion residents, adding further pressure to already-constrained housing systems; climate-related hazards are projected to destroy 167 million homes by 2040, and in 2023 alone, natural catastrophes generated US\$280 billion in losses worldwide, most of it uninsured. Housing and construction, meanwhile, account for roughly 13 per cent of global GDP and over 280 million jobs, making housing as central to economic strategy as it is to social policy.³

The Pradhan Mantri Awas Yojana (PMAY) is among the largest housing missions anywhere by volume, and India's construction sector is a major engine of employment and GDP in its own right. Yet the same pressures visible globally play out domestically: affordable stock has shrunk as a share of new construction in India's largest cities, informal

1 World Cities Report 2026, Chapter 9: "Closing the Adequate Housing Gap," Section 9.1.1, p. 239.

2 World Cities Report 2026, Executive Summary / Chapter 3 Key Findings, p. xvii.

3 World Cities Report 2026, Key Findings and Messages, Chapter 1, p. xiv.

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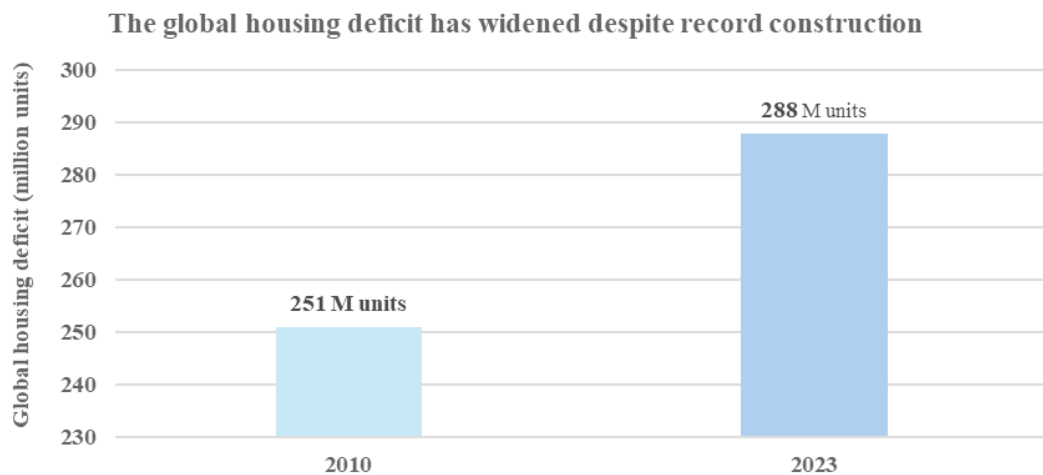


Figure 1: The global housing deficit has widened despite record construction, 2010-2023
Source: World Cities Report 2026, Executive Summary / Chapter 3 Key Findings, p. xvii.

settlements continue to house well over 200 million urban Indians, and evictions persist even where policy explicitly aims to prevent them. What distinguishes India is not the absence of policy response – in fact the country demonstrates a long and varied history of response across nearly eight decades, moving through direct public construction, site-and-services, in-situ upgrading, market-led redevelopment, and now a hybrid, multi-vertical national mission – arguably a more complete sequence of housing-delivery models than almost any other country has attempted. This paper is an attempt to trace this history of experimentation and the insights that this can provide for tackling housing adequacy going forward.

2. Housing as a Multidimensional Right

Adequate housing has never meant simply a roof and four walls. International human rights standards- codified in the UN Committee on Economic, Social and Cultural Rights' General Comment No. 4 and elaborated by UN-Habitat and the Office of

the High Commissioner for Human Rights – identify seven elements that together constitute adequacy: legal security of tenure; availability of services, materials, facilities and infrastructure; affordability; habitability; accessibility for disadvantaged groups; a location that allows access to employment, healthcare, schools and other amenities; and cultural adequacy that respects local traditions and practices.⁴ Because housing is also a tradeable commodity and an investment asset, and not merely an infrastructure to be matched one-for-one against population, simply constructing enough dwelling units to match demographic growth is not, and has never been, sufficient to satisfy this definition.

WCR 2026 translates these seven elements into five interconnected dimensions of the present global crisis: *affordability, displacement, informality, sustainability* and *liveability* (see Figure 1). Together, the report notes,

⁴ UN Committee on Economic, Social and Cultural Rights, General Comment No. 4: The Right to Adequate Housing (1991); UN-Habitat and OHCHR, The Right to Adequate Housing, Fact Sheet No. 21.

these “create a multidimensional problem with persistent gaps in policy and implementation.”⁵ The five reinforce one another: unaffordability pushes households into informal settlements; informal settlements face disproportionate exposure to climate shocks and displacement; displacement, in turn, adds fresh pressure to already-strained housing markets, deepening unaffordability elsewhere. A policy response confined to any single dimension – building more units, for instance, without addressing land, tenure or climate risk – will therefore struggle to resolve the crisis on its own.

It is against this multidimensional definition – not simply a count of roofs against population – that India's own housing trajectory needs to be read.

3. The Trajectory of Housing Models in India, 1947–2029

Unlike many developing economies that settled on a single dominant paradigm for housing delivery, India's system evolved through five broadly sequential

⁵ World Cities Report 2026, Key Findings and Messages, Chapter 1, p. xiv.

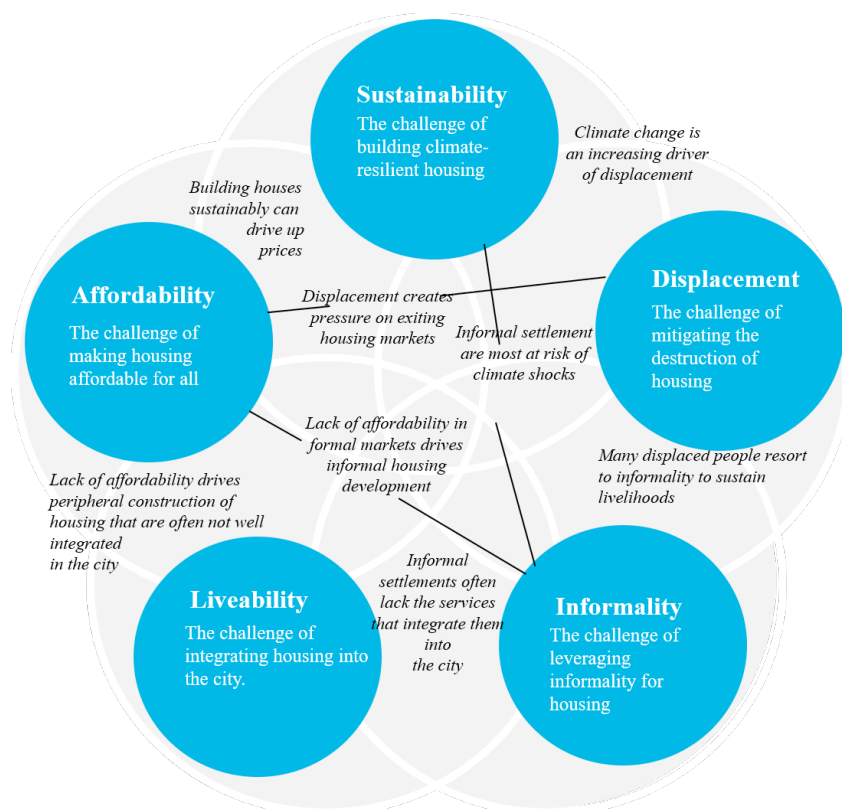


Figure 2: Housing is a multidimensional challenge

– though overlapping and, in practice, still co-existing – models, each emerging partly in response to the limitations of the one before it. Table 1 summarizes this trajectory; the sub-sections that follow examine each model's mechanism and key instruments.

3.1 Model 1 - The State as Direct Builder (1950s–1980s)

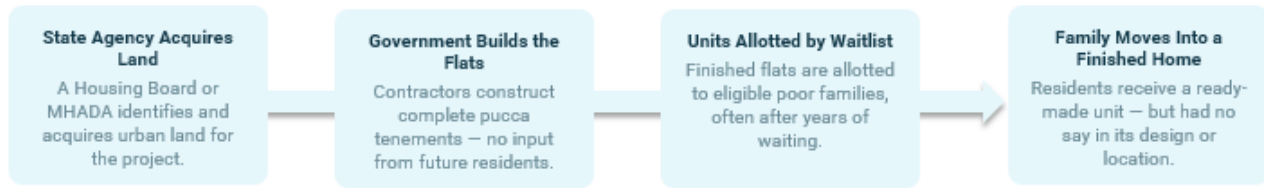
In the first phase of independent India's housing policy, government agencies acquired urban land and built completed tenements or flats for direct allotment to the

poor – a fully provider-driven, top-down model in which the beneficiaries received a finished unit. The Subsidised Industrial Housing Scheme (1952) and State Housing Boards from 1961 (such as the Tamil Nadu Housing Board) were followed by the Housing and Urban Development Corporation (HUDCO), established on 25 April 1970 to finance housing for economically weaker sections and urban infrastructure more broadly.⁶ In Bombay, the Slum Improvement Board (1971) and Building Repairs Board gave way to the Maharashtra Housing and Area Development Authority (MHADA) in 1977, which built ready flats that tenants moved into directly. The approach delivered fast, visible pucca housing without dependence on beneficiaries' own capacity to build, but proved costly per unit, difficult to replicate at city

⁶ Housing and Urban Development Corporation Ltd. (HUDCO), incorporated 25 April 1970 as "The Housing and Urban Development Finance Corporation Private Limited"; renamed HUDCO on becoming a public limited company in 1974.

Table 1: The trajectory of housing models in India, 1947–2029: Acts, schemes and institutions.

Model	Period	Core Mechanism	Key Instruments / Milestones
1. State as Direct Builder	1950s–1980s	Government acquires land, builds complete pucca tenements, allots by waitlist	Subsidised Industrial Housing Scheme (1952); State Housing Boards from 1961 (e.g. TNHB); HUDCO (1970); MHADA (1977)
2. Site-and-Services	1970s–1990s	Government provides serviced plots; households build incrementally as income allows	Madras Urban Development Projects I & II (1977, 1981); Calcutta Urban Development Projects (1978–83); World Bank-financed schemes across 27 Indian cities (1977–97)
3. Slum Upgradation & Networking	1970s–1998	In-place service delivery, without demolition or relocation; slum infrastructure integrated with city-wide systems	Environmental Improvement of Urban Slums (1972); Hyderabad Slum Improvement Project (to 1998); Calcutta Slum Improvement Project (1991–2006); Indore–Baroda–Ahmedabad Slum Networking (1987–98)
4. Market-Led In-Situ Redevelopment	1995–present	Developer demolishes and rebuilds on the same land; free flats for existing residents cross-subsidised by market-rate units	Mumbai Slum Rehabilitation Authority (1995–); JNNURM's Basic Services for the Urban Poor in-situ projects from 2005 (e.g. Yerwada, Pune)
5. National Mission Architecture	2015–2029	Centrally-assisted, multi-vertical mission combining beneficiary-led construction, partnership housing, rental stock and interest subsidy	Pradhan Mantri Awas Yojana (Urban) 1 (2015–22); Pradhan Mantri Awas Yojana (Urban) 2.0 (2024–29)



scale, and often poorly matched the residents' livelihoods and space needs – producing long waitlists that persisted for years.

3.2 Model 2 - Site-and-Services: "Make Your Own House" (1970s–1990s)

The second model reversed the logic of the first: government provided serviced plots – land with roads, water, drains and power already in place – and let families build incrementally as their income allowed, charging only what a household could afford for land and services. The Madras Urban Development Projects I and II (1977 and 1981), developed with the World Bank and planner Christopher Benninger, extended plots, slum tenure and home-improvement loans to over 100,000 households, following an earlier pilot at Arumbakkam that provided roughly 7,000 plots. Calcutta Urban Development Projects, launched from 1978, combined serviced sites with wider metropolitan infrastructure reform. In total, the World Bank co-financed site-and-services schemes in 27 Indian cities between 1977 and 1997 – the approach's high-water mark before it fell out of favour internationally. Many distant sites initially struggled, but most densified successfully over subsequent decades, illustrating both the risks and the eventual payoff of incremental, household-led construction.

3.3 Model 3 - Upgrading in Place: Slum Improvement and Slum Networking (1970s–1998)

A third model abandoned both direct construction and relocation in favour of upgrading settlements where they stood. The Environmental Improvement of Urban Slums (EIUS) scheme, launched nationwide in 1972, added water taps, drains, latrines and street lighting directly into existing slums. The Hyderabad Slum Improvement Project (1980s–1998) and the Calcutta Slum Improvement Project (1991–2006) extended secure tenure and infrastructure upgrading over long, phased programmes, often with World Bank or UK Department for International Development (DFID) funding, while state-level programmes in Andhra Pradesh and Madhya Pradesh continued the approach into the 2000s. This was the cheapest option per household of any model examined here, respecting the years families had already invested in their homes – though it did not always provide legal ownership or improved housing quality.

A related innovation, slum networking, was pioneered in Indore from 1987 by engineer Himanshu Parikh, based on the insight that slums typically sit along natural drainage paths, so their internal infrastructure can double as city-wide drainage. The Indore project integrated water supply, roads, storm drains

and sewage for slums and the wider city together, benefiting an estimated 450,000 people, and went on to win the UN World Habitat Award (1993/94) and the Aga Khan Award for Architecture (1998).⁷ The model was repeated in Baroda (1995–96), where resources were mobilised locally through a municipal partnership with UNICEF providing leverage funds, and in Ahmedabad (1995–98), where a fully local partnership between residents, the Municipal Corporation, NGOs and businesses – without any external aid – was later scaled into the city-wide Parivartan programme covering more than 50 slums.

3.4 Model 4 - Market-Led In-Situ Redevelopment: "Rebuild It, Give a Free Flat" (1995–present)

From the mid-1990s, a fourth model emerged in which a private developer demolishes an existing slum and builds new towers on the same land, giving residents a free, ready-made flat funded by additional flats sold at market rate. The flagship instrument, Mumbai's Slum Rehabilitation Authority (SRA, 1995), allows developers additional floor space (bonus FSI/TDR) in exchange for a free flat – originally around 225 sq. ft. – for every eligible slum household on-site. From 2005, the Jawaharlal

⁷ Archnet/Aga Khan Development Network, "Slum Networking of Indore City"; UN World Habitat Award, 1993/94; Aga Khan Award for Architecture, 1998.

Nehru National Urban Renewal Mission's Basic Services for the Urban Poor (BSUP) component supported similar in-situ rebuilding in many cities; the Yerwada project in Pune, led by the civil society organisations SPARC/Mahila Milan and MASHAL, is a widely cited example of a participatory, house-by-house upgrading process that retained the existing street layout, respected residents' social networks and preserved their proximity to livelihoods in the city centre.⁸ Where this model departs most sharply from Model 2 is in who builds: here the developer or government constructs the whole house, whereas in site-and-services the household builds it on a serviced plot. Vertical densification under this model can strain services and disrupt ground-level livelihoods and community fabric, and documented cases show risks of exclusion, corruption and long implementation delays.

3.5 Model 5 - The National Mission Architecture: PMAY 1 and 2.0 (2015–2029)

The most recent phase combines elements of all four preceding models within a single, multi-vertical national mission. PMAY (Urban) 1, launched on 25 June 2015, targeted 2 crore pucca houses for the urban poor by 2022, delivered through four verticals chosen according to beneficiary and city context: Beneficiary-Led Construction (BLC), Affordable Housing in Partnership (AHP), the Credit-Linked Subsidy Scheme (CLSS) and In-Situ Slum

Table 2 Comparison of PMAY (Urban) 1 and PMAY (Urban) 2.0 verticals

Vertical	PMAY (Urban) 1- 2015–2022	PMAY (Urban) 2.0 - 2024–2029
Beneficiary-Led Construction (BLC)	Central assistance of ₹1.5 lakh to individual EWS families building or enhancing a house on their own land	Central assistance raised to up to ₹2.5 lakh; house size up to 45 sq. m; EWS income ceiling ₹3 lakh/year
Affordable Housing in Partnership (AHP)	₹1.5 lakh per house where at least 35% of units in a project (minimum 250 units) are reserved for EWS	Continues, with States/UTs or private developers building multi-unit projects with a defined EWS/LIG share
Interest Subsidy on Home Loans	Credit-Linked Subsidy Scheme (CLSS): upfront interest subsidy for EWS/LIG/MIG buyers; closed 31 March 2022	Interest Subsidy Scheme (ISS) replaces CLSS: subsidy of up to ₹1.8 lakh on home loans from 1 September 2024 onward
Slum / Rental Housing	In-Situ Slum Redevelopment (ISSR): ₹1 lakh per house, using slum land itself as a resource with private developers	Affordable Rental Housing (ARH) – a new vertical for migrants, students and workers not yet able to afford ownership

Redevelopment (ISSR).⁹ By 2024, roughly 11.8 million houses had been sanctioned under the scheme – making PMAY-U India's largest urban housing programme by volume. PMAY (Urban) 2.0, approved by the Union Cabinet on 9 September 2024 with an outlay of approximately ₹10 lakh crore, targets one crore additional urban families over five years (2024–29) through four verticals: BLC, AHP, a new Affordable Rental Housing (ARH) vertical for migrants, students and workers, and an Interest Subsidy Scheme (ISS) that replaces CLSS.⁹

4. Where India Stands Today: A Diagnostic Reading

Housing demand in India remains overwhelmingly concentrated among Economically Weaker Section (EWS) and Low-Income Group (LIG) households, which together account for at least 79 per cent of demand.

Yet supply has moved in the opposite direction: across India's eight largest cities, the affordable housing segment fell from 52 per cent of new builds in 2018 to just 17 per cent in 2025, as developers increasingly prioritised mid- and high-end units where profit margins are higher. Price-to-income ratios in Mumbai and Delhi now stand at 14.3 and 10.1 respectively, placing formal homeownership far beyond median-income households; even in comparatively "less unaffordable" cities such as Ahmedabad, Chennai and Kolkata, affordability is undermined by a shrinking supply-to-demand ratio for affordable housing, which fell from 1.05 in 2019 to just 0.36 in 2025.¹⁰ A 2020 ICRIER estimate placed India's urban housing shortage at 29 million households in 2018, itself a 54 per cent rise from 18.78 million in 2012 – driven overwhelmingly by congestion

⁸ World Cities Report 2026, Chapter 5, Box 5.6: "The Yerwada project in Pune, India: improving livelihoods and housing," p. 127. Source cited therein: Lamb & Vale, 2024.

⁹ Ministry of Housing and Urban Affairs, Government of India, Pradhan Mantri Awas Yojana – Urban (PMAY-U), launched 25 June 2015; PMAY-U 2.0 approved by the Union Cabinet on 9 September 2024.

¹⁰ World Cities Report 2026, Chapter 3, Box 3.1: "Limited mortgage access and prioritization of high-end housing in India," p. 61. Source cited therein: Haidar, 2025; Knight Frank, 2025; Magicbricks, 2024.



Figure 3: PMAY (Urban) 1



Figure 4: PMAY (Urban) 2.0

rather than homelessness.¹¹

Informality remains the primary mode through which housing is actually produced and consumed in urban India – in the form of Jhuggi-Jhompri clusters, unauthorised colonies, notified and non-notified informal settlements, and urban villages. As of 2024, 40.8 per cent of India's urban population, or roughly 209 million people, lived in informal settlements, down from 48.8 per cent in 2010 – a meaningful decline, but one that still leaves more than two in five urban Indians

outside formal housing systems.¹² Eviction remains a persistent and often under-recognised feature of this landscape. Globally, forced displacement more broadly reached 123.2 million people by the end of 2024 – double the figure a decade earlier – with an additional 64 million people displaced from informal settlements over the past two decades, underscoring that housing displacement is as much a development challenge as a humanitarian one.¹³

Climate risk compounds each of these pressures. Buildings

account for 34 per cent of global energy demand and 37 per cent of CO₂ emissions, with housing alone responsible for 17 to 21 per cent of total emissions worldwide; India has recorded among the largest increases globally in building-sector emissions.¹⁴ Meanwhile, from 1975 to 2025, urban areas expanded physically at nearly twice the rate of population growth, driven by limited access to land – a pattern that has deepened housing segregation and fragmentation and reinforced the conclusion, echoed across WCR 2026, that markets alone cannot efficiently and equitably deliver adequate

11 D. Roy, Housing for India's Low-Income Urban Households: A Demand Perspective, ICRIER Working Paper No. 402 (New Delhi: Indian Council for Research on International Economic Relations, December 2020).

12 World Cities Report 2026, regional data on the share of urban population in informal settlements, India 2010–2024.

13 World Cities Report 2026, Chapter 4: "Beyond Displacement: Mitigating the Loss of Home."

14 World Cities Report 2026, Chapter 6: "Building Climate Resilient Housing."

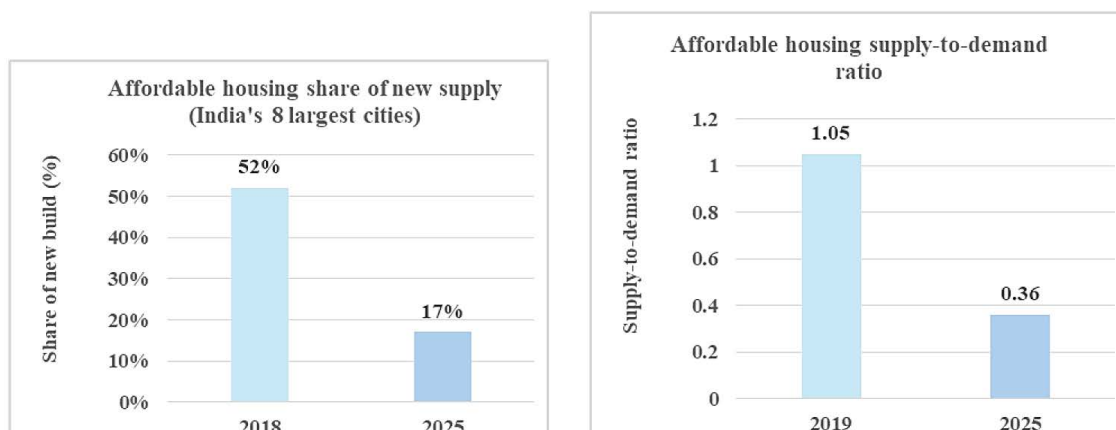


Figure 5: Affordable housing supply is shrinking even as overall construction accelerates
Source: World Cities Report 2026, Chapter 3, Box 3.1, p. 61 (Haidar, 2025; Knight Frank, 2025; Magicbricks, 2024)

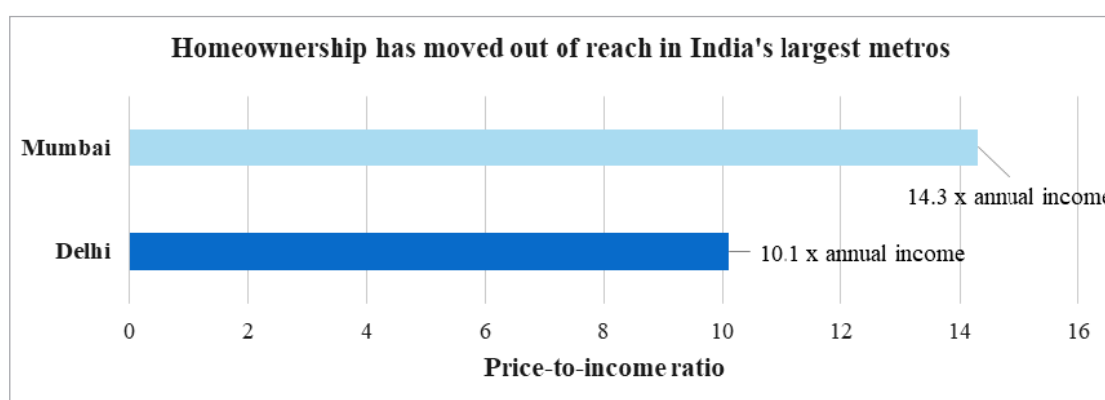


Figure 6: Price-to-income ratios in Delhi and Mumbai, 2025
Source: World Cities Report 2026, Chapter 3, Box 3.1, p. 61.

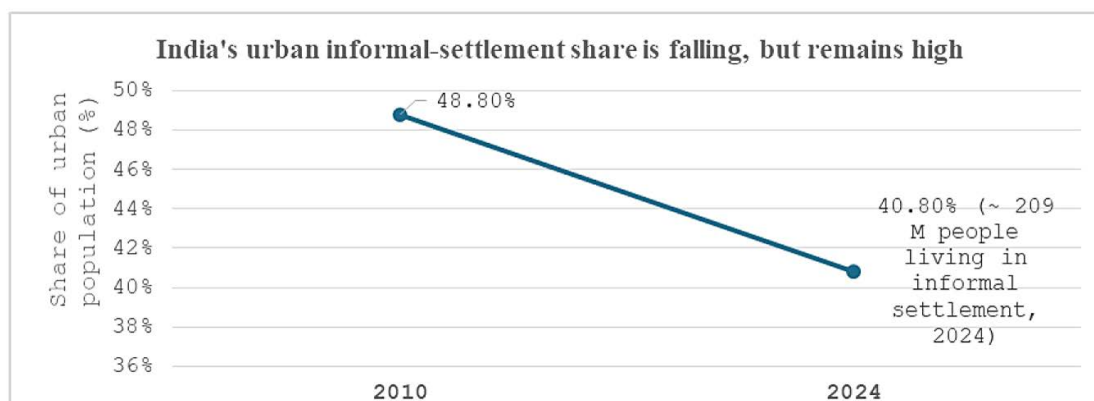


Figure 7: Share of India's urban population living in informal settlements, 2010–2024
Source: World Cities Report 2026, regional data on informal settlements, India 2010–2024

housing.¹⁵ On finance, the picture is similarly constrained: globally, only one in four housing-loan applicants (25.5 per cent) successfully secured a loan in 2023, and the global financing requirement for adequate and affordable housing

is estimated at US\$3–4 trillion annually through to 2030 – with urban land identified as the single most critical enabler of financing adequate housing for low- and middle-income households in cities.¹⁶

5. Gaps in India's Housing Landscape: A Synthesis

Read together, the analysis points to five structural gaps that persist in India's national goal for housing adequacy.

- **The land gap.** Affordable, serviced land near employment

¹⁵ World Cities Report 2026, Chapter 7: "Housing and the City: Delivering Equitable, Liveable and Inclusive Housing."

¹⁶ World Cities Report 2026, Chapter 8: "Beyond the Conventionality of Housing Finance."

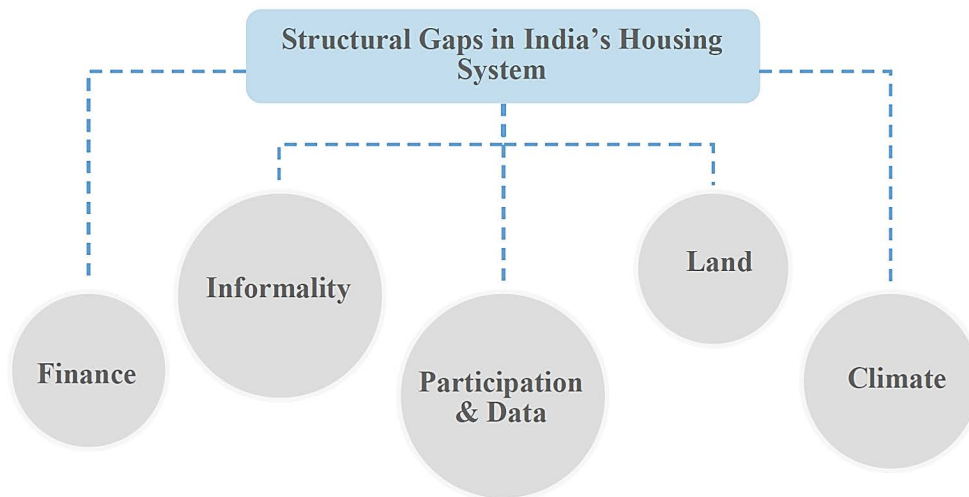


Figure 8: The five structural gaps in India's housing system reinforce one another

centres has become steadily scarcer, pushing affordable housing to peripheral locations poorly integrated with the city – the same dynamic that produced urban sprawl “at nearly twice the rate of population growth” over the past half-century.¹⁷

- **The finance gap.** Formal mortgage penetration remains narrow, and underwriting models built around salaried, documented income exclude the large share of India's housing and construction workforce that is informally employed – precisely the population Section 4 shows keeps construction costs low in the first place.
- **The informality gap.** Policies that have sought either to remove informality or to simply formalise it in line with formal planning standards have, in WCR 2026's own global assessment, “broadly failed” – informality continues to be treated as a problem to be cleared rather than as a housing-delivery

system that already serves over 200 million urban Indians and could be more deliberately supported.

- **The climate-resilience gap.** Despite housing's outsized share of both global emissions and climate vulnerability, resilience considerations remain largely absent from the siting, materials and financing decisions embedded in India's major housing schemes.
- **The participation and data gap.** Few large-scale programmes formally embed community-led planning, diverse tenure recognition or co-produced data collection – even though the best-documented Indian examples of durable upgrading, from Ahmedabad's slum networking to Yerwada's house-by-house redevelopment, were participatory and civil-society-led by design.

6. Pathways Forward: Recommendations for Adequate Housing in India

WCR 2026's closing chapter sets out a three-part global roadmap for

closing the adequate-housing gap: transformative pathways grounded in a rights-based approach; systemic change through integrated planning, inclusive finance and multi-level governance; and the leveraging of housing's knock-on benefits for wider development goals.¹⁸ Adapted to India's specific institutional architecture and historical experience, this suggests three connected priorities.

6.1 Diversify and secure tenure, not just supply units

- Recognise incremental, self-built housing and informal settlements as legitimate delivery channels in their own right, building on the legacy of India's 2001 draft National Slum Policy and 2009 National Urban Poverty Reduction Strategy, and expand tenure regularisation and fit-for-purpose land records for settlements on public land.
- Scale the new Affordable Rental Housing vertical under PMAY 2.0 and pair it with a

¹⁷ World Cities Report 2026, Chapter 7: “Housing and the City: Delivering Equitable, Liveable and Inclusive Housing.”

¹⁸ World Cities Report 2026, Chapter 9: “Closing the Adequate Housing Gap,” Sections 9.1–9.2, pp. 239–242.

regulated rental market – clear landlord-tenant rights, functioning dispute-resolution mechanisms, and policies that expand rental supply through increased land availability and public and private investment.

- Make participatory, in-situ upgrading the default response to informal settlements rather than the exception, institutionalising the house-by-house, civil-society-led approach demonstrated at Yerwada and in Ahmedabad’s slum networking, rather than defaulting to demolition-and-redevelopment wherever land values allow it.

6.2 Fix the land-and-finance connective tissue

- Treat urban land as the binding constraint that it is: scale up inclusionary zoning, land banks with dispensations for pro-poor housing, and land-value-capture instruments that cross-subsidise affordable stock – taking the design-build-finance structure piloted in the Bhubaneswar Affordable Housing PPP as a template for replication across states.¹⁹
- Widen housing finance beyond conventional mortgage models built on formal, documented income: develop alternative credit-risk assessment methods for informally employed and self-employed households, and use blended finance and de-risking instruments to draw private capital toward EWS/LIG

¹⁹ World Cities Report 2026, Chapter 8, Box 8.5: “Bhubaneswar Affordable Housing PPP, India,” p. 259. Source cited therein: Ministry of Housing and Urban Affairs, n.d.; World Bank, 2020; Times of India, 2026; Roy & Kundu, 2024; Press Information Bureau, 2024.

housing.

- Strengthen housing data systems – title records, informal-settlement mapping and beneficiary tracking – to reduce the perceived risk that currently keeps formal lenders away from low-income and informal borrowers, and to allow subsidy to be targeted more precisely.

6.3 Integrate housing into climate, livelihood and governance systems

- Build climate resilience into the design requirements of both new construction and upgrading programmes from the outset, rather than treating it as an add-on – particularly given housing’s dual role as both a major source of emissions and a critical entry point for climate adaptation.
- Protect livelihood proximity in every redevelopment or relocation decision, a lesson that SRA-style, market-led redevelopment has repeatedly relearned the hard way through documented cases of community and livelihood disruption.
- Institutionalise participation through reserved representation for informal-settlement residents on planning and parastatal bodies, participatory budgeting for neighbourhood-level upgrading, and community-led data collection – tools WCR 2026 identifies as central to any pro-poor approach to housing.
- Anchor reforms beyond individual electoral cycles: housing systems are capital-in-

tensive and slow to change, and PMAY’s own two-phase, decade-spanning design is itself an argument for sustained, long-horizon institutional commitment, working through the local-body architecture the 74th Constitutional Amendment put in place in 1992.²⁰

7. Conclusion

India is not short of housing policy models. Across HUDCO, MHADA, site-and-services, slum networking, the SRA, JNNURM and now PMAY 1 and 2.0, the country has tried – and in the case of slum networking, exported – nearly every major approach used anywhere in the world. What this trajectory asks of India next is not a sixth model, but the discipline to combine the best-performing elements of the previous five: the affordability discipline of site-and-services, the tenure security and cost-efficiency of in-place upgrading, the delivery speed of market-led redevelopment, and the fiscal scale of the national mission – built around a participatory core that treats land, finance, climate and informality as parts of one interconnected system rather than five separate departments. That, more than any single new scheme, is what closing India’s housing gap will require over the coming decade.

²⁰ National Housing Bank, established 9 July 1988 under the National Housing Bank Act, 1987; Constitution (Seventy-Fourth Amendment) Act, 1992.

Affordable and Adequate Housing for All in India: Engineering Frameworks, Technology Interventions, and Future Horizons



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Abstract The need for housing that is both adequate and inclusive forms a basic element of human dignity, public health, social equity, urban productivity, and the ability of communities to recover from disasters. Worldwide, more than 2.8 billion people experience some kind of housing inadequacy, this comprising 1.1 billion people who live in informal settlements, and about 96,000 new housing units have to be constructed each day if demand is to be met by 2030. India mirrors this global challenge at scale, needing to expand housing access for economically weaker and low-income households while ensuring that dwellings are safe, durable, climate-responsive, affordable over their life cycle, low-carbon, and connected to livelihoods and essential services. This paper reviews the general need for adequate housing, the specific challenges of the Indian context, the engineering, technological, and policy interventions available, and the future demands that housing must anticipate. It integrates the

global adequate-housing framework articulated by UN-Habitat with an India-specific engineering and policy programme, presenting hazard-informed planning, code-compliant structural design, industrialised and indigenous construction technologies, a life-cycle-carbon-accounting pathway to zero-carbon buildings, artificial-intelligence-assisted non-destructive evaluation (AI-NDE) for quality assurance, and a phased institutional roadmap aligned with PMAY-U 2.0.

Keywords: *Adequate housing; inclusive housing; UN-Habitat; PMAY-U 2.0; hazard resilience; low-cost housing technologies; zero-carbon buildings; embodied carbon; life cycle assessment; non-destructive evaluation; artificial intelligence; digital twin; sustainable construction*

1. Introduction

Housing is a physical shelter, which underpins health, education, livelihoods, safety, identity, and social inclusion for people of all incomes, ages, genders, and occupations. Adequate housing

therefore extends well beyond the provision of a dwelling unit. It includes affordability, security of tenure, access to basic services, structural safety, accessibility, and protection from environmental and disaster risk. Even where housing is nominally provided for economically weaker sections, the needs of groups such as migrant workers, senior citizens, and persons with disabilities are not adequately reflected in the design. The extent of the problem is global. According to UN-Habitat's Annual Report 2024, more than 2.8 billion people suffer from inadequate housing and 318 million are homeless. To meet demand by 2030, about 96,000 new housing units would have to be provided every day, which is equivalent to one new home being built every second. Each year climate change, conflict, and natural disasters continue to force millions of people from their homes, worsening a crisis which the United Nations has said calls for immediate action and much greater investment in affordable housing and basic services.

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The situation is particularly urgent for India. Due to rapid urbanisation, migration, high land prices, the prevalence of informal employment, climate-related hazards, and the unequal levels of capacity amongst urban local bodies (ULBs), housing delivery presents both a developmental and an engineering problem. The Pradhan Mantri Awas Yojana – Urban (PMAY-U 2.0) offers a significant institutional framework by promoting beneficiary-led construction, providing affordable housing through partnerships and adopting rental housing schemes, all backed by digital demand surveys, geo-tagging, and beneficiary verification. Yet the next phase of the housing initiative should place equal emphasis on quality, resilience, occupancy, and life-cycle performance and must make use of India's own research and technological resources. This paper brings together four strands: the global definition and scale of adequate housing framed by UN-Habitat; the engineering principles needed for safe and resilient housing in India; indigenous, field-proven housing technologies, including several developed at CSIR-Structural Engineering Research Centre; and the use of artificial intelligence and non-destructive evaluation (NDE) to assess and ensure quality. The paper concludes with an implementation roadmap and a vision of housing as a resilient, connected, low-carbon habitat.

2. Adequate Housing: Global Context, Crisis and Indian Context

2.1 Adequate Housing: A Global Framework

Adequate housing is recognised internationally as a fundamental right and a cornerstone

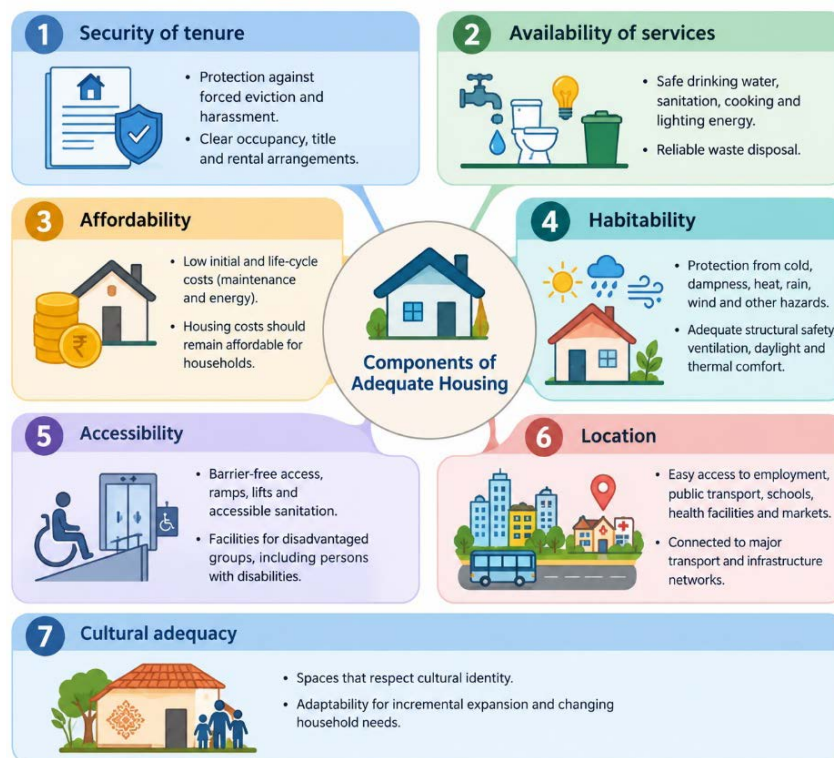


Fig. 1: Components of adequate housing

of an adequate standard of living. UN-Habitat and the wider United Nations system frame adequacy through seven interlocking components as shown in Fig. 1, each of which carries a direct engineering or planning implication for how housing is designed, financed, and delivered.

These seven components are to be realised so that affordability, displacement and informal settlements can be reduced to larger extent, while improving inclusivity, accessibility and quality of life. Low capital cost alone cannot be the basis for a housing located in a poorly connected place. Secure and healthy living environment is required to be provided.

2.2 Inclusive Housing: A broader perspective

Housing is basic necessity of all humans irrespective of their income levels, age, genders, occupation, etc. Main points are

they have to live with safety and dignity. Even though, housing for certain sectors are taken care, say for example, Low Income Groups, there are certain sectors are generally neglected, such as, migrant workers, senior citizens, differently abled people.

Low cost housing is generally focussing on low construction cost, however, another aspect generally neglected is low maintenance cost including expenditure on energy for the occupants. Safety in terms of public health requirements, fire, electrical and structural should not be compromised at any cost. Resilience for various hazards specific to the location of the housing can be ensured through adopting affordable technological solutions. This has another dimension, awareness among the users as well as creators.

Accessibility makes the housing more effective. It is not only interms of ramps, lifts, accessible

sanitation, but in terms of public transport, educational and health facilities. Ventilation and thermal comfort makes the housing livable. Consideration of future expansion and adapt to changes over time will make the housing sustain for more duration, which in turn address the sustainability with efficient use of resources.

Chettinad architecture is one such example, where many of the aspects are addressed. The model is climate responsive as well as sustainable. The central courtyards push hot air upwards and draw cool air through their corridors around the central court yard. Cross ventilation is ample and outer walls absorb the day heat. Lime plaster is eco-friendly with a mix of lime, egg white and palm jiggery, which help to regulate the humidity and temperature indoors. Floor tiles made out of stabilised cement without sintering, keep the floor cool. These houses are constructed based on the resources available and later they are expanded, as and when resources are available. The rain water harvesting, implemented in individual houses, connects to the local tanks. This model could be expanded to high rise building, enabling huge communities to be housed.

2.3 The Global Housing Crisis: Scale and Institutional Response

According to UN-Habitat's Annual Report 2024, there are about 1.1 billion people living in informal housing and much more lack safe water, sanitation and living spaces suitable in climate-change scenario. UN-Habitat addresses this deficit through its 2020-2025 Strategic Plan, which spans inequality reduction, prosperity, climate action, and crisis resilience. Driven

by high-level milestones such as the Pact for the Future, the Cairo Call to Action at WUF12, and the inaugural Open-ended Intergovernmental Expert Working Group on Adequate Housing for All, global initiatives have expanded secure tenure, basic utility access, and displaced-population support. Taken together, these interventions show that genuine housing adequacy requires structural safety, tenure security, essential services, and climate adaptation to be pursued as one agenda - a blueprint India can use to strengthen the resilience, affordability, and quality of its own housing programmes.

2.4 Housing in India: Context and Challenges

2.4.1 Affordability and supply mismatch

In India, there is an increase in mismatch between income, overall housing cost, which includes land cost, construction costs. In metropolitan cities, the affordability to housing has weakened due to land economics, pushing the lower-income groups to move towards unoccupied and unsold spaces. There is a huge thrust for an affordable, accessible and maintainable housing.

2.4.2 Land, location, and tenure

Land is the largest component of urban housing cost. Fragmented titles, litigation, acquisition delays, weak land records, and restrictive floor-space provisions constrain the supply of well-located affordable housing. Housing sited far from employment centres shifts cost from the developer to the household through travel time, transport expenditure, and lost work opportunities; inclusive housing should therefore be integrated

with mass transit, employment zones, and trunk infrastructure.

2.4.3 Infrastructure and service deficits

Housing adequacy requires water supply, sanitation, drainage, solid-waste management, power, transport, digital connectivity, health facilities, and schools in addition to the building. The absence of such facilities causes poor occupancy and asset deterioration. In climate-vulnerable urban areas, inadequate stormwater networks, encroached drainage paths, and low finished-floor levels can turn otherwise functional housing into flood-prone settlements.

2.4.4 Safety, durability, and maintenance

Many low-income households occupy structures built incrementally with limited technical supervision, where risks related to unregulated construction, where a local defect can become a life-safety concern. The Ministry of Housing and Urban Affairs' Model Building Bye-Laws define an unsafe building as one that is structurally unsafe, insanitary, deficient in means of escape, a fire hazard, or otherwise dangerous to life, health, or public welfare, a definition that should guide all housing interventions, including new construction, redevelopment, and retrofitting under PMAY-U 2.0 and State schemes.

For national and State housing programmes, the practical implication is that PMAY-U 2.0, State housing boards, and disaster-rehabilitation agencies do not need to import all resilient and low-cost construction technology. Several field-ready systems for walls, roofing, water storage, and sanitation already exist within India's own

public research system and are available for technology transfer, licensing, or joint-venture deployment.

3. Engineering Principles for Resilient, Inclusive Housing

Inclusive housing must be grounded in engineering performance. The following principles should be treated as mandatory design requirements for housing infrastructure.

3.1 Hazard-informed site selection

Resilience is largely determined before construction begins. Site selection should draw on integrated hazard mapping covering seismic zone and expected ground motion, flood hazard and drainage paths, cyclone and wind exposure in coastal regions, landslide susceptibility, liquefaction potential, soil bearing capacity, heat-island exposure, and coastal corrosion environment. Every large affordable-housing project should be supported by an engineering site-suitability report combining geotechnical investigation, hydrological assessment, hazard maps, and access to infrastructure, employment, and transport.

3.2 Geotechnical investigation and foundation design

Soil investigation should be proportionate to project scale but mandatory for multi-storey and mass-housing developments, accounting for allowable bearing pressure, differential settlement, seasonal groundwater variation, expansive-soil behaviour, flood-induced scour, liquefaction susceptibility, and foundation durability in aggressive soils. In flood-prone or coastal locations, raised plinths,

appropriately designed pile or raft foundations, protective coatings, adequate concrete cover, low-permeability concrete, and well-designed site drainage are essential.

3.3 Hazard - Resilient and Life-Safety Design

Affordable housing must treat multi-hazard resistance and occupant protection as integrated, non-negotiable engineering requirement. Under the provisions of the relevant national standards and recent MoHUA safety mandates, seismic resilience demands regular, compact configurations that avoid soft storeys and discontinuous load paths, supported by ductile detailing, plinth/lintel/roof bands with vertical ties in masonry, robust infill controls, positive anchorage of rooftop equipment, and the deployment of confined masonry or RC shear-wall systems for low-to medium-rise developments. With reference to flood resilience, taking flood levels at the design stage and find solutions such as critical assets located in elevated level, permeable pavements etc. Finally, comprehensive life safety

requires multi-storey complexes to implement the Model Building Bye-Laws through auditable checklists covering compliant staircase egress widths, safe travel distances, fire-resistant construction, fire-rated utility shafts, active detection and alarm systems, dedicated emergency pumping reserves, unobstructed fire-tender access paths, and regulated refuse containment.

3.4 Thermal comfort and heat resilience

Passive design strategies reduce energy consumption and operating costs over the building's life cycle and should therefore be regarded as an integral component of affordable housing, rather than an optional design feature. Various passive heating and cooling strategies for houses are summarised in Fig. 2. In cold regions, passive heating uses the sun's energy and the building's thermal mass to maintain comfortable indoor temperatures during cold periods. Strategies such as south-facing windows, Trombe walls, thermal mass, appropriate insulation and controlled solar gain help capture, store and retain heat, thereby re-

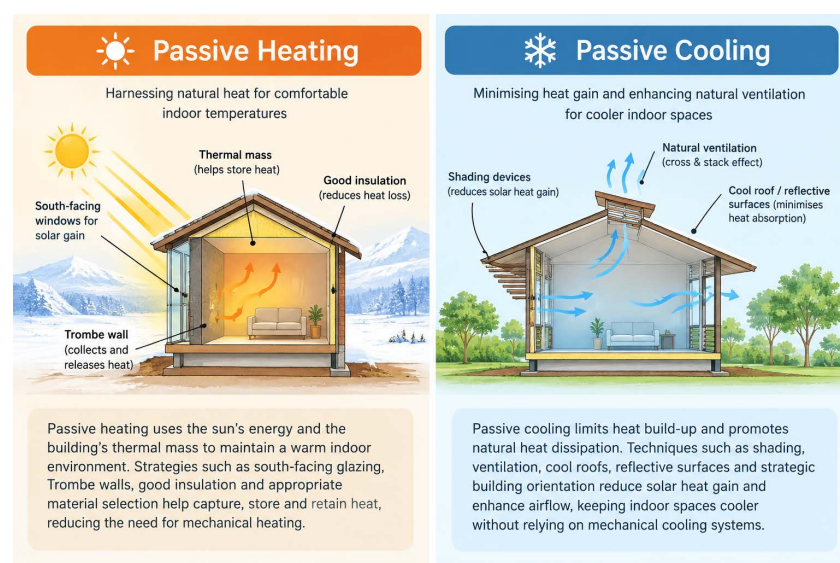


Fig. 2: Passive heating and passive cooling strategies for thermal comfort

ducing dependence on mechanical heating. In hot regions, passive cooling limits indoor heat gain and promotes natural heat dissipation, maintaining comfortable temperatures without mechanical cooling. Measures such as external shading, natural cross and stack ventilation, reflective roofs, thermal mass and appropriate building orientation help limit solar heat gain and promote airflow, reducing indoor overheating and cooling energy demand. Thermal comfort should be treated as an affordability issue, since household energy expenditure rises sharply in poorly designed buildings.

3.5 Construction Technologies for Scale, Speed, and Quality

Mass housing needs construction systems that reduce waste, increase speed, and enable repeatable quality control. Industrialised options include precast walls, slabs, staircases and façade elements, Gauge Steel Frame (LGSF) systems; factory-made modular room units, pre-engineered roofing, and insulated wall and roof assemblies. Technology selection should be guided by a holistic assessment of structural performance, cost, local material availability and supply chains,

workforce skills, thermal and fire performance, ease of repair and maintenance, logistical feasibility, and environmental impact. 3D concrete printing (Fig. 3) has emerging potential for the rapid production of specific components or small units, and Government interest in demonstration projects signals a pathway for innovation. Wide adoption, however, requires rigorous validation of material rheology and interlayer bonding, reinforcement integration, long-term durability, fire performance, and seismic performance assessment. It should therefore be deployed first through performance-based pilots, followed by independent structural validation and codification. The lowest first-cost option is rarely the most economical over the building's life cycle. Durability-oriented choices include low-permeability concrete with adequate cover in coastal areas, supplementary cementitious materials and low-carbon binders, approved recycled materials, and moisture-resistant detailing in wet areas.

4. Zero-Carbon Buildings: A Life-Cycle Pathway to Low-Carbon Housing

Affordability and resilience cannot be pursued in isolation

from carbon performance. The Paris Agreement's goal of limiting global warming to well below 2°C, and preferably 1.5°C, requires global net-zero emissions by 2050, yet the construction sector accounted for 36% of global final energy use and 39% of energy- and process-related carbon emissions in 2018, making it one of the largest contributors to climate change. A zero-carbon approach to housing is therefore not a separate agenda from affordable and inclusive housing. It is what makes affordability durable, since low-carbon buildings are typically also low-energy, low-maintenance buildings.

A zero-carbon building is defined through a net carbon balance of zero or better over its life cycle, expressed as embodied carbon plus operational carbon, minus avoided emissions and carbon offsets. Embodied carbon is quantified through a whole-building Life Cycle Assessment (LCA) using internationally recognised methods as shown in Fig. 4. The governing standards are ISO 14040 and ISO 14044 for LCA principles, and EN 15804, EN 15978, ISO 21929-1, and ISO 21931-1 for construction-specific assessment. The scope is typically cradle-to-grave, covering material extraction, manufacture,



Fig. 3: 3D printed buildings (a) IIT-Madras (b) CSIR-SERC

transport, construction, use, and end-of-life.

4.1 Embodied carbon: the case for low-carbon materials

Embodied carbon covers emissions from extracting, manufacturing, transporting, constructing, maintaining, replacing, and disposing of building materials. Conventional materials such as cement, steel, aluminium, and fired-clay bricks carry high embodied carbon because of energy-intensive production. Cement alone accounts for roughly 7-8% of global CO₂ emissions, chiefly from limestone calcination and kiln fuel combustion. Materials such as timber, bamboo, recycled aggregates, and fly-ash- or industrial-by-product-based products typically carry much lower embodied carbon, reduce demand for virgin resources, and support circular-economy principles. International standards such as the Canada Green Building Council's Zero Carbon Building - Design Standard (v4, 2024) set embodied-carbon-intensity limits of 425 kg CO₂e per square metre of built floor area for most buildings, the kind of quantitative bench-

mark that Indian mass-housing programmes could usefully adapt.

Translating this zero-carbon roadmap into cost-effective delivery requires indigenous engineering solutions. CSIR-Structural Engineering Research Centre (CSIR-SERC), Chennai, has developed, patented, and field-transferred an integrated portfolio of technologies that simultaneously target embodied carbon abatement, thermal efficiency, structural resilience, and basic service infrastructure. Field demonstration buildings show that combining these low-carbon, recycled-aggregate products **reduced embodied carbon by 32%** compared with conventional construction. Table 1 consolidates these indigenous systems, setting out their engineering attributes and their contributions to carbon reduction, affordability, and inclusive housing delivery. Selected field demonstrations of technologies are shown in Fig. 5.

4.2 Operational carbon and thermal-demand reduction

Operational carbon covers direct emissions from fuel combus-

tion and refrigerant leakage within a building, and indirect emissions from purchased energy used over its service life. Reducing thermal demand, and hence cooling and heating energy, is the most effective lever for reducing operational carbon in Indian housing, where cooling load dominates energy use in most climate zones. Lightweight insulated panels and thermally efficient blocks, combined with passive design, reduce this demand at source, while rooftop solar generation offsets part of the residual load.

4.3 Avoided emissions, carbon offsets, and the pathway forward

Avoided emissions arise chiefly from exporting surplus renewable electricity to the grid, crediting the displaced emissions provided renewable-energy certificates are retained. Carbon offsets compensate for residual, unavoidable emissions - particularly embodied carbon and refrigerant leakage through verified reductions elsewhere, and should demonstrate additionality, permanence, and minimal leakage to be credible. Taken together, these elements

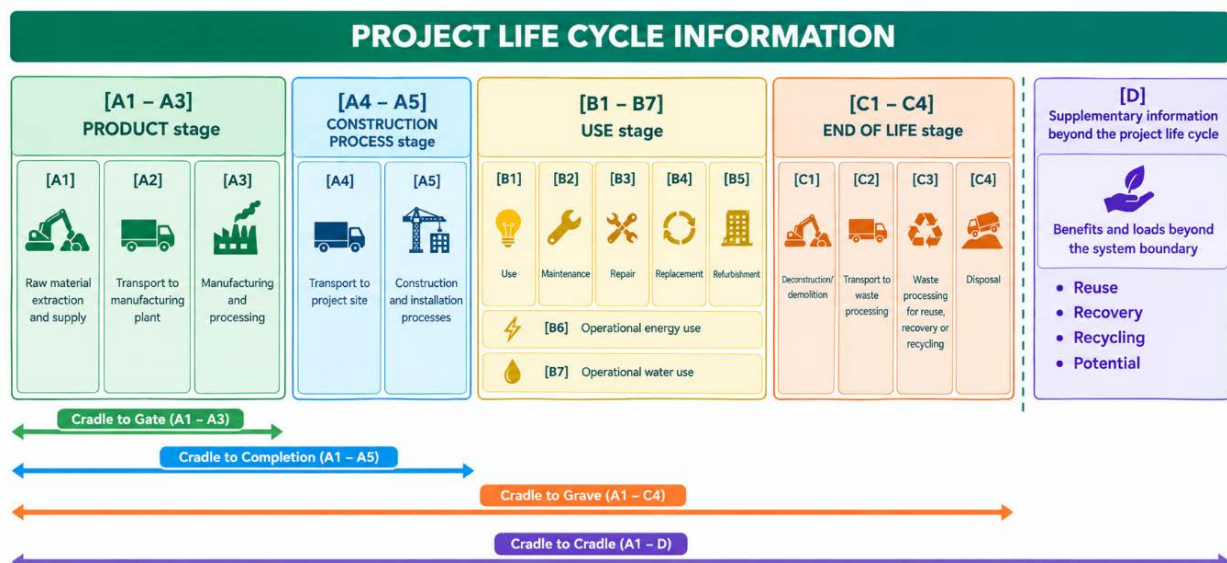


Fig. 4: Models used for life cycle assessment of buildings

Table 1: Indigenous systems supporting decarbonisation and inclusive housing

Indigenous Technology / Material System	Technical & Structural Attributes	Contribution to Decarbonisation and Inclusive Housing
SECROBuIT (Steel-EPS Concrete Re-Organised Building Technology)	Patented precast composite wall-panel system; approximately 40% lighter than conventional masonry with high sound and thermal insulation.	Lowers thermal demand and enables rapid, factory-controlled, low-cost wall construction using trained semi-skilled labour without heavy cranes
Precast Lightweight Large (PLWL) EPS Sandwich Panels	Self-compacting concrete skins over an expanded polystyrene core; lab-tested for flexural, axial, and seismic loads up to Seismic Zone V (G+3).	Roughly two-thirds lighter than standard concrete; provides low thermal conductivity, making it ideal for rapid post-disaster shelters and extreme climates.
Eco-Friendly Recycled-Aggregate Bricks & Hollow Blocks	Engineered masonry incorporating crushed Construction & Demolition (C&D) waste aggregate to replace virgin stone and sand.	Diverts solid C&D waste from landfills, conserves natural mineral deposits, and reduces upfront embodied carbon in walling systems.
Eco-Friendly Geopolymer Concrete Blocks & Pavers	100% cement-free binder synthesised from industrial by-products (fly ash and slag); cured at ambient temperature.	Eliminates clinker-related process emissions and thermal kiln fuels; avoids water curing while meeting standard IS strength requirements.
Ambient-Cured One-Part Geopolymer Binder	Dry-mix, low-carbon geopolymer binder requiring only the addition of water on-site, functioning under ambient temperature.	Simplifies field handling of alkali-activated binders, providing a direct, scalable alternative to ordinary Portland cement.
Fly-Ash & LC3 Mixtures for Concrete 3D Printing	Rheologically tailored mortars incorporating fly ash and Limestone Calcined Clay Cement (LC3) for additive deposition.	Enables automated, formwork-free construction with low material waste while reducing clinker content to about 50%.
Recycled-Aggregate Pavers & Rice-Husk-Ash Interlocking Blocks	Paving elements manufactured by blending agricultural waste (rice-husk ash) with recycled concrete aggregates.	Converts agro-industrial waste into durable, permeable site infrastructure, lowering pavement embodied carbon and facilitating stormwater drainage.
Textile Reinforced Concrete Prototyping Technology (TRCPT)	Non-corrosive, thin-section precast elements reinforced with high-strength technical textiles produced without complex metal moulds.	Delivers lightweight, durable roofing sheets, façade panels, and sunshades; well suited to decentralised on-site micro-factories.
Rooftop-Solar-Integrated Demonstration Housing	Modular dwelling prototype coupling precast lightweight envelopes with a structurally integrated rooftop photovoltaic (PV) array.	Decreases operational carbon via renewable self-generation; allows low-income occupants to offset ongoing utility costs.
Cost-Effective Ferrocement Water Tanks	Thin-walled (~25 mm), durable water storage units fabricated from flowable mortar; erectable by two persons in roughly 30 minutes.	Resolves the “availability of services” requirement by providing affordable, long-lasting, decentralised drinking-water infrastructure without skilled masons.
Precast Segmental - Panel Toilet Units	Thin precast concrete wall panels, slabs, and integrated septic components assembled in ~3 hours without lifting equipment.	Delivers rapid, hygienic, structurally sound decentralised sanitation infrastructure for peri-urban areas, informal settlements, and rehabilitation sites.
Head-T Threaded Rebar Anchors	Mechanical end-anchor hardware mitigating joint rebar congestion	Improved constructability also reduces rework, material wastage, and associated embodied carbon.



Fig. 5: (a) Demonstration building constructed with low-carbon materials (b) Climate-resilient demonstration building (c) Sustainable precast SECROBuIT house with rooftop solar

define an achievable pathway to zero-carbon housing that follows a consistent sequence: integrated design from the earliest stage; prioritising all-electric systems to limit on-site combustion; minimising thermal-energy demand and embodied carbon through passive design and low-carbon materials; improving energy efficiency; deploying renewable generation and storage; and finally addressing any residual emissions through verified carbon offsets. For Indian affordable housing, this sequence reinforces the resilience and quality-assurance agenda as shown in Fig. 6.

5. AI and Non-Destructive Evaluation for Quality Assurance

The principal concern in mass-housing delivery is often not the absence of standards but the inability to verify compliance across

thousands of units and dispersed sites. Artificial Intelligence (AI) and non-destructive evaluation (NDE) can together create a digital quality-assurance ecosystem that equips engineers, ULBs, and residents with evidence-based, traceable, and timely information without displacing the judgement of an engineer. NDE should thus function as a decision-support system.

5.1 AI-enabled defect detection and digital records

AI can assist quality assurance through computer-vision detection and geotagging of cracks and spalling; machine-learning defect-risk prediction combining materials records, workmanship indicators, curing data, and NDE outputs; automated inspection of factory-made components;

Table 2: NDE methods across the project life cycle

Method	Primary application
Rebound hammer / Ultrasonic Pulse Velocity (UPV)	Surface hardness, comparative concrete uniformity, and relative internal integrity
Impact-echo / ultrasonic pulse-echo	Detection of voids, delamination, honeycombing, and thickness anomalies
Cover meter; half-cell potential; resistivity	Reinforcement location and cover; corrosion-probability screening and durability assessment
Infrared thermography; ground-penetrating radar	Moisture ingress, delamination, façade anomalies; rebar mapping and embedded features
Drone-based imaging; targeted coring	Façade, roof, and inaccessible-area inspection; calibration where NDE evidence is inconclusive

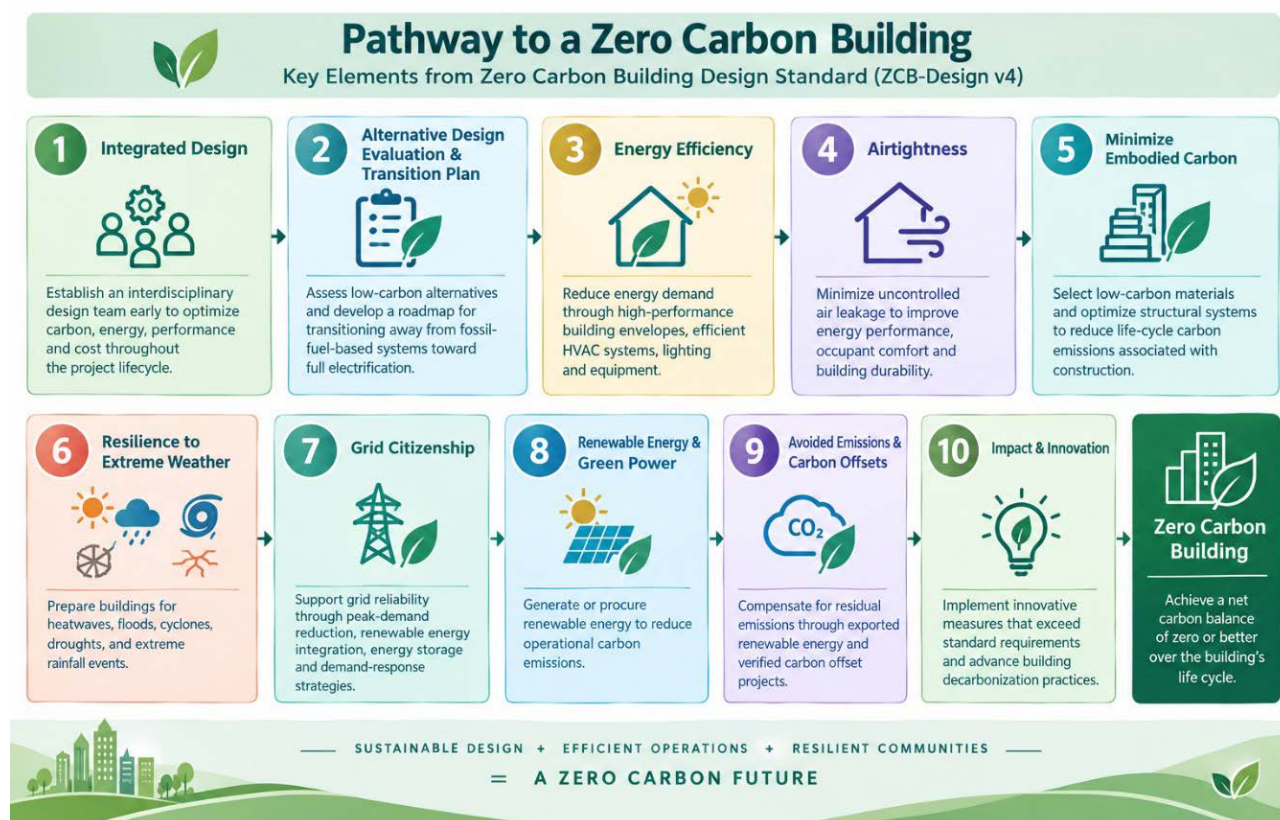


Fig. 6: Pathway to a zero-carbon building

automated review of inspection checklists and test certificates; and predictive-maintenance risk ranking of buildings for inspection. A Building Information Model (BIM) should serve as the digital record of each major project, integrating drawings, material and test records, NDE results, geo-tagged progress, and inspection history; at the operational stage this can evolve into a digital twin supporting asset management. AI output must remain advisory: a qualified engineer retains authority for acceptance, rejection, and safety certification, and every AI-QA system should provide explainable outputs, audit trails, independent validation on field datasets, periodic recalibration for regional materials, and clear liability allocation among providers, consultants, and approving agencies.

6. Phased Implementation Roadmap

Phase	Key actions and outputs
Phase I - Standards, pilots, baseline data	Select 3–5 pilot cities including at least one coastal metropolitan city; publish a standard digital QA protocol and model tender clauses for AI, NDE, BIM, and third-party inspection; establish hazard-screening and NDE test matrices; empanel NDE and structural-audit agencies; pilot indigenous technologies (e.g., CSIR-SERC panel, block, and sanitation systems); train ULB teams; establish baseline cost, defect, and occupancy indicators.
Phase II - Digital integration and scale-up	Integrate QA dashboards with ULB e-permitting and PMAY-U 2.0 monitoring; require geo-tagged inspection and digital test reports; link payment milestones to verified QA; deploy AI-assisted defect screening and BIM-based asset records; conduct post-occupancy evaluations; introduce contractor quality-performance ratings and procurement incentives.

Phase	Key actions and outputs
Phase III - Institutionalisation and asset management	Establish city-level Structural Safety/Audit Cells; conduct random NDE audits of completed projects; implement periodic structural, fire, and service audits; build a city-level inventory of vulnerable housing; apply AI-supported risk ranking to prioritise retrofits; integrate maintenance planning with resident associations and ULB asset-management systems.

7. Futuristic and Climate-Resilient Housing: The Way Forward

Future housing should be resilient, connected, low-carbon, adaptable, and supportive of community life, with technology deployed to improve reliability and reduce household expenditure rather than add recurring costs or complexity. Smart meters, leak-detection sensors, efficient appliances, indoor air-quality monitoring, solar- and battery-ready infrastructure, and digital maintenance platforms can strengthen household performance, while net-zero-oriented design can integrate passive planning, minimised thermal demand, energy efficiency, all-electric systems, renewable generation and storage, and reduced embodied carbon. These principles can be supported through solar-ready roofs, rainwater harvesting and reuse, recycled and low-carbon materials, including appropriate technologies developed at CSIR-SERC and other organisations, and prefabrication-driven waste reduction. Housing should also be designed for adaptation, enabling safe expansion, rental accommodation, home-based work, and multi-generational living through planned extension zones, and retrofit provisions for accessibility

and ageing. Beyond the dwelling itself, integration with health and education facilities, local retail, safe pedestrian and public-transit connectivity, and green, shaded community spaces can transform housing into a productive and inclusive neighbourhood.

Adequate and inclusive housing for all is therefore not only a welfare objective but a national and global engineering, planning, and governance imperative. The goal is to move from a housing-production model towards a housing-performance model in which homes remain safe, affordable, durable, connected, resilient, and functional throughout their service life. India can advance this transition through five integrated commitments: hazard-resilient planning and design from site selection onwards; quality and durability through appropriate technologies, including indigenous solutions, qualified supervision, and life-cycle costing; digital performance verification through AI-enabled NDE, BIM-based records, and auditable quality data; integration of housing with transport, employment, services, and community infrastructure; and long-term asset management through maintenance, safety audits, and retrofit strategies. With mechanisms such as monitoring, geo-tagging, and coordinated implementation already supported under PMAY-U 2.0, these capabilities can be embedded into housing delivery at scale, enabling India to create affordable homes that are safe, sustainable, climate-responsive, resource-efficient, inclusive, and future-ready, while offering a globally relevant model for high-performance housing and resilient communities.

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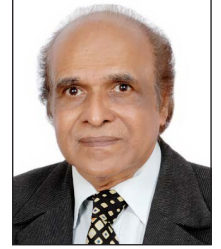
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- Deloitte India, India's Future Homes to Blend Smart Living and Sustainable Materials, 2025.



World Habitat Day is held on the first Monday of October each year. The day centers around the global observance, which is held in a different country each year with keynote speakers and roundtable discussions focused on a specific theme. World Habitat Day was first celebrated in 1986 in Nairobi, Kenya, with the theme 'Shelter is my right'.

On 5 October 2026, the Global Observance of World Habitat Day, under the theme **Adequate Housing for All**, will focus on the global housing crisis whereby an estimated 2.8 billion people face various forms of housing inadequacy, in which close to 1.1 billion reside in slums and informal settlements, calls for urgent and concerted action.

Master Plan for Delhi-2047: Making It Work



A.K. Jain *

"It must be everyone's dream to design a new city. It is the luck of chosen few to be able to do so. To translate dreams of buildings into concrete realities needs a lot of land, lot of money and a plethora of governmental regulations to overcome. It is more than adding the suburb to an existing city. A suburb is an appendage with no personality of its own, a city without distinct personality, is a name without a face."

Khushwant Singh

With Malice Towards One and All, Hindustan Times, 12th August 1989

"Delhi and nearby areas are facing a public health emergency due to severe air pollution. Delhi is choking every year, and we cannot do anything. People are dying and it can't happen in a civilised country".

Supreme Court of India Order (November 4th 2019)

The Master Plan for Delhi 2047 (MPD-2047) has been notified by the Ministry of Housing and Urban Affairs in the Gazette of India on 20th August 2026. The MPD 2047 seeks to align Delhi's development (covering an area of 1483 sq.km) with the agenda of Viksit Bharat, whereby India by 2047 would be a developed economy of about 30 to 40 trillion. From the historic fabric of Shahjahanabad to the planned geometries of Lutyens' Delhi, and further into the post-independence growth, Delhi exists in between past and future, heritage and expansion, ecology and infrastructure, informality and governance. Its planning

and development juxtapose the phenomenon and positionality of Delhi's rich historiography, cultural heritage and ecology. Delhi as a living, breathing megacity engages with its past, present and future (Fig. 1).

In 2047, Delhi's population is projected to increase from the current 22.2 million to about 32 million. This means that during next 20 years, Delhi needs to build about 4 million housing units and double infrastructure services. Building in the greenfields and retrofitting the brownfields would be like building an entire Delhi once again. This can be an opportunity to change the ways of planning and building which are more resilient

and sustainable.

The MPD 2047 aims to address the critical issues, such as air quality, saving of the Aravalli ranges, rejuvenation of river Yamuna, water conservation and management, urban drainage, traffic, climate change and heat mitigation, disaster resilience, informal settlement and housing, renewable energy and gender balance and equity. It also seeks to integrate the ecology, built environment, service network, transport and heritage, based on sustainable, resilient and circular economy. The Master Plan for Delhi 2047 recognises the mandate of the NCR Plan covering 55,083 sq.km and the planning of the NCT

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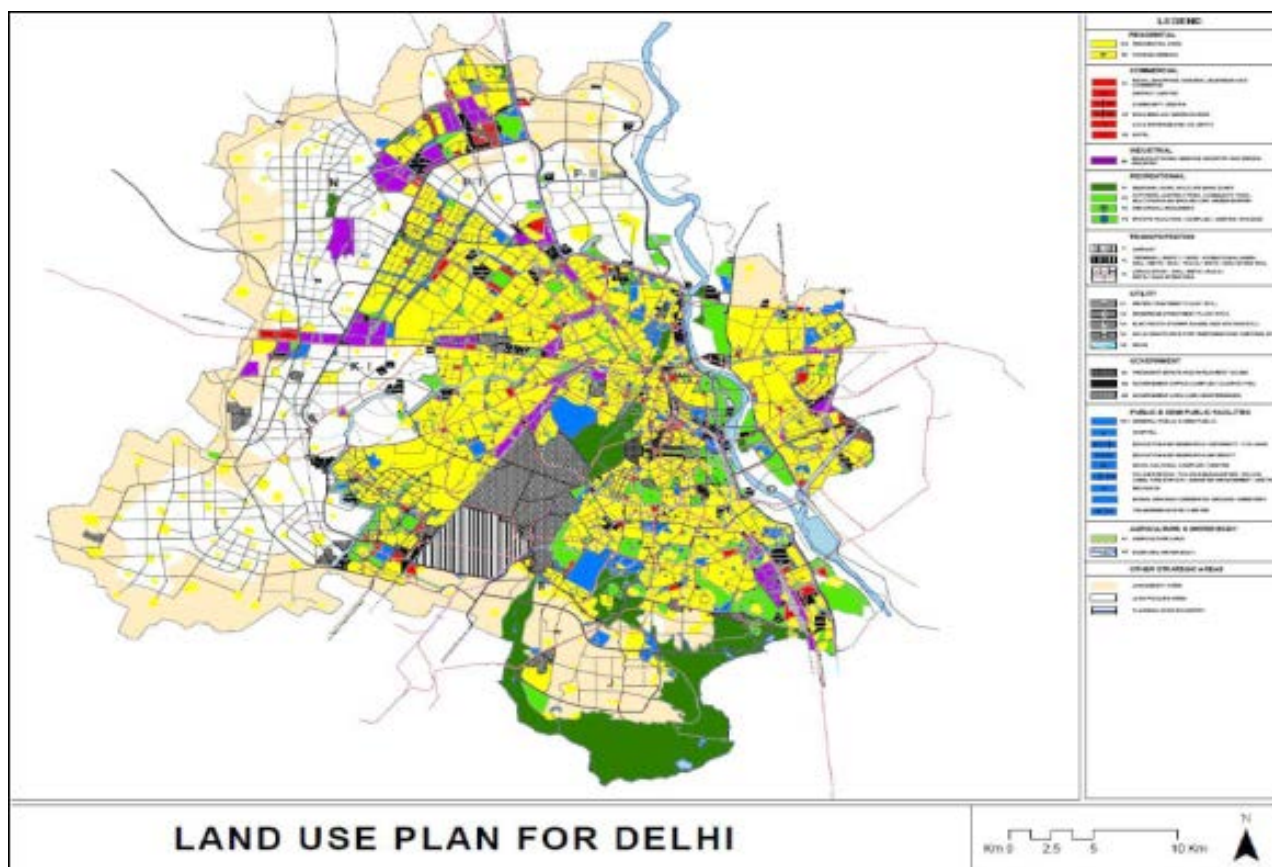


Fig. 1 Land Use Plan - Master Plan for Delhi - 2047
Source: DDA

Delhi in the context of the Central National Capital Region (CNCR) covering an area of about 4000 sq. km.

Delhi has a three tier of governance structure—Central, State and Local, comprising the Delhi Development Authority, Government of Delhi (GNCTD), and the urban local bodies (ULBs) viz. Delhi Municipal Corporation, New Delhi Municipal Council and Cantonment Board.

The Union Budget 2026-27 has projected the concept of City Regions treating clusters of cities as a single, networked economic unit with clear ownership, dedicated funding streams, and a planning authority. This can be a turning point in redefining urban planning and development. As such, it is time to plan Delhi

contiguous to surrounding areas of Ghaziabad, Loni, Noida, Gurgaon-Manesar, Faridabad, Ballabgarh, Bahadurgarh and Sonapat-Kundli. This needs reworking the legislation to enable restructuring of the ULBs/Development Authorities in Delhi Metropolitan Area/Central NCR.

Adoption of the concept of Circular Economy means that the development is restorative, regenerative and minimises wastes (fig. 2). A low carbon lifestyle embedded in social behaviour can drastically minimize the use of natural resources and emission of wastes and pollution. Under the LiFE or Lifestyle for the Environment Mission, it is necessary to adopt a behaviour of caring, sharing, recycling, reuse, repairing and retrofitting. As 70% of carbon dioxide emissions are from urban

transport, buildings and energy, there is no option but to resort to circular economy.

In the book 'Age of the City' (2023), Professor Ian Goldin and Tom Lee Devlin, recommends that for creating resilient cities,

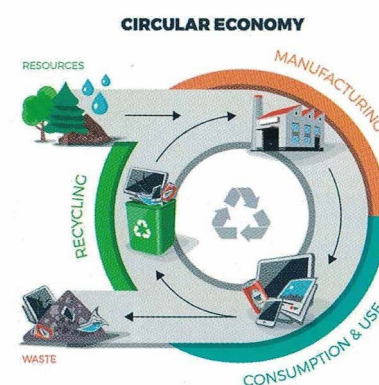


Fig. 2: Circular Economy is Restorative, Regenerative and Minimises Wastes
Source: Khan, Khalil Uttah (2022)
Wastewater Reuse, Linear Economy to Circular Economy, Shashwat, TERI, New Delhi

abandon the car-based sprawl, which is a colossal waste of resources and also a social and environmental failure. Cars pollute the air, generate heat, take up too much space, and 95% of time remain in parking spaces. Instead plan and provide mass transit, bicycle and walking. Embrace the 15 minutes city, the way Paris has done, improving and emphasising its walkability quotient. Carlos Moreno in his book '15-Minute City: A Solution for Saving Our Time and Our Planet' (2024) stresses on improving the quality of life by reducing long commutes. It suggests adopting bio-morphic urbanism and ecosystems that are rooted to a place rather than being superficial. Plants, trees may be a good start, if they belong to the place. Protecting green spaces and water bodies can be like the difference between life and death in a climate crisis scenario, where cities are becoming heat traps of concrete, steel and glass. Urban planning, zoning laws and building codes can mandate the coexistence of nature through green roofs, permeable pavements, renewable energy, traditional materials and ventilation. A valuable lesson from Smart Cities Mission is not to put technology at the centre, but people, infrastructure, jobs, greenery and mobility.

This means redefining the urban planning process and supplementing the Master Plan by a series of Strategic and Action Plans with a focus on participatory local planning and collective vision. These Plans focus on improving the quality of living, working and infrastructure services by balancing the four Es: i.e. economy, engagement, equality and

environment. This need rewriting the script of urban planning by data driven analytics and paradigms, like the Geo-spatial AI, GIS, Digital Twins, Blockchain and Whole of Government Platform.

As such, the Master Plan needs to comprise interlinked layers of the following plans:

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

The breakthrough in digital technology and informatics has multiplied space, energy and time. New forms of energy, services, construction and recycling are characterized by online exchange of information, interactions, dynamic networks and floating nodes. Integration of land use, utilities, infrastructure services, transport

and building on a geospatial and AI network helps optimize space efficiency and configurations. Intelligent strategies have set in motion innovation, sustainability and citizen participation. The design, planning and construction processes need to be compatible with the circular economy by adoption of new technologies, such as digital blockchain, digital twins, combinatorial and discrete optimisation, algorithms, complexity theory, artificial intelligence, big data, and ubiquitous cloud.

A climate-sensitive design approach (CSDA) recognizes that the design of a built-up area directly influences the climatic comfort in an urban environment. Green urban planning combines climate sensitive solutions and adaptation strategies in the context of the SDGs, national and local policies. The Asian Development Bank in its report 'Green Urban Planning' (2022) depicts the tools of adopting a scientific approach towards green and integrated urban planning (Fig. 3).

For a scientific analysis of carbon emissions and impact on climate change, a climate compass can be developed for the urban processes- ecology, resources, health and wellbeing and place making. It predicts the impact of various urban projects on the environment and climate. By using sustainability project compass, the cities, buildings and infrastructure services can be designed for better sustainability (Fig. 4). This implies integration of circular, green concepts within smart, ICT based planning, architecture and technology. The critical aspects of Ecology, Water, Energy, Finances,



Fig. 3: Green Urban Planning - an Integrated Approach

Source: ADB/Egis, 2021 Green Urban Planning Consultant's Report, Asian Development Bank, Manila.

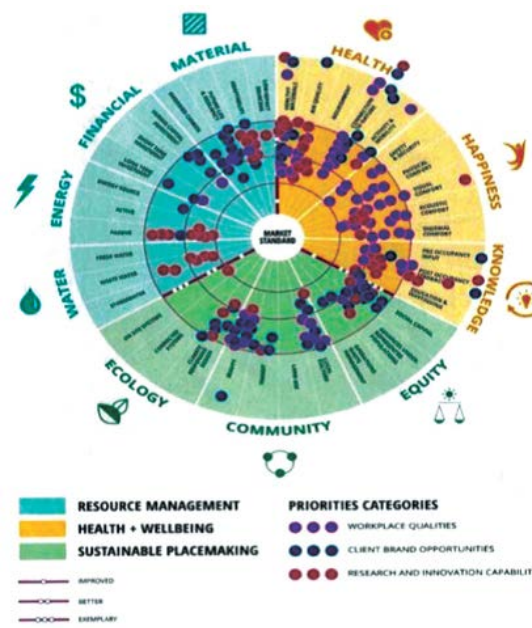


Fig. 4: Sustainable Project Compass Developed by SERA, Architects Converges Health, Happiness, Knowledge, Equity, Community, Ecology, Water, Energy, Financial and Material aspects of Design of Built Environment (Portland, Oregon).

Source: Kathrine Logan (2022) *The Conversation*, Architectural Record, April.

materials, Health. Happiness, Knowledge, Equity and Community are plotted and evaluated with respect to Resource Management, Health Well Being and Sustainable Place Making. It highlights the priority areas of interventions in planning, design and construction.

The cornerstone of making a

circular, sustainable Delhi City-Region is to adopt an integrated approach towards the river Yamuna, canals, drains and ridge, built environment and the conservation of the heritage and natural resources (Fig. 5). Carbon neutral buildings, renewable energy and transport infrastructure

need to minimise the use of fossil fuels by lifecycle approach. Renewables, trigeneration energy systems, sponge parks, roads and pavements that absorb rainwater, dual piping for recycled wastewater, water saving toilets and taps, and satellite controlled micro-irrigation cut water and power consumption. These are the foundation of infrastructure services. Passive climate design rooftop solar panels and district cooling can generate electricity together with rooftop vegetation, ventilation, insulation and super-insulated glazing.

Strategy of 5 Rs of waste management comprises, three bin recycling with separate bins for trash, recyclables and compost. Various options, such as enzyme based STP, bio-remedial treatment, sludge gas/energy recovery, vermi-culture, fossilization and composting can be workout for waste management.

Circular water management is based on the principles of Decentralised Wastewater Treatment Systems (DEWATS), bioswales, rainwater harvesting, wastewater recycling, zero run-off drainage and revival of water bodies (Fig. 6).

The river Yamuna in Delhi (Zone O and Zone P II) flows in a length of 48 km. It is flanked by Hindon River in the East, and Sahibi River (Najafgarh drain) in the West. The Yamuna is connected by a 350 km long network of natural streams, and canals. Flowing in a length of 45 km, the Wazirabad Drain originates from Aravali Hills in Rajasthan as Sahibi River in Delhi has becomes a dirty drain. Barapulla/Kushak Nallah is another rivulet that has become a polluted

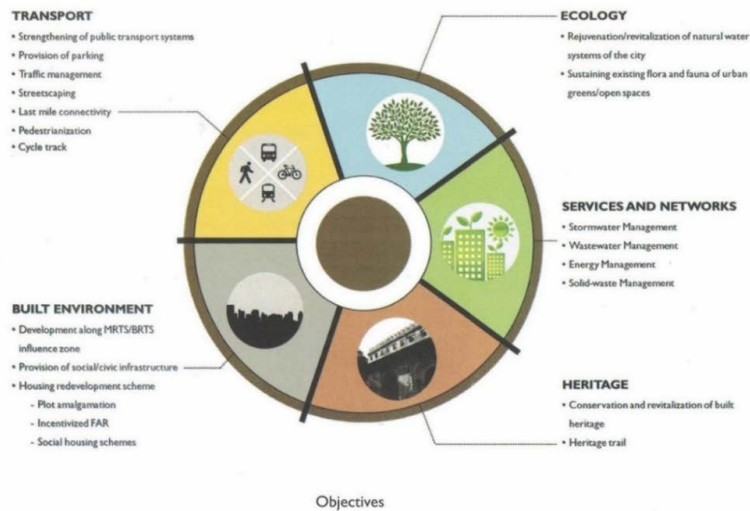


Fig. 5: Integrating Ecology, Service Networks, Transport, Built Environment and Heritage for a Climate Resilient, Green Habitat
Source: DUAC/Amit Ghoshal (2015) Punjabi Bagh Project, DUAC, New Delhi

drain. Delhi also has a 100 km long network of canals and 1045 water bodies. However, many of these have vanished or built upon. It is rather surprising that one of the largest water bodies, Najafgarh Lake has not been reflected in the MPD 2047. More than 110 unauthorised colonies have come up in river zone reducing the drainage area by one-third and endangering its water quality.

The river Yamuna, existing water bodies, Sahibi river (Najafgarh drain), Barapulla/Kushak Drain and existing canals need to be conserved and interlinked as green water channels. Some of these can be redesigned as waterways, which can be landscaped and deepened to facilitate boating and increase their water holding capacity. Adoption of 'Sponge City' concept with zero run off can enrich groundwater and modify the micro-climate and reduce the urban heat.

The concept of the swales, porous paving, bio-drainage and zero run off drainage can help to conserve water and save urban

Delhi from floods (Fig. 7). The lakes, water bodies and riverfront can be rejuvenated, paved and landscaped by recycled carbon neutral materials, planting and water recycling strategies (Fig. 8).

Making it Work

To bridge the implementation gap, we can learn from the PM Gati Shakti Master Plan (Figs 9 & 10). It leverages new technologies in planning, breaking the silos of departmentalisation to achieve synergy in project management. It has coordinated with the Indian Space Research organisation (ISRO) for spatial planning, engaging BiSAG

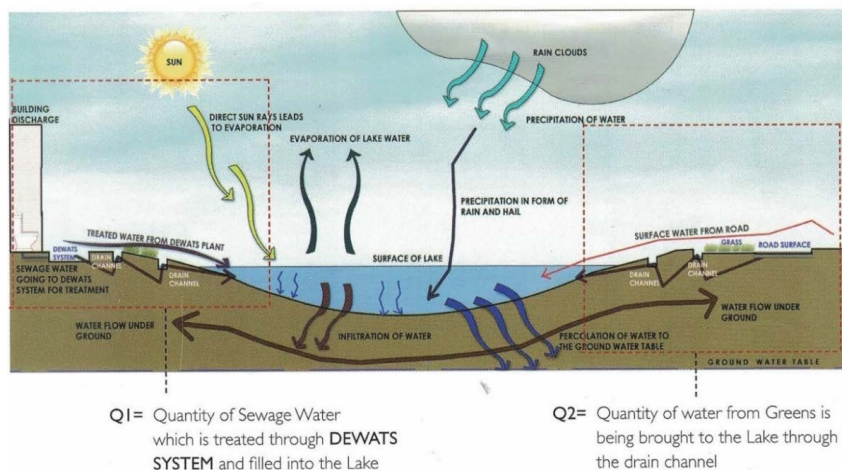


Fig. 6: DEWATS, Stormwater Harvesting and Conservation of Water Bodies for Circular Water Management
Source: DUAC/Rahoul B Singh (2014) Hari Nagar Greens, DUAC, New Delhi

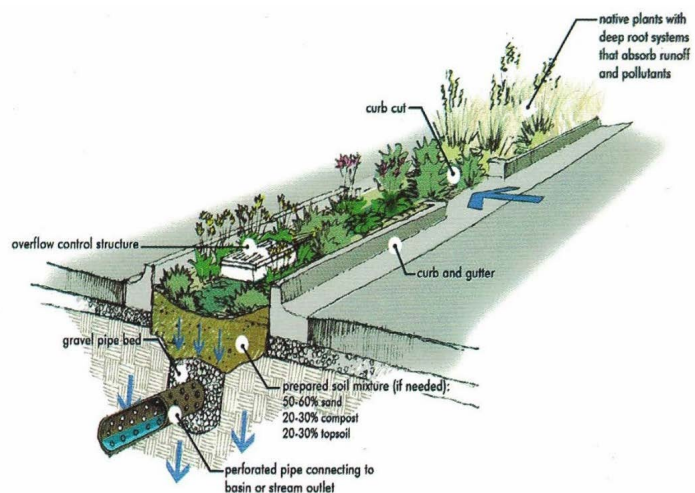


Fig. 7: A Bioswale for Sustainable Urban Drainage and Water Conservation
Source: <http://thewhiteriveralliance.org/eaglecreek/involved/images/bioswale%20enlargement.jpg>

years. The major problems such as traffic jams, water logging and flooding can be addressed using predictive Geo AI models.

For MPD 2047, there is a need to put in place a three-level monitoring, review and coordinating system:

- Monthly Inter-Departmental meetings under VC, DDA
- 3-monthly meetings under LG Delhi with MCD, DDA, NDMC, DMRC, GNCTD, DJB, PWD, Discoms, Delhi Transco, UD Department, DUSIB, SRDC, Traffic Police/DUMTA, UTTIPEC, Delhi Heritage Foundation, ASI, Delhi Biodiversity Foundation, UCRR Yamuna, Delhi Geo Spatial Data Infrastructure, DILRMP, PM UDAY, and other key stakeholders.
- Six monthly meetings under the Union Minister/Secretary (Capital Development) MOHUA for coordination with other ministries/departments, DUAC, NCRPB, NCRTC, NHAI, etc.

Conclusions

With the notification of MPD 2047, Delhi Region stands at an intersection. It can either take the road towards becoming India's foremost ecological, economic, cultural and knowledge urban centre that would reflect country's global image, or a chaotic megacity with pollution, traffic jams, poor housing and infrastructure services. Its future is not to be determined by policy frameworks but by ability to make the Plan work. The emerging shifts such as city, region, digital processes, community participation and adaptive, climate resilient infrastructure demand

sustained monitoring, coordination and review. This is the key for success of the Plan.

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Adequate Housing for All: Can India Build the Future from Its Farms?

Rethinking affordability, agricultural value and bio-based construction for India's next generation of habitats



Gaurav Dixit *

Abstract Adequate housing cannot be reduced to four walls, a roof and the lowest first cost. It must remain healthy, thermally comfortable, durable and valuable over its whole life - for the household, the city, the resource landscape and the generation that inherits it. This article argues that

India can connect its agricultural strength with its construction demand through engineered bio-based materials. Hemp-lime is examined not as a universal replacement, but as one promising envelope system whose adoption should advance through evidence, premium demonstrations, Indian standards, trained execution and

regional supply chains. GoHemp's measured samples and completed projects illustrate both the opportunity and the discipline required.

1. Adequacy Is a Whole-Life Promise

UN-Habitat's theme for World Habitat Day 2026, 'Adequate



Himalayan Hemp Ecostay, Uttarakhand. Photograph: GoHemp.

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Housing for All', arrives at a moment when 2.8 billion people face some form of housing inadequacy. Quantity is urgent, but quantity alone cannot be the measure of success. A house may satisfy a minimum area and still become dangerously hot, acoustically stressful, difficult to maintain or expensive to cool. If it transfers environmental and health costs to other people and future decades, its apparent affordability is incomplete. [1]

I see every house as a cell within a larger living organism. The house becomes part of the mohalla; the mohalla becomes part of the city; the city becomes part of the country and ultimately the planet. Materials extracted in one place, energy consumed in another and waste discarded elsewhere remain connected to that cell. Adequacy therefore has to include comfort, health, dignity, durability, climate response, ease of repair and responsibility beyond the plot boundary.

The cheapest square foot is not necessarily the most affordable square foot. A building's real cost continues through energy, maintenance, health, replacement and the consequences inherited by the next generation.

The cost of a building is not its price

India's architectural heritage offers a useful provocation. Across historic cities and villages, we find carved stone and timber, shaded courtyards, jalis, verandahs, stepwells and buildings carefully fitted to climate and local material. Craft and beauty were not confined to the richest patrons. Ordinary settlements also invested in

durable, meaningful surroundings.

The lesson is not to copy a historical style. It is to recover the thinking behind it: resources were understood as relationships, not isolated commodities. Even a simple practice such as washing beside a tree allowed used water to nourish its roots. At the scale of architecture, the same worldview asks whether one system's output can become another system's resource. That is precisely why agriculture and construction should begin speaking to each other again.

2. The Building Begins Before the Construction Site

Architects usually begin with a site. Yet every building begins earlier - in a quarry, a mine, a factory, a forest or a farmer's field. Bio-based construction changes the origin story. A crop absorbs atmospheric carbon while growing; its fractions are processed for several industries; a suitable fraction becomes part of a durable

building assembly. Agriculture gains a higher-value market, rural processing gains purpose and the building becomes a temporary store of biogenic carbon.

A whole-plant material language: graded shives, hemp-lime, insulation and crafted finishes. Photograph: GoHemp.

India combines enormous agricultural capability with enormous construction demand. Few countries possess both at this scale. A regional farm-to-building economy can create value through cultivation, grading, mineral-binder preparation, component manufacturing, design services, installation and repair. It should complement - not romanticise away - conventional structural systems. The objective is the right material in the right function, backed by repeatable quality.

An Indian precedent, carefully stated

A 2016 Current Science study identified Cannabis sativa as an



A whole-plant material language: graded shives, hemp-lime, insulation and crafted finishes. Photograph: GoHemp.

organic additive in sixth-century clay plaster from the Buddhist caves at Ellora using microscopy and spectroscopy. [2] This is important evidence of plant material in a sophisticated Indian plaster tradition. It is not proof that modern engineered hempcrete, with today's formulations and performance definitions, was used 1,500 years ago. The stronger conclusion is also the more credible one: combining biological fibres with mineral and earthen binders is not alien to Indian material culture. Contemporary India can rediscover that principle through modern testing, engineering and standards.

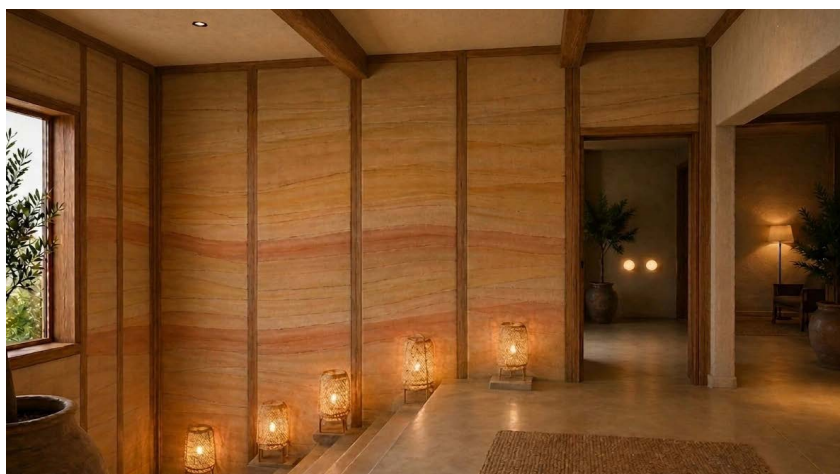
3. Hemp-Lime Is a System, Not a Substitute

Industrial hemp stems can be separated into bast fibre and the woody inner core, commonly called hurd or shiv. When graded shiv is mixed with a predominantly mineral, often lime-based binder and water, the result is a lightweight porous composite commonly called hemp-lime or hempcrete.

Hempcrete is generally non-load-bearing. It works with a structural frame such as reinforced concrete, timber or steel, and is used in infill walls, blocks, prefabricated panels, roof and floor insulation, partitions, plasters and acoustic components. This distinction matters. Claims that a single material will replace the entire conventional building industry are neither technically accurate nor useful to specifiers.

Performance comes from the assembly

Density, shiv grading, binder chemistry, water content, compaction, thickness,



Hempcrete wall installation at Sneha House, Meerut. Photograph: GoHemp.

finishes, moisture exposure and workmanship all influence performance. Vapour-open behaviour can be undermined by impermeable coatings. Thermal resistance can be reduced by bridges and poor junctions. Acoustic values from a laboratory sample cannot be substituted directly for whole-wall field ratings. A successful project therefore depends on coordinated design, material control, detailing, drying, compatible finishes and trained execution.

This systems approach is also where a specialist company adds value. GoHemp's current practice integrates architectural coordination, project-specific material preparation, manufacture,

technical guidance, on-site training and execution support rather than treating hemp-lime as a bagged commodity. That is especially relevant to premium residences, hospitality projects and institutions where design intent and performance must survive the full journey from concept to finished space. [4,7]

4. Evidence Before Adjectives

Bio-based construction earns confidence when claims are tied to identifiable samples, test methods and limitations. GoHemp's technical library publishes the following independent results. They describe the tested specimens - not every hemp-lime mix, wall or climate. [4-6]

Measured property	Reported result	Tested sample and method
Thermal conductivity	0.22 W/mK	50 mm hempcrete; 625 kg/m ³ ; 21.4 C; ISO 22007-2:2022; average of 10 measurements.
Thermal diffusivity	0.7420 mm ² /s	Same 50 mm specimen and test series.
Volumetric heat capacity	0.300 MJ/m ³ K	Same 50 mm specimen and test series.
Average sound transmission loss	57.9 dB	45 mm composite hemp sample; 550 kg/m ³ ; ASTM E2611 impedance-tube test; reported standard deviation 4.4 dB.

Source: Mahindra TERI Centre of Excellence report dated 9 December 2025; Alfa Acoustics report dated 20 December 2025. Results apply only to the submitted specimens and reported conditions.



GoHemp hempcrete blocks are included in the GRIHA Product Catalogue; certificate validity: 28 April 2026 to 27 April 2028. [8]

The thermal result is useful for design comparison but must be read with the specimen's relatively high density. The acoustic number is an impedance-tube average and is not a substitute for STC, R_w

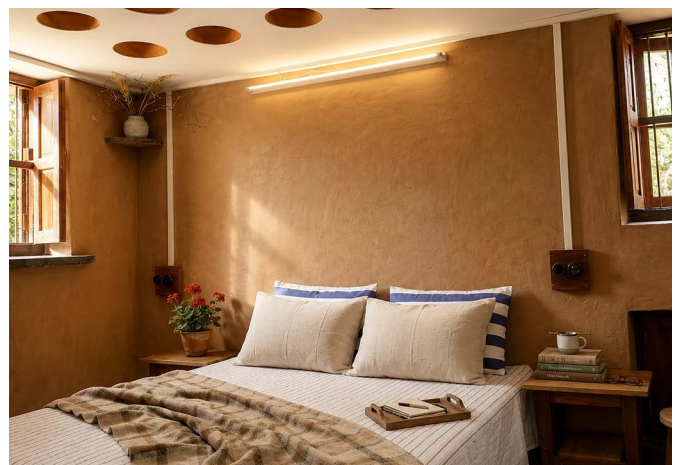
or site-tested performance of a finished wall. These distinctions do not weaken the case for hemp-lime; they demonstrate the engineering maturity that wider adoption requires.

5. Eight Years of Learning Through Buildings

GoHemp reports more than eight years of hemp-building research and contributions to over 15 projects. [4] The most persuasive evidence is not a single object; it is the range of problems addressed across new construction, retrofit, interiors and installation. Each project tests a different part of the system.

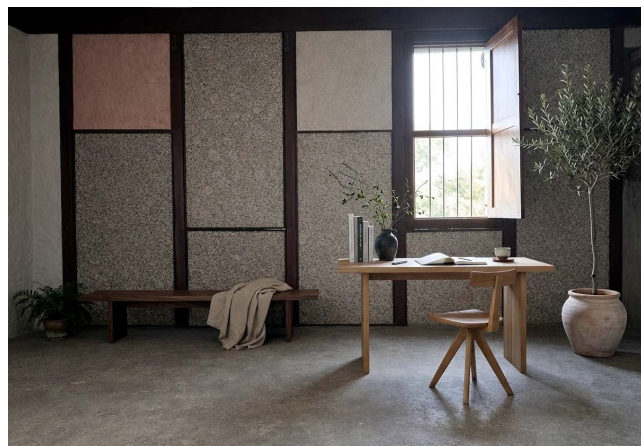
At the Himalayan Hemp Ecostay, the question was whether natural materials could form an inviting, comfortable contemporary place while remaining rooted in the Himalayan landscape. The project became India's first widely recognised modern hemp building and a lived demonstration for visitors rather than a showroom sample.

The Sunny retrofit shifted the challenge to heritage fabric, prefabrication, dimensional coordination and efficient assembly. A Quiet Room in Ludhiana explored material expression in an interior, while Sneha House in Meerut tested integration with a contemporary framed building. Together, these works show a practice moving



Himalayan Hemp Ecostay, Uttarakhand: local stone, hemp-lime and craft brought together in a hospitality setting.

Photographs: GoHemp.



Sunny: a century-old stone room renewed with an interlocking prefabricated hempcrete panel system. Photographs: GoHemp.

from material experiment to coordinated architecture - the kind of evidence that gives architects and developers confidence to commission the next, more ambitious project.

6. Premium Projects Are the Proving Ground

Emerging technologies are often asked to compete immediately with industries optimised over generations. That is the wrong sequence. If hemp-lime is forced into lowest-cost mass housing before supply, standards, contractors and quality systems mature, unreliability will be mistaken for an inherent material failure. A deliberate adoption curve is more responsible.

1. **Demonstration and premium applications.** Begin with residences, farmhouses, resorts, eco-retreats, specialised interiors and institutional pilots where performance, craft and distinctiveness are valued.
2. **Confidence and supply.** Use completed buildings and monitored results to grow processing capacity, binder consistency, quality control, specifications and trained regional teams.
3. **Mainstream middle-income**

construction. As dependable supply and execution networks emerge, apply standardised systems to a wider residential, hospitality, healthcare and education market.

4. **Affordable and mass housing.** Only after scale and learning reduce risk and cost should bio-based systems enter large public programmes with the monitoring, procurement and warranty structures those programmes require.

Premium adoption is not only

a cost strategy; it is where craft, finish quality and performance can be refined. Photograph: GoHemp.

7. India Needs Its Own Hemp-Building Ecosystem

Europe's experience offers important learning, but India should not simply import a product and then discover that it requires an imported ecosystem. Indian climates, monsoons, crop varieties, shiv quality, binders, labour practices, reinforced-concrete construction, logistics and building typologies are different. India



Premium adoption is not only a cost strategy; it is where craft, finish quality and performance can be refined. Photograph: GoHemp.

We should not demand Stage 4 from an industry that is still building Stage 1. Reliability must be established before low cost can be sustained.

needs climate-specific assemblies and locally testable specifications.

From farm to building

1. **Cultivation and responsible procurement.** Align suitable crops, harvesting and buy-back systems with agronomic evidence and state policy.
2. **Regional processing.** Grade shiv and fibre close to the farm so bulky biomass is not transported farther than necessary.
3. **Material engineering and quality control.** Define moisture, grading, density, binder and dimensional tolerances for each intended application.
4. **Project-specific design.** Coordinate structure, thermal and moisture strategy, junctions, services, finishes and construction sequencing.
5. **Trained installation.** Build regional contractor capacity through supervised projects, practical workshops and clear inspection checkpoints.
6. **Monitoring and feedback.** Record indoor conditions, defects, maintenance, energy use and occupant experience so every building improves the next one.

GoHemp's Farm-to-Building model links these stages through a 40,000 sq ft processing and technology-development facility in Roorkee, project-specific material preparation and site support. [7] Its relevance to premium architects and developers is not merely access to hempcrete blocks; it is continuity of responsibility across material selection, design coordination, manufacture and execution. That continuity is often the missing link when a promising material reaches

a real construction site.

8. A Practical Agenda for Adequate Housing

For hemp-lime and other bio-based materials to contribute meaningfully to India's housing future, public policy and private practice must focus on confidence rather than slogans. The priorities are clear.

1. **Build monitored demonstrations across climatic zones.** Residential, hospitality, school and public projects should publish comparable indoor-temperature, humidity, energy and maintenance data.
2. **Expand independent testing.** Material and assembly tests should cover thermal, hygric, acoustic, fire, mechanical, dimensional and durability performance relevant to each use.
3. **Develop Indian standards and specifications.** Guidance should define where hemp-lime is appropriate, what it is not designed to do and how it interfaces with common structural systems.
4. **Create life-cycle evidence.** Carbon claims must include cultivation, processing, binder, transport, construction, service life and end-of-life scenarios.
5. **Invest in skills.** Architects, engineers, contractors, craftspeople and inspectors need hands-on knowledge, not only awareness seminars.
6. **Use procurement to reward whole-life value.** Evaluation should consider comfort, operating energy, maintenance, health and adaptability alongside first cost.

From cheap housing to valuable habitats

India does not need to choose between quantity and quality. It needs an industrial strategy in which better envelopes, renewable materials, regional livelihoods and reliable execution reinforce one another. Hemp-lime will not solve the housing crisis alone, and it should never be presented as a universal answer. Its deeper value is as a demonstrator of a larger possibility: construction materials can be grown as well as extracted; rural producers can participate in urban value chains; and buildings can be judged by what they contribute over time.

Change the way we think about buildings, so that what we build can change the world.

Adequate housing is, therefore, not the cheapest enclosure we can deliver today. It is the most valuable habitat we can responsibly leave behind - comfortable in the present, honest about its origins and worthy of the future.

About the Author

Gaurav Dixit is an architect, material innovator and co-founder of GoHemp Agroventures Pvt. Ltd. He has spent more than eight years working at the intersection of architecture, industrial hemp, rural value chains and regenerative construction. His work includes India's first widely recognised modern hemp building, project-specific hemp-lime systems, prefabricated panels, natural finishes and training for architects and builders. He is also a Visiting Faculty member at the School of Planning and Architecture, New Delhi. His practice focuses on turning bio-based material

research into reliable, climate-responsive buildings.

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BMTPC Showcases Sustainable Building Technologies at Bharat Buildcon 2026

BMTPC participated in the Bharat Buildcon 2026 – One Nation One Expo, held from 18–21 June 2026 at Yashobhoomi, New Delhi, reaffirming its commitment to promoting sustainable, cost-effective, and disaster-resilient construction technologies. The event was inaugurated by Shri Manohar Lal, Hon'ble Minister of Housing & Urban Affairs, marking the beginning of one of the country's premier exhibitions for the construction and real estate sector.

At the BMTPC pavilion, visitors had the opportunity to engage with technical experts, explore the process of technology empanment, access a range of technical publications, and view scaled physical models of successful Demonstration Housing Projects (DHPs). The pavilion highlighted BMTPC's ongoing efforts to mainstream innovative building technologies that support affordable, resilient, and environmentally sustainable housing.

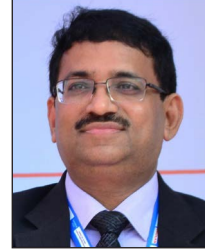
The pavilion also attracted several distinguished dignitaries, including Shri Durga Shanker Mishra, Shri Niranjan Hiranandani, and Shri Praveen Jain, who visited the exhibition to witness BMTPC's latest advancements in alternative building technologies.

Adding to BMTPC's active participation in the event, Shri Arvind Kumar, Executive Director, BMTPC, moderated a high-level technical session on "Advancing Real Estate: New Construction Technologies and Emerging



"Trends in Real Estate" during the NAREDCO Real Estate Conclave 2026. The session brought together policymakers, industry leaders, and technology experts to deliberate on emerging construction practices, innovative technologies, and transformative approaches for large-scale housing development.

Climate-Resilient Housing For All: From Policy Framework To Implementation



Prof Sanjeev Kumar Singh *



Er. Abhishek Rana *

Abstract Climate change is reshaping what constitutes adequate housing, particularly for low-income and climate-vulnerable communities. Housing must not only address the shortage of dwelling units but also ensure safety, affordability, health, comfort, resource efficiency, and the capacity to adapt to changing climatic conditions. This article presents a policy-to-implementation perspective on climate-resilient housing for all, treating housing as an integrated system of land, infrastructure, buildings, materials, energy, water, finance, institutions, and communities. The review synthesises recent research with international climate and urban development frameworks and Indian housing policy mechanisms. Particular attention is given to climate-risk assessment, climate-responsive and climate-zone-appropriate design, sustainable materials, affordability, resilience-linked finance, community participation, and long-term adaptation. Recent research

indicates a shift from predominantly mitigation and energy-efficiency approaches towards integrated adaptation across technological, behavioural, financial, and institutional dimensions. Based on this evidence, the article proposes a ten-stage framework covering policy alignment, climate-risk assessment, resilient planning and design, sustainable materials, financing, quality construction, community participation, monitoring, and long-term adaptation. The framework emphasises that resilience should be embedded throughout the housing life cycle rather than added after construction. The article concludes with policy priorities for affordable, inclusive, and scalable climate-resilient housing aligned with India's Housing for All and Viksit Bharat by 2047 objectives.

Keywords: Circular economy; climate-resilient housing; housing for All; climate adaptation; policy implementation; resilient cities; sustainable construction.

1. Introduction

Housing constitutes the

fundamental cornerstone of human well-being, public health, personal safety, and long-term socio-economic mobility. Yet, addressing the contemporary housing deficit demands far more than tallying completed dwelling units. An interconnected matrix of spatial safety, legal tenure security, financial affordability, universal accessibility, connectivity to municipal infrastructure, construction durability, and life-cycle environmental performance governs a household's actual capacity to withstand intensifying climate-related disruptions. Climate vulnerability reaches its most acute levels precisely where deficient civic services, insecure property rights, and household credit constraints overlap with high exposure to natural hazards. The built environment faces compounding risks across multiple fronts: extreme heatwaves turn uninsulated, poorly ventilated interiors into severe health hazards; intense precipitation exceeds storm-water capacity, triggering flood damage to foundations, building envelopes, electrical

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infrastructure, and household assets; severe storms and cyclones compromise roofs and facades; while protracted droughts and sea-level rise threaten coastal settlements and deepen water insecurity. These impacts are profoundly uneven, as low-income families and residents of informal settlements face systemic barriers, rarely possessing the financial safety nets, credit access, or insurance protections needed to repair structural damage, execute preventive retrofits, or relocate out of high-risk zones. Simultaneously, the residential sector actively drives global warming through high operational energy demand and embodied greenhouse gas emissions from material production. Adaptation and mitigation must therefore converge into a unified agenda: a flood-resistant dwelling reliant on energy-intensive mechanical air conditioning remains an incomplete adaptation response, just as a low-carbon house situated within an unmitigated hazard zone lacking drainage and emergency egress cannot offer genuine safety [1,2].

Consequently, the concept of climate-resilient housing has evolved beyond narrow structural resistance toward an integrated socio-technical understanding of how buildings, households, infrastructure, finance, and institutions interact. In their comprehensive review, Ma et al. [3] identify a definitive paradigm shift from earlier focuses on carbon mitigation and energy efficiency toward holistic adaptation strategies that merge technological, social, and policy dimensions. This shift is vital, as technical adaptation measures fail to deliver resilience

if they are economically out of reach, inadequately maintained, or ill-suited to regional geo-climatic and socio-economic conditions. Recent empirical research strongly reinforces this multidimensional perspective by Bala et al. [4]. It demonstrates the importance of evaluating climate-responsive building performance under real-world occupancy patterns and future climate projections. Climate-resilient architectural features correlate strongly with enhanced tenant satisfaction, establishing occupant well-being and liveability as essential benchmarks of resilience investment [5]. Skjeflo et al. [6], studied the experimental field evidence from Vietnam, which prove that combining targeted financial support with technical assistance substantially accelerates the adoption of resilient housing measures among credit-constrained, low-income households. Seeteram et al. [7] further identify financing constraints, institutional path dependencies and coordination challenges as important barriers to scaling resilient housing. Collectively, these studies indicate that resilience is simultaneously a technical, environmental, economic, social and institutional issue [3–7].

India provides a particularly important context because large-scale affordable housing delivery is occurring alongside rapid urbanisation, increasing climate risks and a transition towards low-carbon development. PMAY-U 2.0 provides a major platform for urban housing delivery, while the Technology and Innovation Sub-Mission (TISM), Building Materials & Technology Promotion Council (BMTPC) and performance

appraisal mechanisms provide opportunities for evaluating and mainstreaming appropriate construction technologies [8]. However, the challenge is to connect these mechanisms systematically with hazard assessment, site selection, climate-responsive design, sustainable materials, finance, construction quality and post-occupancy monitoring. The scale of future construction makes this particularly important. NITI Aayog's scenario work emphasizes the large amount of future building stock that will be constructed in India and therefore the opportunity to avoid long-term carbon and climate-risk lock-in through passive design, energy efficiency, resilient planning and lower-carbon materials [9].

The issue is also directly connected with Viksit Bharat by 2047. NITI Aayog's scenario analysis considers a development pathway towards an economy of approximately USD 30 trillion and per-capita GDP exceeding USD 18,000 by 2047, alongside India's longer-term Net Zero objective [10]. Achieving this transformation will require substantial expansion of housing, infrastructure and urban services. Housing must therefore support economic development while remaining affordable, resource-efficient, climate-resilient and inclusive. The article consequently examines the connection between climate risk, housing policy and implementation by reviewing the principles of climate-resilient housing, international and Indian policy frameworks, risk-informed planning, climate-responsive design, sustainable materials, finance, governance and monitoring. It then synthesises

these dimensions into a policy-to-implementation framework for climate-resilient Housing for All.

2. Review Methodology and Scope

This article adopts an integrative review approach to examine climate-resilient housing from technical, environmental, economic, social, and institutional perspectives. The aim is to connect findings from research studies with relevant policy frameworks and housing delivery mechanisms rather than undertake a statistical meta-analysis. Peer-reviewed literature published mainly between 2015 and 2026 was identified through Scopus, Web of Science, and ScienceDirect using keywords related to climate-resilient design, sustainable materials, affordable housing, housing finance, disaster risk reduction, building codes, urban planning, and policy implementation. The literature was reviewed alongside

major international frameworks, including the Paris Agreement, Sendai Framework, SDG 11, and New Urban Agenda, as well as Indian policies and guidelines such as PMAY-U 2.0, BMTPC Appraisal Systems, ECSBC 2024, the Vulnerability Atlas of India, and NITI Aayog reports on *Viksit Bharat @2047*.

The evidence was synthesised across four levels: **micro** (materials and dwellings), **meso** (occupants and economics), **macro** (settlements and spatial risks), and **institutional** (governance and finance). This approach links research evidence with policy and implementation requirements and provides the basis for the ten-stage framework presented in Section 8.

3. Climate-Resilient Housing: Concept and Principles

Climate-resilient housing encompasses dwellings and settlements planned, designed, constructed, operated, and

maintained to systematically reduce exposure and vulnerability to present and emerging hazards, all while ensuring safety, affordability, health, liveability, and environmental integrity. Resilience therefore transcends mere structural hardening, encompassing a system's capacity to anticipate climate risks, absorb severe shocks, preserve core functionality, recover rapidly from disruption, and adapt dynamically over time. This systemic perspective rests on seven interdependent dimensions. These dimensions and their corresponding performance outcomes are presented in **Fig. 1**, highlighting the interconnected nature of climate-resilient housing.

The seven dimensions of climate-resilient housing should be understood as closely interconnected rather than as separate performance criteria. Improvements in one dimension can influence others, sometimes positively and sometimes



Fig. 1: Seven dimensions of climate-resilient housing and performance outcomes.

(Source: Author's synthesis based on [1,2])

through trade-offs. For instance, elevating a dwelling can enhance flood protection but may raise construction costs, while passive cooling strategies can reduce both heat-related risks and household energy consumption. Similarly, secure tenure can motivate residents to invest in housing improvements, whereas community participation can strengthen preparedness, response and recovery capacities. Therefore, climate-resilient housing should seek an appropriate balance among safety, affordability, durability, environmental performance, maintainability and social inclusion, rather than optimising any single attribute. This integrated perspective is especially relevant to Housing for All, as expanding housing supply without addressing site selection, infrastructure, basic services and climate exposure may simply relocate or redistribute existing vulnerabilities. Climate resilience should therefore

be embedded within housing programmes from the planning and design stage, rather than being introduced later as an additional or premium feature. Moreover, resilience should be viewed as a continuous life-cycle process, encompassing planning, design, material selection, construction, occupancy, maintenance, monitoring, retrofitting and post-disaster recovery. Post-occupancy evaluation is important because actual thermal, energy, water and maintenance performance may differ from design expectations. The life-cycle perspective also creates opportunities to achieve multiple benefits simultaneously, such as using passive cooling to reduce both heat exposure and energy demand or using durable materials to reduce maintenance, replacement and waste.

4. International and National Policy Frameworks

Climate-resilient housing

is supported by multiple complementary frameworks. The Paris Agreement establishes the broader context for climate mitigation and adaptation; the Sendai Framework emphasises disaster-risk knowledge, resilient investment, preparedness and recovery; SDG 11 promotes inclusive, safe, resilient and sustainable cities; and the New Urban Agenda connects adequate housing with integrated and inclusive urban development [11–14]. These frameworks indicate that housing resilience cannot be treated solely as a building-level issue. It is linked with climate policy, disaster-risk reduction, urban planning, infrastructure, social inclusion and sustainable development. The principal international and national frameworks and their implications for climate-resilient housing implementation are summarised in **Table 1**.

Table 1: International and national policy frameworks relevant to climate-resilient housing

Framework / Initiative	Main relevance	Housing implementation implication
Paris Agreement	Mitigation and adaptation	Integrate housing with climate targets, energy efficiency and adaptation planning.
Sendai Framework	Disaster-risk reduction	Use risk knowledge, resilient investment, preparedness and recovery planning.
SDG 11	Inclusive, safe and resilient cities	Link housing delivery with services, planning, resilience and inclusion.
New Urban Agenda	Sustainable urbanisation	Promote integrated, participatory and inclusive planning.
PMAY-U 2.0	Large-scale urban housing	Incorporate measurable resilience criteria into housing delivery.
TISM / BMTPC / PACS	Technology innovation and	Evaluate, certify and mainstream appropriate construction systems.
Vulnerability Atlas	Hazard and housing-risk information	Support risk-informed site and building decisions.
Green procurement / C&D recycling	Low-carbon and circular construction	Encourage resource efficiency, recycled content and tested recovered materials.
Viksit Bharat @2047 / NITI Aayog	Developed, high-income and sustainable India	Align housing expansion with affordability, infrastructure, urbanisation, low-carbon development and climate resilience.

In India, PMAY-U 2.0 provides a large-scale housing-delivery platform through mechanisms including Beneficiary-Led Construction, Affordable Housing in Partnership, Affordable Rental Housing and the Interest Subsidy Scheme. TISM provides an opportunity to promote technologies suited to specific geo-climatic and socio-economic conditions, while BMTPC and performance appraisal mechanisms can support the movement of technologies from research and demonstration towards evaluation, certification, standardisation and wider adoption [8]. The Vulnerability Atlas provides another connection between hazard information and housing decisions by documenting risks including earthquakes, cyclones, floods and landslides. However, the value of such information depends on its integration into land allocation, spatial planning, infrastructure provision and building design.

NITI Aayog's work on affordable housing further highlights land availability, housing supply, access to finance and regulatory constraints as important structural challenges and emphasises coordination, planning reforms, innovative financing and targeted interventions for economically weaker and low-income groups [15]. These challenges are directly relevant to climate resilience because a resilient house cannot be considered successful if it is unaffordable, disconnected from essential services or located in an unsafe area. The central challenge is therefore not simply the absence of policies but the policy-to-implementation gap, namely the difficulty of connecting

policy objectives with actual decisions on land, infrastructure, approvals, procurement, finance, construction quality, inspection and post-occupancy performance.

5. Climate-Risk Assessment and Resilient Spatial Planning

Resilience begins before construction because building-level design cannot compensate for fundamentally unsafe land-use decisions. A technically strong house located in a repeatedly inundated floodplain may still experience major losses, while a structurally sound dwelling may remain inaccessible during a disaster if roads, drainage and emergency routes are inadequate. A location-specific climate-risk assessment should therefore combine hazard, exposure, vulnerability and adaptive capacity. Historical information may include flood extent, rainfall intensity, temperature, wind conditions, landslide inventories, drought indicators and coastal inundation, while future climate conditions should be considered over the expected service life of housing. Vulnerability assessment should additionally consider household characteristics, building condition, service access and recovery capacity [1,12]. The relationship among climate hazards, exposure, vulnerability and adaptive housing responses is illustrated in **Fig. 2**.

Spatial planning should translate this information into site and neighbourhood-level decisions based on a **hierarchical approach that prioritises hazard avoidance, risk reduction, adaptation, preparedness and recovery**. High-risk floodplains, drainage corridors, wetlands and unstable slopes should not automatically

be considered available housing land. Where in-situ upgrading is technically feasible and socially appropriate, drainage improvement, raised access, green infrastructure, evacuation routes and building-level strengthening can be combined. Neighbourhood resilience is equally important because roads, drainage, water supply, sanitation, electricity, health facilities, communication systems and emergency access influence household capacity to cope with climate events. Nature-based solutions, including urban trees, green corridors, permeable surfaces and wetlands, can complement conventional infrastructure by reducing heat and storm-water impacts, provided they are appropriately selected and maintained. The practical outcome of climate-risk assessment should therefore be a location-specific risk profile followed by a resilient settlement plan that guides site selection, infrastructure, building design and technology selection rather than remaining a separate technical exercise.

6. Climate-Responsive Building Design

Once site and neighbourhood risks are understood, building design should respond to the specific combination of hazards and climatic conditions. There is no universal resilient house, and climate-zone adequacy should therefore be a basic criterion for housing design and technology selection. India's climatic diversity requires different responses across hot-dry, warm-humid, composite, temperate and cold conditions. Orientation, ventilation, shading, thermal mass, insulation, roof characteristics,

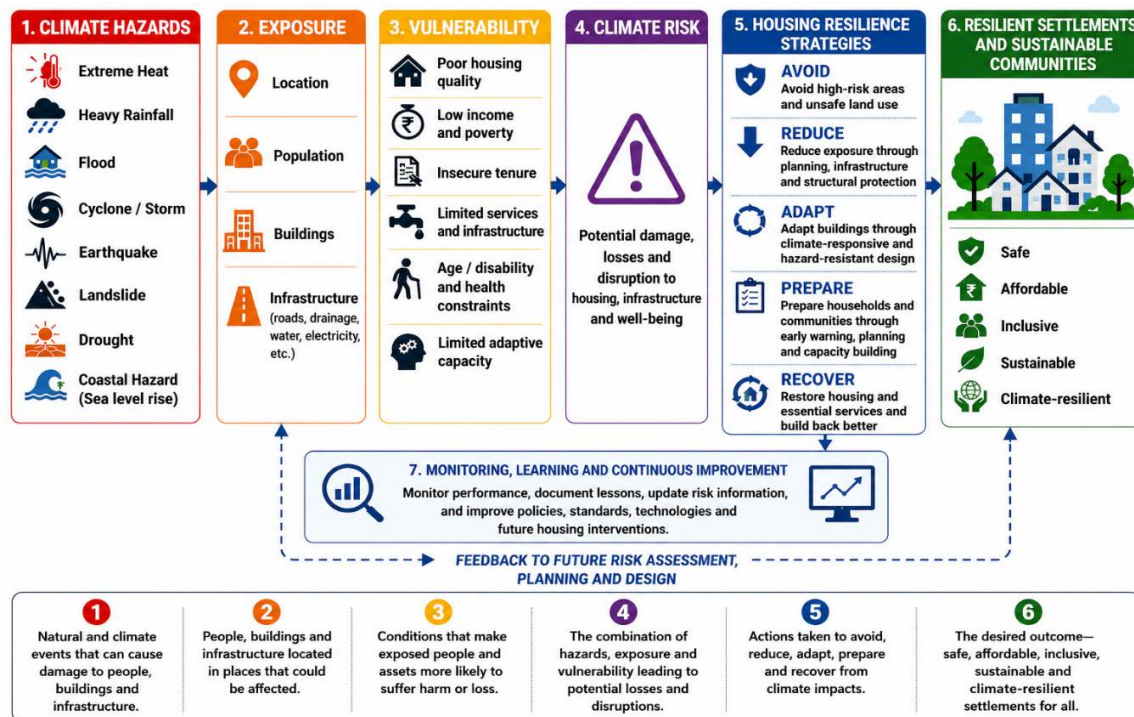


Fig. 2: Climate hazard–exposure–vulnerability pathway and adaptive housing response framework.
(Source: Author's synthesis based on [1,2,12])

moisture protection and energy systems should consequently be selected according to the climatic conditions of the site rather than applied uniformly across regions [16]. Heat resilience can be improved through appropriate orientation, external shading, cross-ventilation, insulated roofs and walls, reflective roof surfaces, vegetation and suitable thermal mass. These measures can reduce indoor heat exposure and cooling-energy demand and are particularly important for low-income households that may have limited capacity to afford mechanical cooling. Flood-resilient design may include elevated floor levels, flood-resistant materials in vulnerable wall zones, protected electrical installations, improved drainage, backflow prevention, raised critical equipment and safe access, while cyclone resilience requires a continuous load path from roof to foundation through

appropriate roof anchorage, wall-to-roof connections, bracing and openings. Earthquake resilience similarly depends on structural configuration, reinforcement detailing, connections, foundations and construction quality. The major climate hazards and their corresponding building-level and planning responses are summarized in Fig. 3.

Water and energy resilience should be integrated with these hazard-specific measures. Rainwater harvesting, efficient fixtures, storage and appropriate wastewater reuse can improve water security, while passive design, efficient appliances, solar photovoltaic systems and, where appropriate, energy storage can reduce dependence on centralized systems. Technology adoption alone, however, does not guarantee resilience; systems must be affordable, locally serviceable and maintainable. Bala

et al. [4] demonstrate that climate-responsive housing performance is influenced by local climatic conditions and occupant behaviour and that future climate conditions can alter expected building performance. This supports the need for locally calibrated design rather than transferring generic solutions between climatic regions. Kavaarpuo et al. [5] similarly show that climate-resilient housing features can contribute to occupant satisfaction even when the corresponding financial return through rental premiums is limited, suggesting that comfort, health, usability and household well-being should be included in housing-performance assessment [4,5].

Accessibility and construction quality should be treated as integral parts of climate-resilient housing. Housing for All must consider persons with disabilities, older residents, children and other vulnerable groups whose

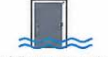
CLIMATE HAZARD	KEY RISKS TO HOUSING	DESIGN / PLANNING RESPONSES			
 Extreme Heat	Overheating, heat stress, high cooling demand	 Orientation, shading	 Natural ventilation and cross-ventilation	 Insulation and thermal mass	 Cool roofs and light-coloured surfaces
 Flood	Inundation, water ingress, damage to structure and services	 Raised plinth / elevated floor	 Site drainage and retention	 Flood-resistant materials	 Backflow prevention for drainage
 Cyclone / Storm	Wind uplift, roof and wall failure, debris impact	 Strong roof anchorage and bracing	 Continuous load path	 Aerodynamic roof design	 Impact-resistant openings
 Earthquake	Structural collapse, cracking, non-structural damage	 Regular and compact building configuration	 Ductile detailing and reinforcement	 Proper connections and tie beams	 Secure non-structural components
 Heavy Rainfall	Water ingress, leakage, erosion, dampness	 Adequate roof drainage	 Proper site slope and grading	 Waterproofing of roofs, walls and foundations	 Permeable surfaces and soak pits
 Drought	Water scarcity, reduced availability	 Rainwater harvesting and storage	 Water-efficient fixtures	 Greywater recycling and reuse	 Drought-tolerant landscaping
 Coastal Hazard (Sea level rise, storm surge, salinity)	Salinity ingress, erosion, coastal flooding	 Setback from shoreline and raised structures	 Natural buffers (mangroves, dunes)	 Corrosion-resistant materials	 Salinity-resistant finishes and coatings

Fig. 3: Climate hazards and corresponding housing design and planning responses.

requirements may be overlooked by generic designs. At the same time, even a technically appropriate design will not perform as intended if materials, workmanship or structural connections are inadequate. Inspection, material testing, supervision, trained workers and simple quality-control procedures are therefore essential to translate design intent into actual resilience.

7. Sustainable Materials, Circularity and Resilience-Linked Finance

Material selection influences both climate resilience and environmental sustainability and should therefore be assessed through a **life-cycle perspective** covering extraction, production, transportation, construction, maintenance, repair and end-of-life. Waste-derived materials should not be adopted solely for their waste-reduction potential;

properties such as **strength, durability, moisture resistance, fire performance and long-term stability** require appropriate testing and quality assurance. Green procurement can support the wider use of verified secondary materials. **Prefabricated and modular systems** can reduce construction time and improve quality control, while standardized components may facilitate repair and post-disaster reconstruction. However, their suitability depends on local manufacturing, transportation, connection systems, labour skills and maintenance capacity. **Vernacular strategies**, including courtyards, shading, natural ventilation, thick walls and elevated floors, can also provide valuable climate-responsive solutions when appropriately integrated with contemporary structural and safety requirements.

Affordability is strongly linked to material and technology selection,

as climate-resilience measures may raise initial construction costs despite their potential to reduce future disaster losses, energy use and maintenance expenses. For low-income households, these additional upfront costs can be difficult to manage, making financial support an essential component of equitable resilience. Skjeflo et al. [6] provide experimental evidence from Vietnam showing that the combination of financial assistance and technical support significantly increased the adoption of climate-resilient housing among low-income households. Their findings suggest that technical assistance alone may not address financial and credit constraints, whereas targeted support can encourage households to invest in preventive measures rather than relying on post-disaster repair [6]. In India, potential mechanisms include subsidies and grants, concessional climate finance, green bonds,

blended finance, resilience-linked loans and suitable insurance or risk-transfer mechanisms. Such incentives can be linked to verified resilience measures, including flood-safe floor levels, heat-resilient roofs, structural strengthening, water efficiency, improved energy performance, renewable energy systems and retrofit interventions.

The affordability of resilient housing should therefore be assessed from a life-cycle perspective rather than solely through initial construction cost. A technically robust solution that results in high energy, maintenance or repair expenses may impose an additional burden on low-income households and create another form of vulnerability. Likewise, low-carbon materials that require specialized maintenance or frequent replacement may face limitations in large-scale

application. Material, technology and financing decisions should consequently be assessed together, considering safety, affordability, environmental performance, local availability and long-term maintainability.

8. Governance, Participation and Policy-to-Implementation Framework

The gap between housing policy and its practical implementation is often rooted more in institutional fragmentation than in a lack of technical solutions. Housing, urban planning, disaster risk reduction, water, energy, finance and environmental agencies frequently function through separate administrative and regulatory frameworks. In addition, responsibilities related to planning, construction approval, inspection and long-term maintenance may be divided among national, state and local authorities. Seeteram et

al. [7] highlight financial limitations, institutional path dependencies and weak inter-agency coordination as major challenges to the large-scale adoption of climate-resilient housing. Bridging this gap requires stronger coordination across national, state and local governance levels, supported by collaboration among government departments, communities, researchers, financial institutions and the construction industry. Meaningful community participation is also essential, as residents possess valuable knowledge of local hazards, household requirements and practical maintenance challenges. Such participation should move beyond one-time consultation and become an integral part of the housing process, including risk assessment, planning, upgrading, implementation, maintenance and monitoring [7]. The proposed policy-to-implementation pathway for integrating these institutional

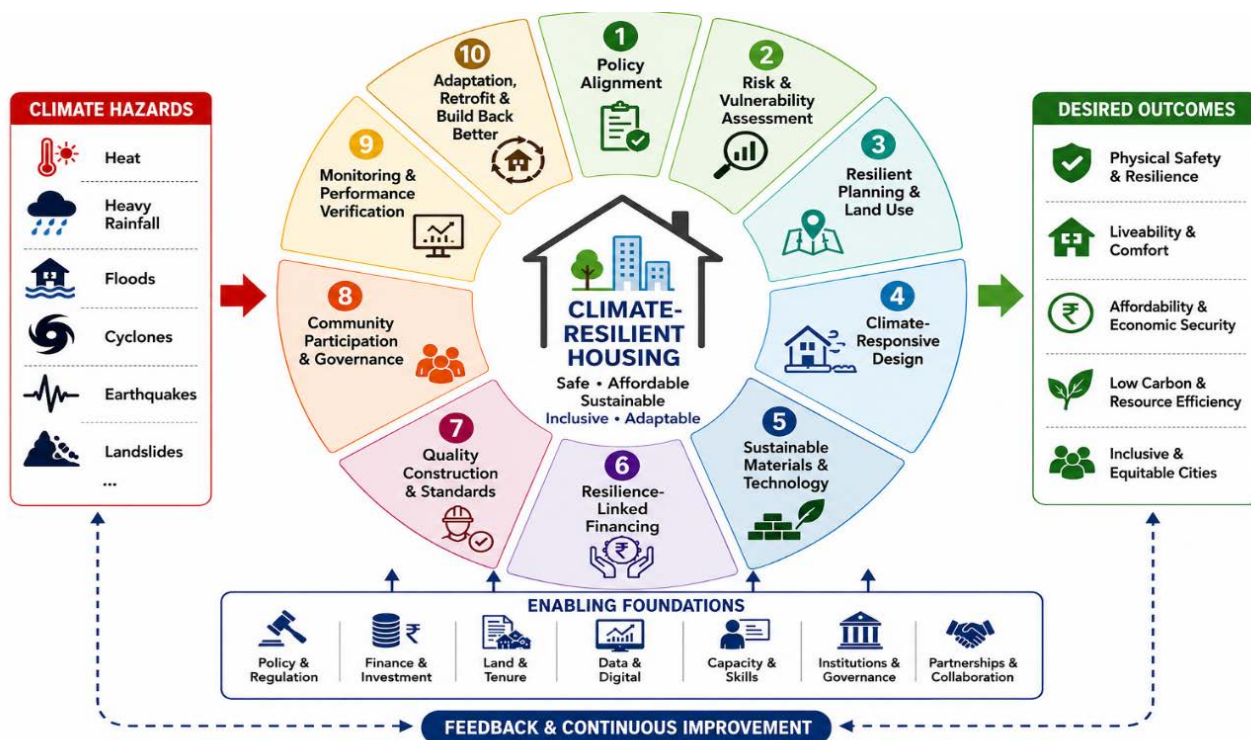


Fig. 4: Proposed policy-to-implementation framework for climate-resilient housing for all.
(Source: Author's synthesis based on [1, 2, 8, 12])

and community dimensions into climate-resilient Housing for All is presented in **Fig. 4**.

9. Monitoring, Evaluation, Barriers and Future Directions

Conventional housing programmes often emphasize dwelling units completed, expenditure and completion time. These indicators are useful for programme management but do not demonstrate resilience. A performance-oriented approach should determine whether households are safer, more comfortable, less vulnerable and better able to recover from disruption. Monitoring should therefore include physical safety, thermal and energy performance, water security, affordability, social inclusion, environmental performance and recovery. Kavaarpuo et al. [5] demonstrate the importance of occupant satisfaction as an outcome of resilient housing, while Bala et al. [4] emphasize the influence of climate conditions and occupancy on building performance. Post-occupancy evaluation should

consequently become part of major housing programmes because actual indoor temperature, energy use, water performance, maintenance requirements and disaster damage may differ from design expectations [4,5]. The key dimensions, illustrative indicators and intended monitoring purposes for evaluating climate-resilient housing performance are presented in **Table 2**.

The implementation of climate-resilient housing is affected by a range of interrelated financial, spatial, technical, institutional and regulatory constraints. High initial costs can make resilient technologies and features unaffordable for low-income households, while the limited availability of safe and suitable land may result in affordable housing being developed in areas exposed to climate hazards. At the same time, inadequate technical expertise can constrain climate-risk assessment, quality inspection and the adoption of appropriate technologies. Uncertain land tenure may further discourage households

from investing in long-term improvements, while fragmented institutional responsibilities can create coordination difficulties. In addition, increasing climate variability and uncertainty may reduce the effectiveness of rigid standards, and inadequate certification systems and supply chains can hinder the wider adoption of innovative and low-carbon construction materials.

These challenges are mutually reinforcing rather than isolated. Financial limitations may restrict access to resilient technologies, insufficient technical capacity can compromise construction quality, and institutional fragmentation can prevent available climate-risk information from being translated into development and investment decisions. Addressing the implementation gap therefore requires an integrated approach combining regulatory reforms, accessible financing, technical capacity building, institutional coordination and stronger material and certification systems, rather than treating individual barriers

Table 2: Key dimensions and indicators for monitoring climate-resilient housing

Dimension	Illustrative indicators	Purpose
Physical safety	Structural condition, hazard damage, flood performance, roof and wall performance	Verify hazard resistance
Thermal / energy	Indoor temperature, overheating, energy demand, renewable share, climate-zone suitability	Assess comfort and energy resilience
Water	Consumption, storage, drainage and flood performance	Assess water security
Affordability	Initial cost, energy bills, maintenance, repair and life-cycle burden	Ensure resilience remains accessible
Social inclusion	Tenure, accessibility, participation, satisfaction and service access	Assess equity and usability
Environmental	Embodied carbon, operational carbon, waste diversion, resource efficiency	Measure mitigation and circularity
Recovery	Time to restore habitability and essential services	Assess post-disaster resilience

(Source: Author's synthesis based on [1, 2, 5, 16])

independently [6,7].

Future research should move beyond the evaluation of individual technologies and place greater emphasis on understanding housing as an integrated and interconnected system. Important research priorities include the development of multidimensional climate-resilience indices that incorporate safety, affordability, energy and water performance, and social equity; the application of digital monitoring and building-scale digital twins; improved climate-risk mapping; development of low-carbon and climate-resilient materials; nature-based approaches to neighbourhood planning; and decision-support frameworks that can evaluate trade-offs among cost, carbon emissions and resilience. Greater attention should also be given to long-term field-based studies, since laboratory experiments and simulation-based assessments may not accurately represent performance under actual operating conditions. Factors such as occupant behaviour, maintenance practices, availability of local skills, infrastructure quality and household affordability can significantly influence the effectiveness of resilient housing solutions. Further empirical research is therefore required to determine how effectively policy mechanisms—including subsidies, concessional financing, technical assistance, certification systems, public procurement requirements and building regulations—can translate climate-resilience objectives into widespread and sustained adoption in the housing sector.

10. Policy Recommendations and Conclusions

The review shows that achieving climate-resilient Housing for All requires attention to several interconnected areas, including planning, design, materials, finance, construction, governance and monitoring. First, major housing projects should be subject to climate-risk assessment before land allocation and construction begin. Such assessments should consider not only present risks but also the likely climate conditions during the expected service life of the buildings. Second, housing programmes should establish clear and measurable resilience requirements addressing aspects such as structural safety, thermal comfort, flood protection, water availability, energy performance, material sustainability, accessibility and the ability of households to recover after climate-related events. Third, greater emphasis is needed on the evaluation and certification of new technologies. Innovations should progress through a clear process involving research, field demonstration, testing, validation, certification, standardisation, procurement and eventual deployment. Fourth, sustainable and circular materials should be promoted through performance-based standards and green procurement, while ensuring that recycled and waste-derived materials meet appropriate safety and durability requirements. Fifth, resilience-linked finance should combine public subsidies, concessional finance, private investment, technical assistance and appropriate insurance or risk-transfer mechanisms, with financial support linked where

feasible to verified resilience improvements. Sixth, structured retrofit programmes should be developed for existing vulnerable housing, particularly where heat, flood, structural or energy risks can be reduced cost-effectively. Seventh, local-government capacity should be strengthened through climate-risk data, technical training, planning tools, inspection resources and adequate financial support. Eighth, community participation should be institutionalised from risk assessment through planning, construction, maintenance and monitoring so that local knowledge and household requirements influence decisions. Finally, post-occupancy performance monitoring should become a regular component of major housing programmes, with monitoring results used to improve standards, procurement, future projects and retrofit strategies.

Climate-resilient housing can be viewed as a **critical advancement of the Housing for All agenda**. The focus must extend beyond merely increasing the number of housing units to ensuring that homes remain **safe, affordable, healthy, resource-efficient and functional** throughout their service life while responding effectively to both present and emerging climate risks. The reviewed literature demonstrates that resilience is a multidisciplinary issue. Climate-responsive design is influenced by local climatic conditions and occupant behaviour; adoption of resilient measures is influenced by financial capacity and technical assistance; occupant satisfaction provides an important measure of actual benefit; and institutional coordination determines whether

individual solutions can be scaled. These findings reinforce the need to move from isolated technological interventions towards integrated housing systems.

The proposed policy-to-implementation framework connects policy alignment, climate-risk assessment, resilient spatial planning, climate-responsive and climate-zone-appropriate design, sustainable materials and technologies, resilience-linked finance, quality-assured construction, community participation, performance monitoring and long-term adaptation. Its principal contribution is to treat resilience as a continuous life-cycle process rather than a characteristic achieved at project completion. Ultimately, the success of climate-resilient Housing for All should not be measured only by the number of policies announced or dwelling units constructed. It should be measured by whether households experience reduced climate vulnerability, improved safety and comfort, affordable life-cycle costs, reliable essential services and greater capacity to recover and adapt. Climate-resilient housing should therefore be understood as a continuous system of risk-informed planning, resilient construction, inclusive governance, sustainable resource use, performance monitoring and long-term adaptation.

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Life Cycle Assessment: A Simple Tool for Building “Adequate Housing for All”



Navneet Sharma *

Setting the Scene

Every year on the first Monday of October, the world pauses to reflect on one basic question: does everyone have a safe, decent place to live? The United Nations has chosen “Adequate Housing for All” as the theme for World Habitat Day 2026, drawing attention to the fact that an estimated 2.8 billion people worldwide still live in slums, informal settlements, or homes that fall short of being truly adequate. Adequate housing is not just about four walls and a roof. It means a home that is structurally safe, affordable, located near services, and - increasingly - built and operated in a way that does not damage the environment for future generations.

This is where a quiet but powerful tool from environmental science enters the housing conversation: Life Cycle Assessment, or LCA. It rarely makes headlines, yet it may be one of the most practical tools we have for making housing genuinely sustainable and genuinely adequate, at scale.

What Exactly Is Life Cycle Assessment?

In simple terms, Life Cycle Assessment is a method of tracking the environmental “footprint” of a building - or any product - from the moment its raw materials are taken from the earth to the day the building is finally demolished. Think of it as a cradle-to-grave report card for a building’s impact on energy use, carbon emissions, water consumption, and waste generation.

Instead of judging a building only by how it looks or performs on the day it is inaugurated, LCA asks a deeper question: what did it cost the planet to build this, operate it for the next 40-60 years, and eventually take it down? By answering this question with data, architects, engineers, and policymakers can make far more informed choices.

The Six Stages of a Building's Life

A building passes through a fairly predictable journey. Understanding each stage helps in identifying where the biggest environmental impacts actually

occur - and, more importantly, where they can be reduced (See Table-1).

Why Adequate Housing Needs LCA

At first glance, LCA might sound like a concern only for high-end “green” buildings. In reality, it is even more relevant to affordable and mass housing, for three practical reasons:

- **Cost over time, not just cost today:** A cheaper building material may look attractive at the time of construction but could demand far higher energy for cooling or heating over its life-time. LCA helps compare the true long-term cost - to both the resident’s pocket and the environment.
- **Scale matters:** Housing-for-all programmes involve building millions of units. Even a small reduction in embodied carbon per unit - achieved through better material choices identified via LCA - adds up to an enormous saving across an entire mission.
- **Resilience and resource security:** LCA studies often reveal

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Table-1: Six Stages of a Building's Life

Stage	What Happens	Why It Matters
1. Raw Material Extraction	Mining/quarrying sand, limestone, iron ore, timber, etc.	Depletes natural resources; disturbs land and ecosystems.
2. Material Manufacturing	Making cement, steel, bricks, glass, paints, tiles.	Highly energy-intensive; a major source of carbon emissions ("embodied carbon").
3. Transportation	Moving materials from factory to construction site.	Fuel use and emissions rise with distance travelled.
4. Construction	On-site assembly - foundation, structure, finishing.	Site energy, water use, and construction waste generated.
5. Use / Operation	Living in the building - lighting, cooling, heating, water use, maintenance.	Usually the longest and most energy-consuming stage (40-60 years or more).
6. End of Life	Demolition, and disposal, recycling or reuse of materials.	Determines how much waste goes to landfill versus back into the economy.

opportunities to use local, low-carbon materials such as fly-ash bricks, stabilised mud blocks, or recycled aggregate, reducing dependence on energy-intensive imported materials while supporting local livelihoods.

LCA in the Indian Context

India's own housing journey offers a natural laboratory for applying LCA thinking. Programmes such as Pradhan Mantri Awas Yojana have added crores of homes to the country's housing stock, while rating systems like GRIHA and IGBC increasingly encourage life cycle thinking - rewarding the use of fly ash, alternative building materials, and technologies that cut both construction time and embodied energy.

Organisations such as BMTPC have long championed cost-effective, disaster-resilient, and environment-friendly construction technologies. Many of these technologies - precast systems, monolithic concrete construction, and use of industrial by-products - naturally score well on a life cycle basis, since they reduce material wastage and construction-stage emissions even before a resident moves in.

A modest but telling example: studies comparing conventional burnt-clay brick walls with fly-ash brick or AAC block alternatives typically show a noticeably lower embodied carbon footprint for the alternatives, alongside comparable or better thermal performance - meaning lower cooling loads for the resident for decades to come. This is precisely the kind of evidence LCA is designed to surface.

From Data to Decisions: Making LCA Usable

The real value of LCA is realised only when its findings are translated into everyday decisions. A few practical entry points for practitioners and policymakers include:

- **Material selection at the design stage:** Comparing two or three material options for walls, roofing, or flooring using simple LCA data before finalising drawings.
- **Standardised material databases:** Building a shared, India-specific database of embodied energy and carbon values for common construction materials, so that every project does not have to start from zero.
- **Simplified LCA tools for mass housing:** Developing easy-to-

use calculators or checklists that field engineers can apply without needing to be LCA specialists themselves.

- **Linking LCA to incentives:** Rewarding developers and housing boards who demonstrate lower life cycle impact, through faster approvals, rating recognition, or financing benefits.

Challenges That Remain

LCA adoption in mainstream housing is still limited by a few practical constraints: the lack of India-specific data for many materials, the additional time and cost of conducting a study, and limited awareness among project teams working under tight delivery timelines. None of these are insurmountable - they call for capacity building, simplified tools, and institutional support rather than complex new regulation.

Conclusion: A Tool Worthy of the Theme

"Adequate Housing for All" is ultimately a promise about the quality of life a home offers - today and for the decades a family will live in it. Life Cycle Assessment gives that promise a measurable foundation. It moves the conversation beyond how a building looks or what it costs to build, toward what it will genuinely cost the planet and its residents over its entire lifetime.

As India continues its ambitious housing programmes, weaving life cycle thinking into everyday design and material decisions - even in simple, practical ways - can help ensure that the homes being built today remain truly adequate: safe, affordable, and sustainable, for generations to come.

BAMBOO FOR ADEQUATE HOUSING FOR ALL

A Sustainable Housing Opportunity for India through PMAY, Local Resources and the SDGs



Kamesh Salam *

Abstract The global housing challenge is no longer simply a question of providing more houses; it is about ensuring adequate, safe, affordable, resilient, climate-responsive and dignified housing. This is at the heart of the 2026 World Habitat Day theme, “Adequate Housing for All.” UN-Habitat has highlighted the scale of the global housing crisis, with an estimated 2.8 billion people experiencing some form of housing inadequacy.

India has made substantial progress in expanding access to housing through programmes such as the Pradhan Mantri Awas Yojana (PMAY). The next stage of the housing agenda provides an opportunity to look beyond the number of houses constructed and focus equally on the quality, affordability, sustainability, climate resilience and local economic value of housing.

Bamboo can contribute significantly to this transition. India possesses considerable bamboo resources, traditional knowledge

and an expanding ecosystem of bamboo-based enterprises, artisans, designers, engineers and technology providers. With appropriate treatment, grading, design, engineering and quality assurance, bamboo can be used in structural and non-structural applications in housing.

India already has an enabling policy and technical environment for innovative and sustainable construction. PMAY-Urban’s Technology Sub-Mission promotes modern, innovative and green technologies and materials, including environmentally responsive and disaster-resistant construction. India also has IS 15912, the Bureau of Indian Standards code of practice for structural design using bamboo.

The opportunity, therefore, is not to replace conventional construction with bamboo overnight, but to develop a Bamboo Housing Mission within the broader Housing for All framework, demonstrating how locally available renewable material can support affordable housing, rural livelihoods, climate

action and sustainable settlements.

1. The Meaning of “Adequate Housing”

The 2026 World Habitat Day theme, “Adequate Housing for All,” invites us to reconsider what constitutes adequate housing.

A house is more than a roof over one’s head. Adequate housing needs to address several dimensions simultaneously: structural safety; protection from weather and climate; affordability; thermal comfort; access to water and sanitation; adequate space and privacy; accessibility and inclusiveness; resilience to disasters; access to basic infrastructure and services; suitability to local climatic and cultural conditions; and long-term durability and maintainability.

This perspective is particularly relevant for India, where housing conditions vary enormously across geographical and climatic regions.

A housing solution appropriate for Rajasthan may not necessarily be appropriate for Assam, Manipur, Meghalaya, Tripura, Kerala or the Himalayan states. Housing

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policy must therefore combine national standards with local materials, local skills and local climatic intelligence.

Bamboo provides an interesting opportunity in this context.

2. My Three-and-a-Half Decades with Bamboo: From Material to Development Opportunity

My engagement with bamboo spans more than 35 years, during which I have had the opportunity to work across different dimensions of the bamboo value chain—from resource development and treatment to product development, construction, enterprise development, policy advocacy and international cooperation.

Over these decades, one lesson has remained consistent:

“Bamboo should not be viewed merely as a traditional craft material. It should be viewed as a renewable industrial, construction and livelihood resource.”

Bamboo connects several development objectives simultaneously.

Natural resource → raw material → local processing → skilled employment → enterprise → construction → housing → livelihood → carbon and climate benefits.

This interconnected value chain is particularly important for regions such as Northeast India, where bamboo is deeply embedded in local landscapes, cultures, livelihoods and traditional construction practices.

My experience working with government institutions, development organisations, international agencies, enterprises, designers, engineers, communities and practi-

tioners has also demonstrated that the principal challenge is no longer whether bamboo can be used.

The more important questions are: How can bamboo be standardised? How can it be engineered? How can it be treated and protected? How can it be incorporated into approved building systems? How can trained local people construct with it safely? And how can financing and insurance recognise bamboo-based construction?

Most importantly: How can bamboo move from isolated demonstration projects to mainstream housing delivery?

3. India Already Has an Enabling Housing-Technology Framework

An important opportunity exists within the existing framework of India's housing programmes.

The Technology Sub-Mission under PMAY-Urban was established to facilitate adoption of modern, innovative and green technologies and building materials for faster and quality housing construction. It also addresses building designs appropriate to different geo-climatic zones and disaster-resistant and environmentally friendly technologies.

This is significant because bamboo does not need to be introduced as an entirely new philosophy.

It can be positioned within an existing policy objective:

innovative + green + affordable + locally appropriate + resilient housing.

The Ministry's experience with the Global Housing Technology Challenge and Demonstration Housing Projects has also created

an institutional pathway for demonstrating alternative construction technologies and subsequently scaling them across different regions.

The opportunity now is to systematically include engineered bamboo and bamboo-based construction systems within this innovation ecosystem.

4. BMTPC's Contribution: Taking Bamboo Housing to the Mainstream

The proposed Bamboo Housing 1000 initiative could therefore be implemented with BMTPC as a key technical and knowledge partner, bringing together MoHUA, State Governments, BIS, technical institutions, IITs/NITs, bamboo organisations, industry and communities. Such a programme would provide the evidence required to move bamboo housing from isolated demonstrations towards replicable, standards-based and scalable housing solutions.

In this context, BMTPC can become the bridge between “bamboo as a traditional material” and “bamboo as a mainstream construction technology”. The objective should not be to promote bamboo indiscriminately, but to establish where bamboo and bamboo-hybrid systems are technically appropriate, economically viable, environmentally responsible and acceptable under the applicable regulatory and quality framework.

Going forward, BMTPC can play an even stronger catalytic role by bringing together bamboo technologies developed by different institutions and creating a coordinated Bamboo Housing Technology Platform. Such a platform could identify technically validated sys-



tems; facilitate performance evaluation; prepare standardised design and construction packages; support demonstration projects under appropriate housing programmes; train engineers, architects and artisans; document lifecycle cost and performance; and facilitate adoption by States, Urban Local Bodies, Housing Boards, public agencies and private developers.

BMTPC's role is especially relevant to mainstreaming because adoption requires more than a successful prototype. It requires a pathway connecting research, performance evaluation, standards, demonstration, skills, enterprise, finance and public procurement. BMTPC's broader mandate includes technology assessment, performance appraisal, dissemination and support for formulation of standards, providing an institutional mechanism through which emerging bamboo technologies can move towards wider acceptance.

Another important contribution is the creation of confidence and technical knowledge among practitioners. BMTPC has developed and disseminated information on bamboo selection, treatment and preservation, construction sequences, joinery details and relevant standards. Its "Bamboo in Housing and Building Construction" mobile application was intended to provide practical information to bamboo workers and professionals.

BMTPC has also contributed to the transition from technology development to field application. Its documented activities in the Northeast include demonstration houses and other structures, Bamboo Mat Production Centres and hands-on training programmes for local artisans and construction personnel. In Manipur, BMTPC organised a Building with Bamboo training programme with the Manipur State Bamboo Mission, Forest Department and South Asia Bamboo Foundation, combining technical training with practical construction.

A significant example is BMTPC's collaboration with the Indian Plywood Industries Research & Training Institute (IPIRTI), Bengaluru, in developing bamboo-based building technologies. These include Bamboo Mat Corrugated Sheets, Bamboo Mat Ridge Caps, prefabricated bamboo houses and a Two Storey Bamboo Housing System. The latter incorporates bamboo columns, bamboo grid walls, bamboo-mat corrugated roofing, bamboo-composite beams and bamboo-composite slabs.

BMTPC's contribution to bamboo housing has extended beyond advocacy. The Council has worked on technology development, demonstration, training, dissemination and commercialisation, particularly in bamboo-growing regions including the Northeast. Its documented work includes bamboo-based materials and technologies, demonstration structures, Bamboo Mat Production Centres, training of local artisans and collaboration with research institutions and State agencies.

BMTPC, under the Ministry of Housing & Urban Affairs, has

an important institutional role in taking innovative, cost-effective, environment-friendly and energy-efficient construction technologies from "lab to land". Its work on bamboo demonstrates how a material with strong traditional roots can be developed, tested, demonstrated and promoted for contemporary housing.

5. Bamboo and the Pradhan Mantri Awas Yojana

PMAY has created an unprecedented platform for expanding access to housing.

The next opportunity is to ask a broader question:

"Can PMAY become not only a housing delivery programme but also a catalyst for sustainable local construction economies?"

Bamboo provides one possible pathway.

A bamboo-based housing approach can be designed around five interconnected objectives:

5.1 Affordable housing

Bamboo is locally available in many parts of India. Where sustainable supply chains exist, the use of local material can reduce transportation requirements and create local value addition.

However, affordability should not be assumed merely because bamboo is locally available. Proper economic assessment must include harvesting, treatment, grading, transportation, skilled labour, connectors, foundations, maintenance, replacement cycles and lifecycle costs.

The objective should therefore be lifecycle affordability, rather than simply low initial construction cost.

5.2 Climate-responsive housing

Bamboo can form part of building systems designed for thermal comfort and passive climatic response.

Wall systems, roof systems, shading devices, screens, ventilated facades and other bamboo components can be adapted to local climatic conditions.

5.3 Disaster-resilient construction

Bamboo structures need to be engineered for the specific hazards of a location.

The Northeast, for example, requires particular attention to earthquake resistance, wind, heavy rainfall, moisture and biological durability.

The solution is not simply “use bamboo.”

The solution is:

properly selected bamboo + scientific treatment + engineered connections + structural design + skilled construction + quality control.

5.4 Local employment

Perhaps one of bamboo’s greatest advantages is that housing construction can become a livelihood programme.

Instead of transporting a finished building into a community, a bamboo housing programme can create a local ecosystem involving bamboo growers, harvesters, treatment units, artisans, carpenters, fabricators, engineers, designers, transporters, construction workers and maintenance enterprises.

Thus, every housing unit can potentially create economic activity beyond the construction site.

5.5 Local ownership

A housing programme using local materials and local skills can encourage greater community participation.

This is particularly important in rural and tribal areas where housing is not simply a technical product but part of social, cultural and environmental identity.

6. Bamboo Is No Longer Only a Traditional Material

One of the persistent misconceptions about bamboo is that its use in construction necessarily means returning to traditional or temporary construction.

That perception needs to change.

Modern bamboo construction can incorporate engineered bamboo; treated structural bamboo; prefabricated components; bamboo trusses; bamboo roof systems; bamboo wall panels; bamboo flooring; bamboo ceilings; bamboo screens and shading systems; bamboo doors and windows; bamboo composite boards; bamboo-based furniture and fittings; and hybrid bamboo-concrete, bamboo-steel and other composite systems.

The distinction is therefore between traditional use without engineering and modern use based on engineering, standards and quality assurance.

India already has a national standard addressing structural design using bamboo. BIS lists IS 15912:2018, Structural Design Using Bamboo — Code of Practice (First Revision).

This provides an important foundation for bringing bamboo into professionally designed construction.

struction.

7. From “Bamboo House” to “Bamboo Housing System”

For bamboo to contribute meaningfully to PMAY, we should move away from the concept of a one-off “bamboo house”.

What India needs is a Bamboo Housing System.

Such a system could consist of standardised and tested components:

- **Structural system** – engineered bamboo columns, beams, trusses and frames.
- **Wall system** – bamboo-based infill, panels or composite wall systems suitable for different climatic regions.
- **Roof system** – lightweight bamboo-based roof structures combined with suitable weatherproof roofing materials.
- **Foundation** – conventional or appropriate engineered foundations designed according to site conditions.
- **Services** – integrated water, sanitation, electrical and plumbing systems.
- **Thermal comfort** – passive ventilation, shading and appropriate insulation.
- **Disaster resilience** – design parameters corresponding to seismic, wind, flood and other local hazards.
- **Finishing** – durable and low-maintenance finishes appropriate to the climate.

Such standardisation would make it easier for architects, engineers, contractors, financial institutions and government agencies to understand and adopt the technology.

8. A “Bamboo + Hybrid” Approach May Be the Most Practical

The debate should not be framed as:

“Bamboo versus concrete.”

The more productive question is:

“Where can bamboo provide the greatest technical, environmental and economic value within a housing system?”

A hybrid approach may therefore be particularly appropriate.

For example:

Concrete or appropriate foundation + bamboo structural components + bamboo-based walls + conventional waterproof roof covering + bamboo shading + locally appropriate finishes.

Such systems can combine the strengths of different materials.

The objective should be to use the right material in the right place, while maximising renewable and locally available materials wherever technically appropriate.

9. Bamboo and SDG 11

The relationship between adequate housing and the Sustainable Development Goals is direct.

SDG 11.1 calls for ensuring access for all to adequate, safe and affordable housing and basic services by 2030, while SDG 11 more broadly seeks inclusive, safe, resilient and sustainable cities and human settlements.

A bamboo-based housing strategy can potentially contribute to several interconnected SDGs:

SDG 1 – No Poverty: Bamboo value chains can create rural employ-

ment and enterprise opportunities.

SDG 8 – Decent Work and Economic Growth: Processing, construction, design and manufacturing can generate local skilled employment.

SDG 9 – Industry, Innovation and Infrastructure: Engineered bamboo provides an opportunity for material innovation and decentralised manufacturing.

SDG 11 – Sustainable Cities and Communities: Bamboo can contribute to affordable, safe, resilient and locally appropriate housing.

SDG 12 – Responsible Consumption and Production: A rapidly renewable biological resource can form part of more resource-efficient production systems when responsibly managed.

SDG 13 – Climate Action: Low-carbon and climate-responsive construction systems can contribute to broader climate objectives, subject to appropriate lifecycle assessment and responsible sourcing.

SDG 15 – Life on Land: Sustainably managed bamboo resources can form part of diversified landscape and land-management systems.

The key point is that bamboo is not an SDG by itself. Its contribution depends on how it is cultivated, harvested, treated, processed, transported, designed, constructed, maintained and eventually reused or disposed of.

10. From Carbon Storage to a Circular “Bamboo Economy”

The sustainability discussion around bamboo should also move beyond simply describing bamboo as a “carbon sink”.

The larger opportunity is to create a circular bamboo economy.

A mature bamboo ecosystem can potentially utilise different parts of the resource:

Construction poles → structural components

Off cuts → boards, panels and products

Residues → biochar, energy or other value-added applications

Bamboo waste → further material recovery

This approach can increase the economic value obtained from each harvested culm while reducing waste.

For bamboo-producing regions, this could create a new development model:

Bamboo cultivation → sustainable harvesting → treatment → processing → housing → products → residues → circular applications.

Housing can therefore become an anchor market for a much larger bamboo economy.

11. A Special Opportunity for Northeast India

The Northeast represents one of India’s compelling regions for demonstrating this approach.

The region combines significant bamboo resources; strong traditional bamboo knowledge; diverse climatic conditions; seismic vulnerability in several areas; rural and dispersed settlements; indigenous construction traditions; and significant opportunities for livelihood generation.

A bamboo housing initiative in the Northeast should not, however, be treated as a regional experiment isolated from the rest of India.

It could serve as a national

demonstration platform.

The Northeast can demonstrate how local resources + modern engineering + traditional knowledge + government housing + skill development + enterprise can come together to create sustainable habitat.

The model could subsequently be adapted to other bamboo-producing states.

12. The Need for a National Bamboo Housing Demonstration Programme

A practical next step could be the establishment of a National Bamboo Housing Demonstration Programme under the broader innovation and technology framework of PMAY.

The programme could begin with demonstration projects across different geo-climatic regions.

Region 1 – Northeast India: seismic resilience, heavy rainfall, humidity, local bamboo species and indigenous knowledge.

Region 2 – Eastern India: rural affordable housing, local bamboo supply chains and flood-resilient applications.

Region 3 – Central India: thermal comfort, rural livelihoods and bamboo-based components.

Region 4 – Southern India: hot and humid climatic conditions, shading, ventilation and bamboo-based architectural systems.

Region 5 – Himalayan region: seismic conditions, cold climate and lightweight construction.

The objective should be to test, measure, document and standardise, rather than simply construct demonstration houses.

13. What Should Be Measured?

Every demonstration project should generate evidence.

The following parameters should be evaluated:

1. Construction cost.
2. Construction time.
3. Local material content.
4. Labour generated.
5. Local income generated.
6. Thermal performance.
7. Energy consumption.
8. Structural performance.
9. Moisture performance.
10. Biological durability.
11. Maintenance requirements.
12. Lifecycle cost.
13. Embodied carbon.
14. Disaster resilience.
15. User satisfaction.
16. Replicability.

This evidence can then support appropriate inclusion of bamboo systems in government housing programmes.

14. The Importance of Standards and Quality Assurance

Scaling bamboo construction without quality assurance would be counterproductive.

The sector requires an integrated quality framework covering:

- **Bamboo resource** – identification of suitable species, age and harvesting practices.
- **Treatment** – scientific preservation against insects, fungi and moisture-related deterioration.
- **Grading** – classification according to mechanical and physical properties.
- **Design** – structural design by qualified professionals using appropriate standards.
- **Connections** – reliable and repeatable connection systems are fundamental to structural

bamboo.

- **Fabrication** – controlled pre-fabrication can improve consistency.
- **Construction** – trained and certified construction personnel should be involved.
- **Inspection** – independent quality control should form part of government-supported projects.

The existence of Indian standards for structural bamboo provides an important starting point, but wider capacity building and implementation are essential.

15. Creating a Bamboo Housing Skill Ecosystem

Technology alone will not create bamboo housing on a scale.

People will.

A national bamboo housing programme should therefore include a dedicated skill-development component.

Training can be structured at multiple levels:

- **Level 1** – Basic bamboo construction worker: selection, handling, treatment and basic assembly.
- **Level 2** – Bamboo fabricator: component fabrication and prefabrication.
- **Level 3** – Master craftsman: advanced joints, detailing and architectural applications.
- **Level 4** – Bamboo construction supervisor: quality control and site management.
- **Level 5** – Engineer/architect: structural design, detailing and project certification.

This would transform housing expenditure into an investment in local human capital.

16. Financing and Market Development

For bamboo housing to become mainstream, technology must be supported by finance.

Government housing programmes can create the initial demand, but long-term scale will require participation from banks, finance housing companies, insurance companies, developers, contractors, bamboo enterprises and technology providers.

Once technically approved and adequately documented, bamboo housing should be able to participate within appropriate financing and insurance frameworks on the basis of performance and compliance, rather than assumptions about the material.

This distinction is critical.

The question should not be:
"Is this a bamboo house?"

The question should be:
"Does this housing system meet the required standards for safety, durability, affordability and performance?"

17. From Beneficiary to Participant

Another opportunity lies in changing the role of the housing beneficiary.

Instead of viewing a beneficiary simply as the recipient of a government-funded house, the person can become a participant in the local housing economy.

Where appropriate, beneficiaries and communities could be trained in bamboo preparation, simple construction activities, maintenance, repair, landscaping and future expansion.

This can increase ownership and reduce dependence on external contractors for every small repair.

It can also help preserve local construction knowledge.

18. Bamboo and the Rural–Urban Continuum

The World Habitat Day theme is relevant not only to cities.

India's housing challenge exists across the rural–urban continuum.

Bamboo can contribute across this continuum.

Rural housing – Locally sourced bamboo can support affordable and climate-responsive construction.

Peri-urban housing – Bamboo-based prefabricated components can be integrated into rapidly expanding settlements.

Urban affordable housing – Bamboo can be used selectively for architectural, shading, interior and structural applications where technically appropriate.

Rental housing – Lightweight, modular and prefabricated components could potentially contribute to certain affordable rental housing applications.

Community infrastructure – Bamboo can also support schools, community centres, markets, public spaces and other social infrastructure.

Thus, bamboo should be considered not simply a "rural material", but as part of a broader sustainable construction ecosystem.

19. A Proposal for "Bamboo Housing 1000"

As an immediate demonstration, India could consider a Bam-

boo Housing 1000 initiative.

The objective would be to construct approximately 1,000 demonstration housing units across selected bamboo-producing and climate-diverse regions.

Each project would be monitored for:

Cost | Time | Carbon | Comfort | Durability | Resilience | Employment | User satisfaction

The data would create a national evidence base.

The programme could bring together:

MoHUA + BMTPC + State Governments + BIS + technical institutions + IITs/NITs + bamboo organisations + industry + communities.

Such a programme would transform the discussion from:

"Can bamboo be used for housing?"

to:

"Which bamboo housing systems work, where do they work, what do they cost, and how can they be scaled?"

20. A New Development Paradigm: House + Livelihood + Ecology

The most important opportunity may be to move beyond the conventional definition of a housing programme.

A successful bamboo housing programme can potentially deliver three outcomes simultaneously:

1. A house – a safe, affordable and adequate dwelling.
2. A livelihood – income for farmers, processors, artisans, fabricators and construction workers.

3. An ecological resource – a renewable material that can be sustainably managed and incorporated into more resource-efficient construction systems.

This creates a powerful development equation:

Adequate Housing + Local Livelihoods + Sustainable Materials = Sustainable Habitat

This is where bamboo can contribute beyond the individual building.

21. The Way Forward

India does not need to choose between modern technology and traditional knowledge.

We need to combine them.

The future of bamboo construction should therefore be based on:

Traditional knowledge + Scientific treatment + Engineering + Standards + Modern design + Prefabrication + Skill development + Digital technology + Government housing programmes + Sustainable resource management

Such an approach can help transform bamboo from a largely decentralised resource into a modern construction material with national relevance.

PMAY has already established a powerful platform for Housing for All. The next opportunity is to strengthen this platform by integrating sustainability, climate resilience, local materials and local livelihoods into housing delivery.

Bamboo can be one of the materials that helps make this transition.

22. Conclusion: From Housing for All to Adequate Housing for All

The theme of World Habitat Day 2026—“Adequate Housing for All”—is a reminder that the housing challenge cannot be measured only by the number of houses constructed.

The real measure is whether people have access to homes that are safe, affordable, comfortable, resilient, sustainable and dignified.

India’s housing programmes have created the scale.

India’s technological ecosystem is creating new construction possibilities.

India’s bamboo resources provide an additional opportunity.

The task before us is to bring these three together.

After more than three decades of working with bamboo, I believe that the future opportunity is not to romanticise bamboo as an ancient material, nor to promote it simply because it is renewable.

The opportunity is to engineer bamboo for modern needs, build standards around it, develop skilled human resources, establish reliable supply chains, create markets and integrate it into appropriate housing systems.

For bamboo-producing regions, this can mean more than building houses.

It can mean building local economies.

For India, it can mean more than adopting another construction material.

It can mean creating a new model of sustainable habitat development.

development.

And for the global ambition of Adequate Housing for All, bamboo offers an important question worth exploring:

“Can the house that provides shelter also create livelihoods, strengthen local economies and use renewable resources responsibly?”

With the right policy, technology, standards and investment, the answer can increasingly be yes.

The opportunity is now to move from demonstration to mainstreaming, from material to system, and from housing delivery to sustainable habitat creation.

Bamboo can help us build not only houses, but a more sustainable future of housing.

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Thermal Comfort, Materiality and Beyond...



*Rajan Rawal **

Homeownership remains a determining milestone in the human life course, dictated by a complex matrix of socio-cultural values and macroeconomic factors. Beyond its basic utility as a repository for shelter and security against environmental hazards, a home is sociologically expected to serve as an adaptive space that evolves alongside its occupants' shifting priorities and life-cycle needs. Since the mid-twentieth century, residential construction has transitioned into the domain of mass industrial production. This paradigm shift has driven major advances in materials science and construction technology, which—when paired with targeted state housing policies and institutional credit mechanisms—have substantially improved access to housing. Nevertheless, industrialisation has not fully addressed critical environmental and ecological obligations. Contemporary housing production consistently exhibits limitations in generating a thermally comfortable

indoor environment and also reducing heat stress for occupants. Context-specific passive design strategies and the selection of construction materials that are less harmful to the environment over their life cycle have yet to reach their potential in practice.

Owing to India's varied tropical and subtropical geography, the regional climate necessitates diverse architectural approaches to maintain optimal residential thermal comfort. Over the past decade, a measurable increase in operating hours exceeding desired humidity thresholds, leading to more uncomfortable hours, compounded by the urban heat island (UHI) effect, has exposed the limitations of conventional passive design strategies. Nevertheless, these passive frameworks remain critical in reducing both the required capacity and the operational duration of mechanical HVAC systems. The efficacy of passive design relies primarily on two core components: first, the spatial configuration at both the individual dwelling and neighbour

scales; and second, the strategic deployment of building materials and construction methodologies. While spatial optimisation is frequently constrained by site boundary limitations, economic variables, and gaps in technical expertise, the selection of materials and construction techniques offers a more viable and highly impactful pathway.

The strategic selection of building envelopes with lower thermal transmittance is critical for extending indoor thermal comfort hours and reducing operational energy consumption. This is primarily achieved through two distinct approaches: first, thermal insulation, which impedes conductive heat gain, and second thermal mass, which rely on the heat capacity of materials to store thermal energy and introduce a time-lagged release on it to the indoors. Material and construction technology selection must aligned with seasonal and diurnal outdoor climatic variations. For instance, a standard single-layer solid clay brick wall exhibits vastly different

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thermal behaviour compared to a rat-trap bond masonry wall, which introduces internal air cavities that inherently enhance localised thermal resistance, both are made from the same material but the method of construction is different.

Often, it is observed that one set of design and engineering professionals expresses affinity towards materials and construction practices that have evolved over time in various geographies. Unstabilised or Compressed Stabilised Rammed Earth and Wattle and Daub construction are examples of these for wall construction purposes. Another set of design and engineering professionals expresses an affinity for materials and construction practices that have emerged from controlled research and development and are produced through highly industrialised processes. Examples include light-gauge framed steel structures with expanded polystyrene or glass fibre-reinforced gypsum panels, and RCC. To mitigate residential overheating, the thermal characterisation of the envelope that consists of wall, roof and fenestration is vital. Ultimately, providing practising professionals with standardised, empirical data on material and construction thermal performance is essential to bridge the gap between theory and application, fostering the widespread adoption of climate-responsive building envelopes.

Establishing a comprehensive repository of the thermal properties of building materials and construction assembly technologies represents a critical milestone in democratisation and data accessibility to achieve the aim

of thermally comfortable housing for all. In the Indian context, this initiative has been significantly advanced by the Centre for Advanced Research in Building Science and Energy (CARBSE) at CEPT University, Ahmedabad. Over nearly two decades, CARBSE has pioneered the systematic thermal and optical characterisation of localised building materials and diverse industrialised construction methodologies. By rigorously adhering to both national and international testing and characterisation protocols, its long-term research has generated robust empirical data. This foundational data empowers architects, engineers, and policymakers to make informed construction technology selections that directly respond to regional climatic stressors, thereby optimising indoor thermal comfort and lowering cooling loads. A seminal iteration of this database has been integrated into practice through its publication on the Building Materials and Technology Promotion Council (BMTPC) web platform, serving as a vital bridge between rigorous academic research and scalable market application.

While individual homeowners should reduce their operational energy use, society also gains immensely from lowering the carbon intensity of building materials—known as embodied energy. This term represents the total energy consumed to manufacture and transport a material. To truly understand a material's environmental impact, we must analyse its full life-cycle emissions: from initial production and site delivery, to its effect on operational energy, and finally,

its ability to safely return to nature. This holistic approach is championed by the 'Cradle to Cradle' concept, which evaluates how building materials interact with natural ecosystems from start to finish.

Numerous global and domestic initiatives are currently working to establish comprehensive databases that measure the embodied energy of construction materials. An accurate, continuously updated database is vital for the construction sector, as it provides the standardised, empirical data necessary to conduct reliable Life Cycle Assessments (LCAs). These platforms enable professionals to objectively compare the environmental footprints of different materials and optimise their procurement strategies. Consequently, these data hubs improve the precision of carbon accounting, which helps accelerate industry-wide emission reductions and informs evidence-based environmental policy.

Crucially, developing an embodied energy database requires a fundamentally different approach than compiling and maintaining datasets for the thermal and optical properties of materials. While thermal and optical testing relies on advanced laboratory infrastructure and specialised scientists, managing embodied energy data presents unique structural challenges on three specific fronts: (i) High Uncertainty: Embodied energy values change continuously as manufacturing efficiencies shift and transportation technologies evolve year-on-year. (ii) Methodological Consensus: Creating a universally accepted framework demands extensive,

Sustainable Market Transformation for Energy Efficiency in Buildings (SMARTEE-B)

A hybrid meeting was held with representatives of the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) and the Executive Director, BMTPC on March 20, 2024 at New Delhi to deliberate on the project outline and implementation timeline of the IKI-supported project titled “Sustainable Market Transformation for Energy Efficiency in Buildings (SMARTEE-B)”, submitted by the Global Green Growth Institute (GGGI). The project has successfully cleared the selection process under the thematic priority “Building Energy Efficiency: Business Models for Scaling Energy Efficiency Measures.”

During the discussions, Shri Arvind Kumar, Executive Director, BMTPC, suggested exploring the inclusion of eligible beneficiaries from the Economically Weaker Section (EWS) under Pradhan Mantri Awas Yojana–Urban as key stakeholders in the project. He further recommended undertaking Demonstration Housing Projects (DHPs) to showcase quantifiable reductions in greenhouse gas emissions through the application of both active and passive energy



efficiency strategies, with a view to facilitating replication and informing policy outcomes across other States/UTs under the SMARTEE-B project. Shri C.N. Jha, BMTPC, also suggested the application of insulation for improving attic thermal performance.

Meeting was attended by Mrs Barbara Schaefer, BMUKN; Mr. Christian Giesa, ZUG; Ms. Nora Schlagenwerth, ZUG; Mrs. Taina Dyckhoff, German Embassy; Mr.

Soumya Garnaik, Country Head, GGGI; Mr. Vivek Sen, Country Director, CPI; Mr. D. Rajanikanth, Director, NPC; Ms. Joelle Onimus-Pfortner, Sr. Officer, GGGI; Mrs. Neha Sharma, EE Officer, GGGI; Mr. Ashok Thanikonda, Sr. Energy Officer, GGGI, Mr. Bonam Ashok, Regional Coordinator, GGGI; Mr. C N Jha, BMTPC; Shri Pankaj Gupta, BMTPC; Shri Dalip Kumar, BMTPC and Shri Manish Kumar, PMU, MoHUA.

ongoing coordination and formal agreements among policymakers, industrial manufacturers, and academic researchers. (iii) Structural Diversity: The sheer variety of building designs, regional seismic safety mandates, and land-use requirements creates vastly different architectural structures,

making it exceptionally difficult to establish a standard baseline.

Despite the inherent complexities of this mission and the extensive stakeholder cooperation it requires, reducing embodied energy within the building sector, particularly in housing, remains an urgent necessity. The intricate

nature of this challenge must not delay action. It is an essential responsibility that the construction sector must undertake immediately and support continuously until long-term climate targets are fully achieved.

Second Project Steering Committee (PSC) Meeting of the Asia Low Carbon Buildings Transition (ALCBT) at New Delhi

Shri Arvind Kumar, Executive Director, BMTPC, chaired the 2nd Project Steering Committee (PSC) Meeting of the Asia Low Carbon Buildings Transition (ALCBT) Project held on July 31, 2026 at New Delhi, marking his first meeting as Chairperson following the responsibility entrusted to him by the Ministry of Housing and Urban Affairs (MoHUA) earlier this year.

The number that anchors this project: 70% of the buildings that will stand in India by 2030 haven't been built yet. That's not a statistic to worry about — it's the largest opportunity we will ever have to get low-carbon construction right, from the first brick.

ALCBT is built around a whole-life approach to building decarbonisation: operational energy efficiency, embodied carbon assessment, capacity building, and investment mobilisation — working alongside PMAY-U 2.0's Technology & Innovation Sub-Mission and our Lighthouse Projects, which stand as live laboratories across the country.

Since first PSC, the project has moved with real momentum. The BEAT institutionalisation programme now spans six states, with teams already at work in four. Thousands of professionals have been trained. A pipeline of bankable retrofit projects is taking shape. Today also saw the launch of two new knowledge products: the India Building Taxonomy Report, and a policy review on low-carbon buildings in India.



Today's discussions carried real weight for what comes next - from bringing the Lighthouse Projects at Lucknow and Panchkula into our pipeline, to hosting the BEAT platform on an Indian government server, to the peer review that will let us trust it at national scale.

The continued progress of ALCBT reflects the strength of collaboration among its partners, including

GGGI, EESL, HEAT International, every consortium and State partners, the Government of Germany through the International Climate Initiative (IKI) and from MoHUA and the Bureau of Energy Efficiency (BEE). Through this collective effort, the project is translating ambition into action, supporting the transition towards low-carbon buildings across India.

Artificial Intelligence And Digital Technologies

For Achieving Adequate Housing For All: Opportunities, Challenges, and Future Directions



Dr. Janardan Singh Chauhan *

Abstract The global demand for adequate, safe, affordable, and sustainable housing continues to grow due to rapid urbanization, population growth, climate change, and increasing economic disparities. According to the United Nations, ensuring “Adequate Housing for All” is a central target of Sustainable Development Goal 11 (SDG 11). Traditional planning and construction methods alone are insufficient to meet the increasing housing demand within the desired time frame. Artificial Intelligence (AI), Building Information Modelling (BIM), Geographic Information Systems (GIS), Digital Twins, the Internet of Things (IoT), drones, robotics, and data analytics are transforming the housing sector by enabling faster planning, efficient resource utilization, improved quality, reduced costs, and better lifecycle management.

This paper reviews the applications of AI and digital technologies across the entire housing value chain, including site selection, planning, design,

construction, project management, operation, and maintenance. It examines global best practices and India’s digital initiatives, discusses implementation challenges, and proposes an integrated framework for AI-enabled affordable housing. The study concludes that responsible adoption of AI, supported by strong governance and capacity building, can significantly accelerate the achievement of SDG 11 while promoting sustainability, resilience, and social inclusion.

Keywords: *Artificial Intelligence, Affordable Housing, SDG 11, BIM, Digital Twin, GIS, Smart Housing, IoT, Digital Construction, Housing Policy.*

1. Introduction

Housing is a basic human need and a cornerstone of social and economic development. Adequate housing provides security, dignity, health, education opportunities, and economic stability. However, rapid urbanization, climate change, rising land values, and increasing construction costs have created an unprecedented housing challenge.

The United Nations has recognized housing as a key component of sustainable development under SDG 11: Sustainable Cities and Communities, which aims to ensure access to adequate, safe, and affordable housing for all by 2030.

Conventional construction practices, however, continue to be constrained by persistent cost overruns, schedule delays, poor coordination among stakeholders, material wastage, quality deficiencies, limited productivity, and adverse environmental impacts. These recurring inefficiencies have underscored the urgent need for a paradigm shift in how housing is planned, designed, and delivered.

Artificial Intelligence and digital technologies offer transformative solutions to these long-standing challenges by enabling data-driven decision-making, automation, predictive analytics, and intelligent infrastructure management across every stage of the housing value chain.

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2. Objectives of the Study

This study seeks to examine the role of Artificial Intelligence in advancing affordable housing and to review the emerging digital technologies that support housing delivery worldwide. It further evaluates the application of AI throughout the housing lifecycle and assesses the opportunities such technologies present for improving sustainability and affordability. In addition, the paper identifies the principal challenges associated with implementation, develops an integrated framework for AI-enabled housing systems, and puts forward policy measures that can help accelerate progress toward SDG 11.

3. Research Methodology

This paper is grounded in a comprehensive review of peer-reviewed research papers, United Nations publications, government policy documents, international case studies, and industry reports, complemented by a comparative analysis of AI technologies, digital construction practices, and sustainable housing literature. The study adopts a qualitative and analytical research approach.

4. Artificial Intelligence in the Housing Sector

Artificial Intelligence refers to computer systems capable of performing tasks that normally require human intelligence, including learning, reasoning, prediction, optimization, and decision-making.

The AI technologies most relevant to housing encompass Machine Learning, Deep Learning, Computer Vision, Natural Language Processing, Expert Systems,

Predictive Analytics, Generative AI, and Reinforcement Learning. Collectively, these technologies improve efficiency throughout the housing lifecycle, from initial demand forecasting to long-term facility management.

5. Digital Transformation of Housing

The housing sector is undergoing rapid digital transformation, driven by the convergence of Artificial Intelligence, Building Information Modelling, Geographic Information Systems, Digital Twins, Cloud Computing, Big Data, Blockchain, the Internet of Things, Robotics, and Drone Technology. Together, these technologies enable integrated planning, faster project execution, improved quality control, and smarter asset management across the entire housing value chain.

6. AI Applications Across the Housing Lifecycle

6.1 AI-Based Housing Demand Forecasting

Machine learning models analyze population growth, migration trends, household income, employment patterns, urban expansion, and demographic changes to generate accurate housing demand predictions. These insights support better investment planning, help reduce housing shortages, and contribute to improved policy formulation.

6.2 AI-Based Site Selection

Selecting appropriate land is one of the most critical decisions in housing development. Artificial Intelligence integrates data relating to soil conditions, flood susceptibility, seismic zones, transportation networks, utilities, land-use regulations,

and environmental constraints, enabling faster decision-making, reduced project risks, optimized infrastructure planning, and more sustainable land utilization.

6.3 AI-Assisted Architectural Design

Generative AI tools can produce multiple design alternatives based on user-defined constraints such as plot dimensions, budget, energy efficiency, ventilation, daylighting, structural requirements, and local building codes. This capability reduces design time, optimizes space utilization, enhances energy performance, and improves occupant comfort.

6.4 AI in Structural Design Optimization

AI algorithms assist engineers by optimizing structural layouts, member sizing, material quantities, foundation systems, seismic performance, and wind resistance, leading to structures that are both safer and more economical, with significantly lower material consumption.

6.5 AI-Based Cost Estimation

Traditional estimation methods often rely on historical data and manual calculations. Artificial Intelligence improves quantity take-offs, material forecasting, labour estimation, equipment scheduling, budget optimization, and risk assessment, resulting in more accurate and reliable project costing.

6.6 AI in Construction Scheduling

Artificial Intelligence enhances project management by predicting delays, optimizing resource allocation, identifying bottlenecks, improving labour productivity, and monitoring project progress in real

time, thereby reducing overall construction time and improving delivery performance.

7. Building Information Modelling (BIM)

Building Information Modelling (BIM) is a digital representation of the physical and functional characteristics of a building throughout its life cycle. BIM serves as a shared knowledge resource that enables architects, engineers, contractors, and facility managers to collaborate efficiently.

7.1 Applications of BIM in Affordable Housing

In affordable housing projects, BIM supports digital architectural and structural design, quantity take-off and cost estimation, and clash detection among building services. Its multidimensional capabilities extend to construction sequencing through 4D BIM, cost management through 5D BIM, sustainability analysis through 6D BIM, and facility management and maintenance through 7D BIM.

7.2 Benefits

The adoption of BIM has been shown to deliver a 15–20% reduction in construction costs and up to a 30% reduction in design errors, alongside faster project completion, improved quality control, reduced material wastage, and better lifecycle asset management.

8. Digital Twins for Smart Housing

A Digital Twin is a virtual replica of a physical building that continuously receives data from sensors installed in the structure. It is built upon an integrated combination of a BIM model, IoT sensors, cloud computing, artificial

intelligence, and a data analytics platform.

8.1 Applications

Digital Twins support structural health monitoring, predictive maintenance, and energy optimization, while also enabling water consumption monitoring, indoor environmental quality assessment, occupancy management, and emergency response planning.

8.2 Benefits

These capabilities translate into lower maintenance costs, extended building life, reduced operational expenditure, improved occupant safety, and enhanced sustainability.

9. Geographic Information System (GIS)

GIS enables planners to analyze spatial and geographic data for better housing development decisions, including the identification of suitable housing sites, land-use planning, population density mapping, utility infrastructure planning, flood risk assessment, earthquake hazard mapping, and transportation accessibility analysis.

AI + GIS Integration

When combined with Artificial Intelligence, GIS enables automated land suitability analysis, urban growth prediction, climate risk assessment, infrastructure optimization, and smart city planning.

10. Internet of Things (IoT) in Housing

The Internet of Things connects building components through sensors and communication networks, giving rise to a wide range

of smart housing applications.

10.1 Energy Management

Smart electricity meters, occupancy-based lighting, HVAC optimization, and solar energy monitoring together enable more efficient and responsive energy use within housing developments.

10.2 Water Management

Smart water meters, leak detection systems, rainwater harvesting monitoring, and greywater reuse systems help conserve water resources and reduce wastage.

10.3 Safety

IoT-enabled fire detection, gas leakage monitoring, intrusion detection, and integration with earthquake early warning systems significantly enhance occupant safety.

10.4 Indoor Comfort

Continuous monitoring of temperature, humidity, air quality, and noise levels contributes to healthier and more comfortable indoor living environments.

11. Drone Technology

Drones are becoming indispensable in affordable housing projects, supporting topographic surveys, site mapping, progress monitoring, material inventory inspection, roof inspection, thermal imaging, and disaster assessment.

Their use delivers faster surveys, improved accuracy, reduced labour requirements, enhanced worker safety, and better project documentation.

12. Robotics and Automation

Construction robotics addresses labour shortages and improves

productivity through emerging applications such as robotic bricklaying, concrete 3D printing, automated plastering, steel reinforcement tying, autonomous earthmoving equipment, and robotic demolition.

These technologies improve construction quality, reduce human errors, accelerate execution, enhance worker safety, and lower long-term costs.

13. Blockchain Technology

Blockchain provides secure and transparent digital records, with housing applications spanning digital land records, property ownership verification, smart contracts, housing subsidy management, construction payment tracking, and supply chain transparency.

These applications reduce fraud, enable faster transactions, improve transparency, and enhance trust among stakeholders.

14. Big Data Analytics

Housing generates enormous volumes of structured and unstructured data. AI-powered analytics supports housing demand forecasting, market trend analysis, construction productivity evaluation, infrastructure planning, energy consumption analysis, and policy impact assessment, allowing governments to develop evidence-based housing policies.

15. Smart Housing Ecosystem

A future-ready housing ecosystem integrates multiple digital technologies, including Artificial Intelligence, BIM, GIS, Digital Twins, IoT, Blockchain, renewable energy systems, smart grids, cloud computing, and mobile applications.

The resulting outcomes include more affordable housing, sustainable communities, greater energy efficiency, climate resilience, improved public services, and an overall better quality of life for residents.

16. International Best Practices

16.1 Singapore

The Housing & Development Board (HDB) uses BIM, digital construction technologies, AI-assisted planning, and smart estate management to deliver high-quality affordable housing efficiently.

16.2 Finland

Finland employs AI-driven urban planning and digital governance while following the “Housing First” model to reduce homelessness and improve social inclusion.

16.3 Japan

Japan integrates robotics, prefabrication, BIM, and earthquake-resistant smart construction technologies to enhance housing quality and resilience.

16.4 United Arab Emirates

Dubai has adopted AI-enabled building approvals, digital permitting systems, BIM, and 3D printing technologies to accelerate housing and infrastructure development.

16.5 India

India is increasingly adopting a range of digital initiatives, including the PM Gati Shakti Digital Platform, national GIS initiatives, BIM in infrastructure projects, drone-based land surveys, digital land records, the Smart Cities Mission, technology innovations

under the Pradhan Mantri Awas Yojana (PMAY), and the Affordable Sustainable Housing Accelerators (ASHA) programme.

17. Discussion

The integration of AI and digital technologies across the housing lifecycle demonstrates significant potential to improve affordability, quality, sustainability, and resilience. BIM and Digital Twins enable better planning and lifecycle management, while GIS and AI support evidence-based site selection and urban development. IoT enhances operational efficiency, and blockchain improves transparency in land records and housing subsidies.

However, successful implementation depends on digital infrastructure, skilled professionals, supportive regulations, data governance, cybersecurity, and sustained investment in research and innovation.

18. Challenges in Implementing AI for Affordable Housing

Although AI and digital technologies have enormous potential, several barriers continue to hinder their widespread adoption across the housing sector.

18.1 Technical Challenges

Technical barriers include the lack of standardized digital construction practices, poor interoperability between software platforms, limited availability of high-quality datasets, cybersecurity vulnerabilities, and inadequate digital infrastructure in rural areas.

18.2 Financial Challenges

Financial barriers include the high initial investment required for AI software and hardware,

the cost of BIM implementation and training, the limited financial capacity of small developers, and the ongoing maintenance costs of digital infrastructure.

18.3 Human Resource Challenges

Human resource barriers include a shortage of AI and BIM professionals, limited digital literacy among construction workers, resistance to technological change, and inadequate academic curricula on AI-enabled construction.

18.4 Policy and Regulatory Challenges

Policy and regulatory barriers include the absence of comprehensive AI standards for housing, fragmented digital governance, a lack of legal frameworks for AI-based decision-making, and slow approval processes.

18.5 Ethical Challenges

Ethical concerns include algorithmic bias in housing allocation, data privacy issues, limited transparency of AI-driven decisions, unclear accountability for AI-generated outcomes, and the risk of digital exclusion among vulnerable communities.

19. AI Governance Framework for Housing

To ensure responsible adoption, an AI governance framework for the housing sector should rest on five interconnected pillars.

Pillar 1: Data Governance

This pillar calls for secure housing databases, standardized data formats, robust data quality assurance, strong privacy protection, and the promotion of open data where appropriate.

Pillar 2: Technology Standards

This pillar encompasses national BIM standards, Digital Twin protocols, AI interoperability guidelines, and clearly defined cybersecurity requirements.

Pillar 3: Institutional Capacity

This pillar emphasizes AI training for engineers and planners, capacity building for government agencies, university–industry collaboration, and the establishment of dedicated research and innovation centres.

Pillar 4: Legal and Ethical Framework

This pillar requires robust AI accountability mechanisms, fair and transparent algorithms, safeguards against discrimination, and the responsible use of citizen data.

Pillar 5: Continuous Monitoring

This pillar involves the use of clear performance indicators, independent audits, structured user feedback systems, and periodic policy review.

20. Proposed AI-Enabled Housing Delivery Model

An integrated, AI-driven housing system is proposed below to improve efficiency and sustainability across five key stages.

Stage 1: Planning

The planning stage relies on AI-based housing demand forecasting, GIS-assisted land suitability analysis, climate risk assessment, and comprehensive infrastructure mapping.

Stage 2: Design

The design stage draws on BIM-based collaborative design, generative AI for optimized layouts, structural optimization, and energy

performance simulation.

Stage 3: Construction

The construction stage employs AI-assisted project scheduling, robotics and automation, drone-based monitoring, and smart procurement systems.

Stage 4: Operation and Maintenance

The operation and maintenance stage utilizes Digital Twins for lifecycle management, IoT-enabled monitoring, predictive maintenance, and energy and water optimization.

Stage 5: Policy and Governance

The policy and governance stage is supported by blockchain-enabled land records, digital approval systems, AI-supported subsidy management, and real-time performance dashboards.

21. Expected Outcomes

Implementation of the proposed framework can deliver a 20–30% reduction in project duration and a 10–20% reduction in construction costs, alongside improved quality and safety, lower material wastage, and reduced carbon emissions. It can further enhance transparency in housing allocation, strengthen resilience against climate-related disasters, and improve overall citizen satisfaction.

22. Policy Recommendations

Realizing the full potential of AI-enabled housing will require a coordinated set of policy actions. Governments should prepare a National AI Strategy for Affordable Housing and mandate BIM adoption for all large public housing projects, while developing a National Housing Digital Platform that integrates AI, GIS, and BIM

into a single system. Public–Private Partnerships should be encouraged to drive AI-enabled housing innovation, supported by tax incentives for digital construction technologies and the promotion of low-carbon, sustainable building materials.

On the institutional side, it is important to establish AI and Digital Construction Centres of Excellence within engineering institutions and to introduce AI, BIM, GIS, and Digital Twin courses into engineering curricula. These efforts should be complemented by stronger cybersecurity and data protection regulations, together with deeper international collaboration in AI-enabled housing research.

23. Future Research Directions

Further research should focus on Explainable AI (XAI) for transparent housing decisions and AI-based disaster-resilient housing systems, as well as the integration of renewable energy with smart housing. Additional priorities include Digital Twins for affordable housing maintenance, AI-driven carbon-neutral housing, robotics for low-cost construction, climate-adaptive housing using predictive analytics, and circular economy applications supported by AI.

24. Conclusion

Artificial Intelligence and digital technologies are reshaping the future of affordable housing. From planning and design to construction, operation, and maintenance, AI enables faster decision-making, optimized resource utilization, enhanced quality, and reduced lifecycle costs.

The integration of BIM, GIS, Digital Twins, IoT, blockchain, drones, robotics, and data analytics offers a transformative pathway for achieving Sustainable Development Goal 11 – Adequate Housing for All. These technologies not only improve project efficiency but also contribute to environmental sustainability, climate resilience, and social inclusion.

For countries such as India, where rapid urbanization and housing shortages remain major challenges, AI-driven housing systems can play a pivotal role in accelerating housing delivery while ensuring affordability and quality. Success, however, will depend on supportive policies, skilled human resources, ethical AI governance, robust digital infrastructure, and strong collaboration among governments, academia, industry, and communities.

The future of housing lies in combining human-centered policies with intelligent digital technologies, ensuring that every citizen has access to safe, affordable, sustainable, and resilient housing.

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32. Dr. J.S. Chauhan – Education, Employability, & Aatmanirbharta: Housing Federation Initiatives for Bridging Youth SKILL Gaps (NCHF Bulletin Vol. XXXVIII No. 07 January 2026).

33. Dr. J.S. Chauhan – Advanced roofing materials and Innovative concrete technologies for sustainable construction (NCHF Bulletin Vol. XXXVIII No. 10 April 2026).

Technical Session on Building Emission Assessment Tool (BEAT)

A technical session to evaluate the Building Emission Assessment Tool (BEAT) was organised at BMTPC on 24 April 2026 by the Global Green Growth Institute (GGGI), in association with HEAT International, Germany, and CII, India.

BEAT is an open-source, web-based platform developed by HEAT GmbH under the Asia Low Carbon Buildings Transition (ALCBT) Project. The tool assesses carbon emissions across a building's life cycle, including embodied emissions (A1–A3), operational energy emissions, and flexible data entry through Bill of Quantities (BoQ) or component-based methods. The session provided an opportunity to understand the tool's features and explore its applicability for low-carbon building practices.



Beyond The Minimum: Shelter For Recovery



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Introduction

Disasters are defined as events that cause loss of life, injury or other health impacts along with damage to assets, ecosystem and resources (IPCC, 2022), transforming the security of everyday life in a matter of minutes. Homes are damaged or destroyed, infrastructure is disrupted, livelihoods are interrupted, and familiar places become unsafe or inaccessible. People are forced to evacuate their homes due to immediate threats or may become displaced due to damaged dwellings.

In this immediate aftermath, the question of safety & security becomes one of the most urgent concerns of disaster response. Food, water, healthcare and sanitation are critical, but each of these services must reach people somewhere. Shelter therefore becomes the physical setting within which relief is delivered and the first conditions for recovery are established, creating an

immediate need for safe temporary accommodation until affected populations can return home or transition to other forms of shelter. The need for shelter is thus closely associated with disaster response & recovery, with varying degrees of requirement as the circumstance of displaced population change.

Shelter needs evolve throughout the disaster cycle. From immediate refuge focused on life safety, protection & essential services, to stable temporary/transitional shelters supporting livelihood, education, & everyday activities during early recovery and finally to permanent housing through rehabilitation & reconstruction. The shelter forms a continuum corresponding to the duration and changing needs of displacement, from emergency relief to permanent housing. The distinction between these is important because a shelter meant for emergency response may not be expected to fulfil all the requirements of a shelter for long

term rehabilitation. Although, the quality of each remains significant as it forms the space where displaced people experience life after loss.

Immediate Relief: First step towards Recovery

The immediate relief stage is a crucial point of intervention within the shelter continuum. Although emergency shelters are temporary, they may become the primary living environment of displaced population for days or weeks. They act as temporary centers around which essential services such as food, water, sanitation, healthcare, protection & information are catered to. Their effectiveness consequently depends not only on meeting the minimum specified requirements, but also providing safe, accessible & habitable environments for the people. Agencies frame the vitality of such environments not only to cater to survival and protection, but to improve health, dignity and well-being of its residents.

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Figure 1 Existing scenarios in emergency shelters/ relief camps in India
(Source: Sikkim state legal services; South china morning post)

Shelter shaped by bare Necessities: Ground Reality

Since the primary objective following a disaster is to remove people from the hazard and to provide a safe place. The immediate response is to use purpose-built emergency shelters or public and community infrastructure to house the displaced people. A major part of this requirement is met by permanent public buildings such as schools, auditoriums, as well as religious buildings. Such spaces are preferred partly by the people because of their familiarity, existing social bonds as well as perceived safety (Andrew et al., 2013). The active shelter accommodates people collectively depending on the resources, along with basic provisions for amenities made available by the government or organizations addressing water, sanitation, food, healthcare, etc.

The existing condition of the building directly affects the health, safety and comfort of its inhabitants, especially to vulnerable groups such as the elderly, people with chronic illnesses, etc. (Thomas et al., 2023). Prolonged collective living can create social difficulties

through various issues such as lack of privacy, conflicts among inhabitants, unsocial behavior & psychological stress. The quality of living in the shelter tends to influence the psychological well-being of the people, during the period of uncertainty, loss and disruption of normalcy. Poorly organized shelters, catering only to minimum survival standards, create difficulties related to habitability, privacy, services and overall quality of living.

From Minimum to Adequate: Beyond survival

Global and National guidelines pertaining to humanitarian response and emergency relief operations establish minimum standards for aspects related to basic services that are deemed necessary for early recovery. These form the baseline for technical and operational planning & action for an adequate relief system. However, beyond the minimum standards are the diverse experiences and challenges faced by the people. Sphere frames humanitarian standards around rights of people to assistance, protection, security and dignity

(Sphere, 2018). UNHCR Collective Centre Guidelines recommends safe & secure living environment with privacy and dignity (UNHCR & IOM, 2010). Quantifiable requirements recommended are directly addressed, whereas less tangible dimensions such as privacy, social relationships, cultural appropriateness, comfort, etc are difficult to establish and consequently easier to overlook.

Habitability forms an important basis for shelter planning through safety, health, sociality & comfort, where the shelter quality extends beyond physical provision to include privacy, accessibility, community and indoor environmental quality (IEQ) (Choi et al., 2020). Interviews with inhabitants, staff & volunteers identified deficiencies in space, protection, privacy, accessibility & sanitation, recommending that it should provide space beyond legal minimums, manage IEQ and distinguish spaces according to functions and user groups (Kim et al., 2021). Minimum standards establish the baseline for emergency response, whereas adequacy must be interpreted through lived experiences and vulnerabilities.

What makes a Shelter Suitable?

A structurally sound building may still perform poorly as a relief shelter if it is difficult to reach, inaccessible to people with reduced mobility, lacks privacy, has inadequate spaces for everyday activities or creates conflicts between different users. Current research point to Multi Criteria Decision Making (MCDM) models for shelter assessment and selection through several criteria ranging from physical, environmental, social, financial and operational. Analytical Hierarchy Process (AHP) based framework evaluates the relative weights of each criterion to recommend priority based on acquired data. Aggregated weightings gave equal importance to hard characteristics (hazard, physical vulnerability) and soft characteristics (accessibility, communication, living environment) (Tsioulou et al., 2021). Assessing the adaptive reuse potential of buildings as emergency shelters should be done in a 2-step qualitative manner – first, identifying the veto criteria including hazard risk of the site, structural stability, ownership status, etc., which will directly eliminate the building. Secondly, a risk-based design evaluation pertaining to health, security, safety, psychological risks & risk to vulnerable groups, complying to the human factors (Idemen et al., n.d.). The human dimension can be brought into assessment through criteria such as accessibility, privacy, living environment, sociality, comfort, support for vulnerable groups and proximity to social and essential services.

From Standards to People: Designing With, than For

Participation provides a practical bridge between standards and lived experience. International humanitarian guidelines place participatory approach at the foundation of quality humanitarian response and emphasize that the displaced population should be involved in decisions for recovery (Sphere, 2018). Diverse needs are difficult to anticipate through universal physical standards alone. Community consultation

to formulate spatial brief and carry out iterative design process through continued consultation contributes to making culturally appropriate and socially relevant outcomes (Dev, K. N. & Das, A. K., 2020). Operating on several levels, from identifying vulnerabilities before disasters, assessing infrastructure, developing standards, testing interventions to evaluating functioning shelters, participation recognizes residents as contributors than mere recipients of assistance. In case of public buildings, this is particularly



Figure 2 Participatory building for feedback-based iterations
(Source: Camarinhas et al., 2025)



Figure 3 Full scale mockup by participants
(Source: Camarinhas et al., 2025)

significant, since its functionality, perception, and challenges can effectively be obtained from those who use and manage the space.

Prototyping: Design, Test, Revise

Translating identified criteria into tangible interventions that can function under emergency situations can be achieved through prototyping, where it acts as a bridge between research, participation and implementation. Unlike a top-down fixed design approach, prototyping and participation adopts a bottom up and feedback based iterative process to build, test, evaluate and revise. Dev and Das (2020) developed a temporary bamboo shelter by understanding the local culture to develop a spatial brief, generating a design and refining it through continued interactions with users (Dev, K. N. & Das, A. K., 2020). Dash (2022) combined literature guidelines along with material analysis

and stakeholder consultation to propose a prototype, engaging local communities and victims in the process (Dash et al., 2022).

Conclusion

Emergency shelter, although the shortest and most temporary phase of post-disaster response, can become the first setting of rest and recovery after uncertainty and loss for the displaced. International standards establish minimum requirements and recognize human principles yet fail to get translated into reality. A vulnerability-based approach can be the bridge between policies and people. Who will use this space? What are their necessities? Can people with diverse needs use it independently? Can families maintain social relationships while retaining personal space? Does the environment support easy recovery and wellbeing? Such questions can guide pre-disaster building assessments, ranking frameworks,

guidelines and ultimately, preparedness. Community participation, expert knowledge and feedback can create a system improved continually through experience. The ultimate objective of emergency shelter is to create a safe and habitable environment from which recovery can begin. Adequate housing, therefore, begins before permanent houses are built. Recovery traverses throughout the shelter continuum.

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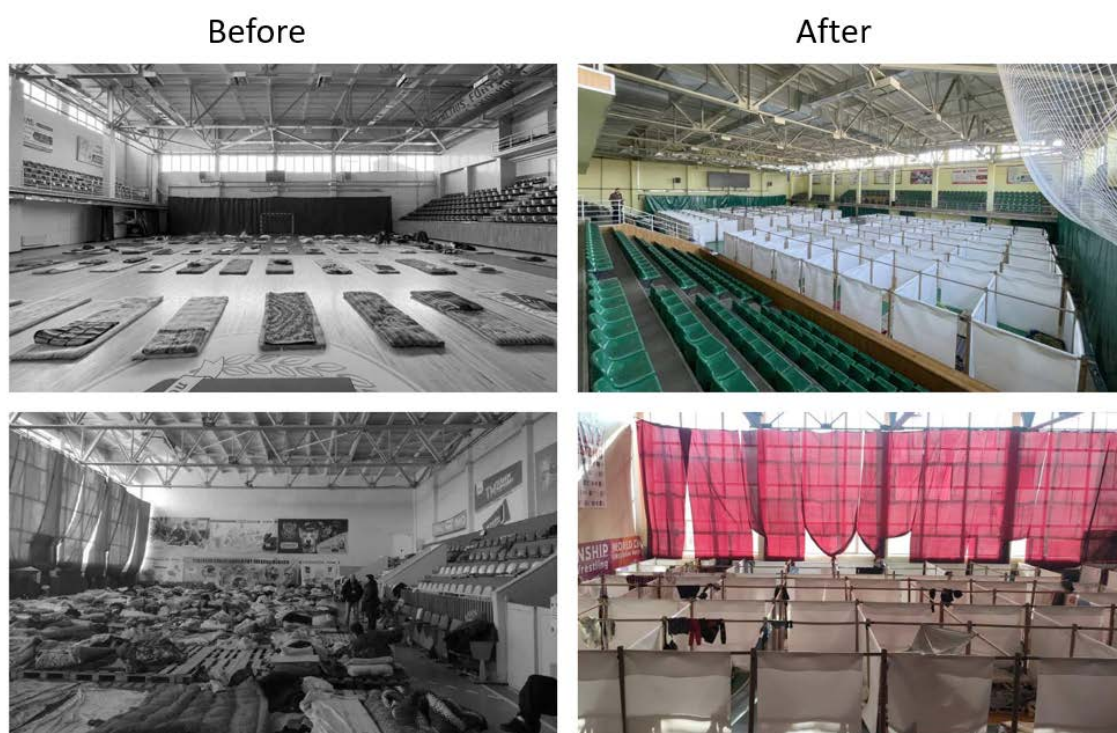


Figure 4 Temporary shelters, Japan – Shigeru Ban Architects

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Policy Prototyping Workshop on Green Building Materials at New Delhi

BMTPC was invited to deliver special remarks at the Policy Prototyping Workshop on “Accelerating the Market Adoption of Green Building Materials – Pathways to Net Zero”, organised by the Global Buildings Performance Network (GBPN) on 14 May 2026 in New Delhi. The workshop brought together key stakeholders to deliberate on strategies for accelerating the adoption of green building materials and promoting low-carbon, resource-efficient construction practices in India. Discussions focused on identifying policy measures, market-based interventions and enabling frameworks to facilitate the wider use of sustainable building materials and technologies. The need for greater innovation, awareness and market readiness was also highlighted to support the transition towards greener construction practices. Particular emphasis was placed on developing actionable and time-bound roadmaps for effective implementation.



SENTINEL: Advancing Affordable, Resilient and Sustainable Housing in India



Dr. R. Senthilkumar *



Dr. Uma Chandru *

Abstract
Rural housing is a critical component of India's socio-economic development, contributing to improved living conditions, public health, and reduced migration. Government initiatives such as the Pradhan Mantri Awas Yojana-Gramin (PMAY-G) aim to provide permanent and disaster-resilient housing. However, delivering safe and affordable housing at scale remains challenging, particularly in hazard-prone regions, due to prolonged construction periods, labour dependence, high material consumption, and variability in workmanship. SENTINEL is a full-scale housing prototype developed by translating laboratory research into a practical field construction system. It integrates cold-formed steel (CFS)-concrete composite members with lightweight and eco-friendly materials. CFS columns and CFS-concrete composite beams provide gravity-load resistance, while composite shear walls serve as the principal lateral-load-resisting system for improved earthquake resilience. A

demonstration building developed at NIT Tiruchirappalli achieved completion of its defined civil works in approximately 25 active working days at a reported cost of about ₹1,750 per sq.ft against the prevailing market rate of ₹2100–₹2200 per sq ft, resulting in an approximate 20% cost reduction. The prototype demonstrates the potential of SENTINEL as a rapid, affordable and resilient housing system, while providing a platform for further validation, standardization, prefabrication and wider deployment. It represents a promising pathway towards scalable and sustainable housing solutions for diverse regional and socio-economic contexts.

Keywords: *Cold-formed steel; Composite construction; Earthquake resilience; Affordable housing; Rapid construction; Sustainable construction.*

1. The Housing Challenge

Adequate housing is increasingly recognized as a multidimensional requirement that extends beyond the provision

of basic shelter. A suitable dwelling must ensure safety, durability, affordability and a healthy living environment, while also responding to the specific climatic, geographical and socio-economic conditions of its occupants. For India, particularly in the rural and economically vulnerable segments, the challenge is therefore both quantitative and qualitative: housing must be delivered at scale without compromising structural safety, serviceability, affordability or long-term performance. Improved housing plays an important role in enhancing living standards and supporting broader rural development. Beyond providing secure shelter, housing can stimulate employment in construction and allied sectors, strengthen local economies, and contribute to the overall well-being of rural communities. Sustainable and affordable housing therefore contributes not only to individual welfare but also to India's broader development priorities and the objectives of the Sustainable Development Goals (SDGs).

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In this context, the rapid delivery of rural housing is essential for addressing housing shortages, improving living conditions and accelerating inclusive rural development. Delays in housing construction can prolong the dependence of families on inadequate or unsafe dwellings and hinder improvements in overall living conditions. Faster and more efficient construction approaches can help address housing backlogs while reducing project durations and enabling households to access safe and durable shelter at the earliest possible stage. This highlights the need for cost-effective, scalable and rapidly deployable construction technologies that can support large-scale rural housing programs while maintaining quality, safety and long-term performance. Conventional Reinforced Cement Concrete (RCC) construction remains widely adopted; however, its suitability for rapid and large-scale housing can be constrained by extended construction cycles, dependence on skilled and semi-skilled labour, and the intensive use of cement, steel and water [1]. In remote and rural locations, transportation and handling of construction materials can further influence project cost and schedule. Moreover, the relatively high self-weight and material intensity of conventional construction increase the demand on structural components and foundations. In hazard-prone regions, the safety of RCC buildings also depends strongly on appropriate structural design, seismic detailing, construction quality and workmanship. At the same time, growing emphasis on sustainable construction calls for reduced material

consumption, construction waste and environmental impact. These considerations create a need for innovative systems that combine structural efficiency with faster construction, affordability and resilience.

The SENTINEL project responds to this need by exploring an integrated, technology-driven approach to housing delivery. Its central proposition is that adequate housing should be safe, durable, affordable, sustainable and rapidly deployable, providing a pathway towards resilient housing solutions that can be adapted and scaled for diverse regional requirements. Achieving these objectives together calls for a shift from construction conceived as a sequence of site-intensive trades towards construction conceived as an integrated technology and housing-delivery system.

2. Introducing SENTINEL

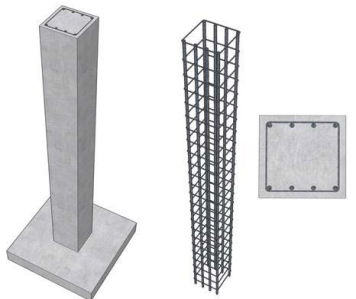
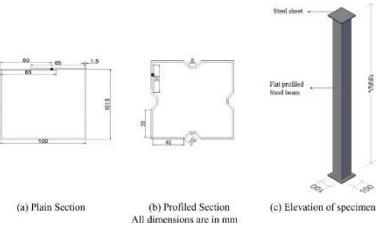
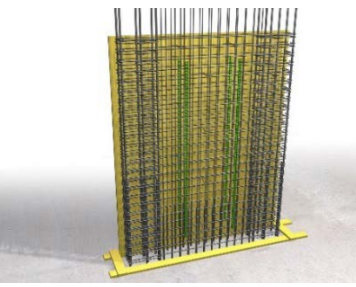
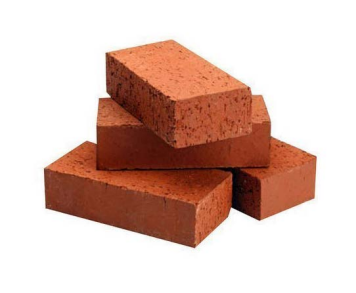
SENTINEL is a full-scale housing prototype developed to demonstrate the translation of laboratory-based research into a practical, rapidly constructible and resilient building system. Developed by Senvira Engineering Pvt. Ltd., a faculty-led start-up incubated at NIT Tiruchirappalli, the prototype was conceived as a rapid and earthquake-resilient housing model and constructed within the NIT Tiruchirappalli campus. The project documentation describes a single-storey demonstration building of approximately 420 sq.ft., providing a full-scale platform for evaluating the constructability and integration of the proposed system.

The structural concept combines cold-formed steel (CFS)

and concrete through composite construction. CFS columns [2] and CFS-concrete composite beams [3–7] provide an efficient gravity-load-resisting framework, with the potential to reduce structural self-weight compared with conventional RCC construction. CFS-concrete composite shear walls [1,8,9] constitute the principal lateral-load-resisting system and are intended to address lateral and seismic actions.

By combining the complementary properties of steel and concrete, the system seeks to achieve an efficient balance of strength, stiffness and reduced structural weight. The SENTINEL prototype incorporates eco-friendly bricks for the entrance steps, demonstrating the integration of more sustainable material options within the overall construction system. This application promotes responsible material utilisation and offers an opportunity to reduce the environmental impact associated with conventional construction materials. Table 1 presents the conventionally used components vs. lab-tested and field-executed components in the structure. Importantly, SENTINEL extends beyond the development of individual structural components to address the overall construction process. The use of repeatable CFS sections, lightweight walling and simplified construction sequences supports a more streamlined approach to building execution. This creates opportunities for improved construction efficiency, consistency and scalability. Thus, SENTINEL is positioned not merely as an alternative structural system, but as an integrated housing-delivery approach that brings together structural performance,

Table 1 : Components used in the structure

Sl. No	Conventionally used component	Lab-Tested component	Field Executed component
1			
	Conventionally used RCC beams with heavy reinforcement	Optimized Cold-formed Steel-concrete composite beam [3–7]	Erection of Cold-formed Steel-Concrete composite beam
2			
	Conventionally used RCC columns with heavy reinforcement	Concrete-filled plain and profiled cold-formed steel column specimens [10]	The back-to-back CFS channel sections are connected using self-tapping screws to form a CFS I-section as a column
3			
	Conventionally used RCC shear walls with dense reinforcement	Profiled Cold-formed steel - lightweight concrete composite shear wall [1,8,9]	Flat Cold-formed steel concrete composite shear wall
4			
	Conventionally used Clay bricks	Lightweight, eco-friendly blocks incorporating SCMs	Eco-friendly, low cost bricks incorporating SCMs

constructability, material efficiency, construction speed and resilience. The successful realisation of the full-scale prototype represents an important step from laboratory research towards further validation, standardisation, prefabrication and potential deployment of the technology for scalable housing and disaster-resilient construction.

3. From Laboratory Research to Full-Scale Demonstration

One of the key strengths of SENTINEL is its systematic progression from laboratory research to the realisation of a full-scale building. Rather than limiting the development to individual structural components, the project demonstrates how research outcomes can be integrated into a functional construction system and evaluated under actual site conditions. This transition provides an important link between experimental investigation, structural design and practical construction. The development of SENTINEL followed a progressive pathway encompassing component-level research and

testing, structural optimisation, material development, design, fabrication, field construction and full-scale demonstration. Laboratory investigations included the development and evaluation of CFS-concrete composite beams, CFS column specimens and CFS-concrete composite shear wall specimens. The knowledge gained from these investigations was subsequently translated into field-executable structural components.

3.1 Optimised Cold-Formed Steel-Concrete Composite Beam

Cold-formed steel-concrete composite beams combine a CFS beam and RCC slab to act as a single structural unit, providing enhanced stiffness and strength. In this study, back-to-back channel CFS sections connected with self-tapping screws were used with an RCC slab. CFS elements are very thin making it impossible to weld the shear connectors to the CFS beam, as it may induce residual stresses. Hence, the conventionally used shear connectors of hot-rolled steel cannot be used for CFS-concrete composite beams.

Hence, six different novel shear connectors were proposed, and their performance was assessed by the Push-out test as per Eurocode 4. The different shear connectors adopted were single-channel, double-channel, trapezoidal, hexagonal, self-tapping screw and prefabricated shear connectors. The prefabricated shear connector is a novel cold-formed steel shear connector that can be easily amended for CFS construction without welding, and it has been granted an Indian Patent No. 414619 [7]. Among the six connectors, the double-channel (Fig. 1) and prefabricated shear connectors (Fig. 2) demonstrated good composite action and were subsequently tested in full composite beams [3–6]. Additionally, both the shear connectors were incorporated in cold-formed steel-concrete composite beams and tested experimentally. Both connectors remained intact until beam failure, confirming their effectiveness and reliability for CFS-concrete composite construction (Fig. 3).

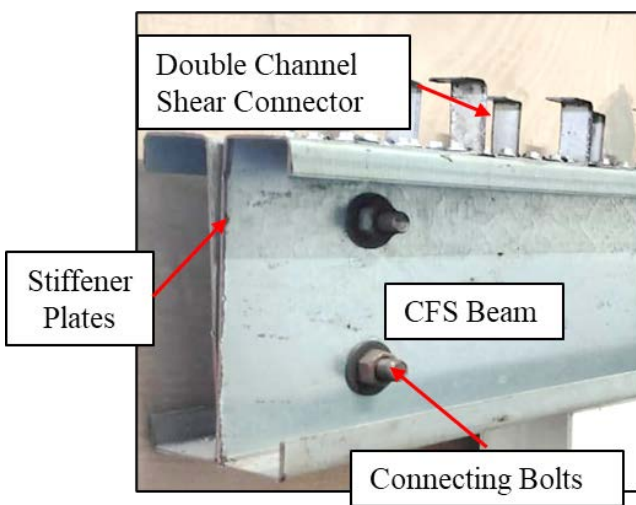


Figure 1 - Composite Beam with Double Channel Shear Connector

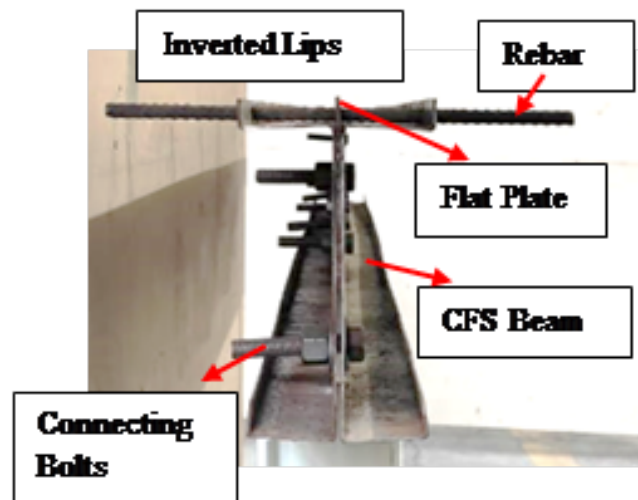


Figure 2 - Composite Beam with Prefabricated Shear Connector



Figure 3 – Failure of Cold-formed steel-concrete composite beam under flexural loading

3.2 Optimised Cold-Formed Steel Columns

CFS sheets can be efficiently formed into various cross-sectional configurations and assembled using self-tapping screws to develop lightweight structural columns. Concrete-filled CFS composite columns can also be employed to enhance structural performance under axial gravity loads. Experimental and numerical investigations were conducted on plain and profiled CFS columns, with and without web stiffeners, as well as their concrete-filled composite counterparts. The results demonstrated that concrete-filled CFS composite columns achieved nearly four times the axial load-carrying capacity of hollow CFS columns, while the incorporation of web stiffeners further enhanced the load-carrying capacity and overall structural performance [2].

3.3 CFS-concrete Composite Shear wall

A double-skinned steel-concrete composite shear wall consists of CFS sheets placed on both sides of a concrete core. During construction, the profiled steel sheets provide temporary lateral stability to the structural frame and serve as permanent

formwork for the concrete infill. In the completed system, the steel sheets and concrete core act compositely to resist lateral loads, providing enhanced shear capacity with reduced reinforcement requirements. Unlike conventional composite walls using hot-rolled steel plates, cold-formed steel composite walls can employ flat or profiled sheets. Profiling improves mechanical interlock with the concrete, increases plate stiffness and reduces the susceptibility to local buckling. Experimental and numerical studies under monotonic lateral loading and combined lateral and axial loading

demonstrated that profiled steel-concrete composite shear walls exhibit higher load-carrying capacity, stiffness and ductility than their flat-sheet counterparts, making them suitable for low-rise buildings and cold-formed steel housing system [1,8,9]. However, the flat composite walls are comparatively cost-efficient and are easy to construct. Figures 4 and 5 represent the failure pattern of the profiled CFS-concrete composite shear wall specimen.

At the demonstration stage, the building incorporated an optimised CFS-concrete composite beam system, CFS I-section



Figure 4 – Failure in the tension side of the shear wall specimen



Figure 5 – Failure in the compression side of the shear wall specimen

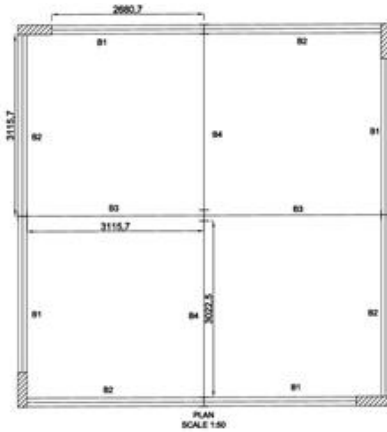


Figure 6 – Plan (All dimensions are in mm)



Figure 7 – Field executed housing model

columns formed using back-to-back CFS channels connected with self-tapping screws, and flat CFS-concrete composite shear walls. This progression illustrates how experimentally developed components can be adapted to practical construction requirements while maintaining an integrated structural system. The full-scale prototype was constructed at NIT Tiruchirappalli, as shown in Figures 6-7. The structural skeleton and masonry works were completed in approximately 25 active working days, excluding festival holidays and interruptions due to rainy conditions. This reported duration specifically relates to the defined civil-works scope and does not include flooring, doors and

windows, roof finishes, staircase provisions and other customizable works.

The SENTINEL prototype therefore represents an important laboratory-to-field transition, demonstrating the constructability of the proposed system and establishing a foundation for further performance assessment, validation, standardisation and potential large-scale deployment.

4. Performance and Construction Advantages

The project data demonstrate the promising construction speed and cost potential of SENTINEL, as represented in Table 2. The reported civil works were

completed in approximately 25 active working days, compared with the reported 2–3 months for the corresponding stage of conventional RCC construction, as shown in Figure 8. The achieved project cost was approximately ₹1,750 per sq.ft., against a project-context benchmark of ₹2,100–₹2,200 per sq.ft., indicating an approximate 20% reduction. The prototype also demonstrated self-supporting structural behaviour after removal of props, along with constructability, stability and architectural feasibility. These results represent an important first-stage demonstration; however, long-term performance, standardisation and wider deployment require continued

Table 2: Parameters used in Sentinel and conventional construction

Parameter	SENTINEL demonstration	Conventional construction
Civil construction duration	≈ 25 active working days	≈ 2–3 months for corresponding civil-works stage
Demonstrated construction cost	≈ ₹1,750/sq.ft.	≈ ₹2,100–₹2,200/sq.ft.
Structural system	CFS–concrete composite	Conventional RCC
Structural weight	Lower self-weight	Generally higher
Seismic concept	CFS–concrete composite lateral-load system	Conventional RCC lateral system
Plastering	Reduced/avoided in selected areas, subject to finish specification	Commonly used
Industrialisation potential	High potential through prefabrication/standardisation	Moderate in conventional site-based practice

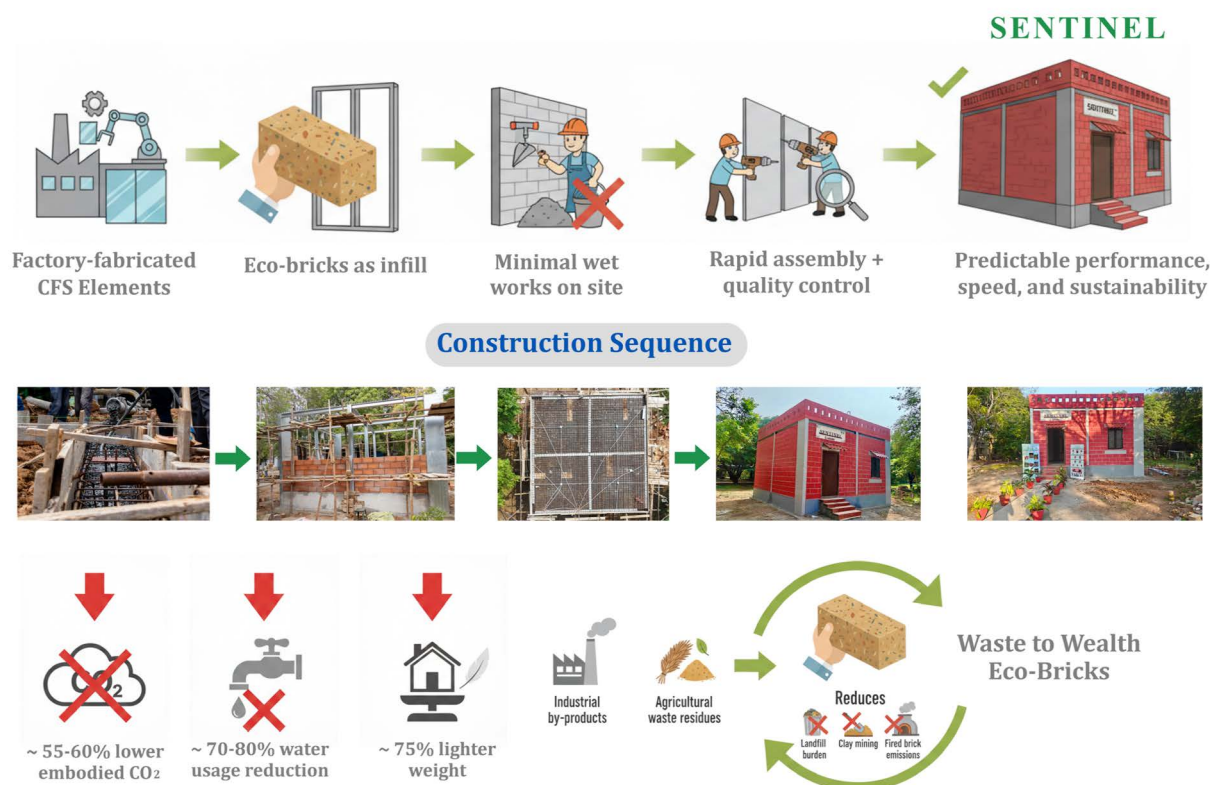


Figure 8 - Construction Timeline

monitoring, independent evaluation and further validation.

5. Why SENTINEL Can Support “Adequate Housing for All”?

SENTINEL addresses the key requirements of adequate housing through five interrelated attributes:

- **AFFORDABLE** - The demonstrated project cost is approximately ₹1,750/sq.ft. The reduced structural weight may also offer opportunities for foundation optimisation, subject to site-specific design.
- **RAPID** - The defined civil works were completed in approximately 25 active working days, demonstrating the potential for shorter construction cycles.
- **SAFE-CFS**—concrete composite shear walls form the principal lateral-load-resisting system, with earthquake resilience as a key design objective.

- **SUSTAINABLE** - Lightweight construction and the use of eco-friendly materials support reduced material intensity and environmental impact, subject to project-specific assessment.
- **SCALABLE** - Repeatable CFS components, standardised connections and modular planning provide opportunities for prefabrication, standardisation and wider deployment.

6. Potential Applications in India

The versatility of SENTINEL provides potential for application across diverse **low-rise and rapid-construction housing contexts**, subject to appropriate structural, climatic, regulatory and economic validation. Potential applications include **rural and peri-urban affordable housing, government-supported housing, low-rise multi-unit housing, worker and**

student accommodation, housing in seismic regions, cyclone-prone areas, remote locations, and rapid post-disaster reconstruction. For hazard-prone regions, SENTINEL should be adapted to site-specific conditions rather than treated as a generic hazard-resistant solution. Structural members, connections, foundations, building envelope and non-structural components must be appropriately designed for the relevant **seismic, wind, flood and geotechnical conditions**. This site-specific adaptability is essential for ensuring reliable performance and responsible deployment.

7. Pathway from Demonstration to Deployment

The transition from a successful demonstration building to a technology suitable for large-scale housing requires structured validation and standardisation. A practical roadmap is mentioned in Table 3.

Table 3: Stages involved in the deployment of the structure

Stage	Objective
Stage 1- Demonstration	Full-scale SENTINEL building at NIT Tiruchirappalli.
Stage 2- Structural validation	Long-term monitoring, targeted testing and systematic performance assessment.
Stage 3- Standardisation	Design guidelines, connection details, fabrication specifications and construction protocols.
Stage 4- Prototype housing clusters	Multiple units under different climatic, seismic and site conditions.
Stage 5 - Technology evaluation & certification	Engagement with relevant government and technology agencies, including technical evaluation and guidance from BMTPC.
Stage 6- Mass deployment	Adoption through validated designs, trained fabrication/construction networks and suitable housing programmes.

8. Future Vision

The ultimate objective of SENTINEL is not simply to substitute one construction material for another, but to rethink the way safe, affordable and adequate housing is designed, manufactured and delivered. The demonstrated structural concept provides a foundation for further development towards more industrialised, efficient and evidence-based housing solutions. Future development could focus on prefabricated CFS components, factory-controlled production, digital design and detailing, modular housing configurations, sensor-based structural monitoring, lower-carbon materials and digital or AI-assisted quality control. A validated modular system could also support rapid post-disaster reconstruction, particularly where conventional supply chains and skilled labour are disrupted.

SENTINEL should therefore be viewed as a platform for further development rather than a finished solution. The immediate priority is to progress from a single full-scale demonstration towards validated housing prototypes, standardised designs, independent technical evaluation and adoption through

appropriate real-world housing programmes. This pathway can help establish the technology's suitability for scalable, resilient and sustainable housing delivery.

9. Conclusions

SENTINEL demonstrates the potential of translating laboratory research into a full-scale housing system addressing the interconnected requirements of affordability, rapid construction, structural resilience and sustainability. The integration of CFS–concrete composite beams, composite shear walls and lightweight, eco-friendly material solutions provides an alternative approach to low-rise housing construction. The reported completion of the defined civil works within 25 active working days and a project cost of approximately ₹1,750/sq.ft. represent promising results within the documented project context.

The broader significance of SENTINEL extends beyond these initial project outcomes. The prototype establishes a platform for further validation, standardisation and technology transfer. Future efforts should focus on independent technical assessment, long-term

performance monitoring, multi-location demonstrations and the development of standardised structural and construction details. With systematic validation and responsible deployment, SENTINEL has the potential to contribute to the broader objective of adequate housing for all, particularly by enabling housing solutions that are efficient, resilient, scalable and responsive to diverse regional requirements.

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21st Meeting of Technical Assessment Committee (TAC) of Performance Appraisal Certification Scheme (PACS)

The 21st Meeting of Technical Assessment Committee (TAC) of Performance Appraisal Certification Scheme (PACS) was held on July 29, 2026 at New Delhi under the Chairmanship of Shri Arvind Kumar, Executive Director, BMTPC. The meeting was attended by the representatives of NBCC, HUDCO, BIS, NCCBM, DSIIDC, DDA, CSIR-CBRI, IIT GUWAHATI & other subject experts. Thanking members for their continued support, ED highlighted the importance of flagship PAC for promoting innovation in the Indian construction sector.

Three emerging products namely “Steel Mesh Masonry Reinforcement (SMMR)” to improve the structural performance & prevent the cracks in AAC masonry, “Politerm Blu- Thermally Insulated EPS Beads Aggregates” for roof thermal insulation and “Agrocrete Blocks and Bricks” manufactured from agro industrial waste were approved for PAC. Seven new applications for PAC certification were also discussed, for further processing.



Proposed Solutions for Providing Affordable & Sustainable Housing in India



Dr. Deepak Bansal *

The world is getting rapidly urbanised, but there is already an acute shortage of proper & affordable housing in urban areas and this trend of rapid urbanization is increasing this gap. There is a shortage of housing in rural areas also, but the typology & covered area of the rural houses, are quite unique & diverse in India, given the diverse cultural, socio economic, climatic and geographical variations in this vast country, marred by several types of natural disasters, which have resulted in evolution of vernacular housing in various parts of India, as per the affordability, availability of construction materials, skill & requirements. Further, in rural housing, there is no pressure on land to go high on FAR/FSI, hence low-rise houses with local vernacular construction materials & construction techniques are constructed. Whereas in the urban scenario, the pressure on land is very high, hence compact and high-rise construction with high FAR/FSI is preferred with smart construction materials & construction techniques. Further,

the existing Indian cities have exhausted their capacities of accommodating more people, hence people are forced to live in slums under unhygienic conditions. The quality of housing is very bad and many of the urban houses in these areas are unregulated, non-engineered and unapproved, hence are unsafe also. There are lots of news on houses/ buildings collapses and related casualties due to illegal constructions, extensions, building mis-use, fires, earthquakes, cyclones, floods, rains, landslides and lightening. However, people have no choice, as cities are growth centres and employment generators, hence people are migrating into the urban areas and forced to live in these urban slums. This is a global housing crisis, whereby an estimated 2.8 billion people face various forms of housing inadequacy, in which close to 1.1 billion reside in slums and informal settlements, calls for urgent and concerted action.

Government of India has launched many social affordable

housing program on pan India basis, under the various social housing schemes like EWS housing, VAMBAY, IAY, RAY, JnNURM, PMAY, etc., under which, millions of affordable, all weather proof housing has been constructed for eligible beneficiaries. These houses are two rooms housing with a kitchen, toilet and bathroom, having carpet area ranging from 20-60 sqm in various low-rise and high-rise construction. All of these houses are NBC (National Building Code) of India and state building bye-laws compliant and are designed & constructed in consultation with all the stakeholders. There are several models of these housing schemes such as, in situ construction, beneficiary led construction, affordable housing in partnership, credit link subsidy schemes, rental housing program and light housing projects, where various proven housing technologies from all over the world have been used in construction of demonstration housing in various parts of India. These programs are very successful and many cities have been declared

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slum free after construction of such houses.

However, the scale of this problem (shortage of housing) is very high as with the massive Indian population of 1.4 billion and the current level of urbanization of about 30% (last census), poised to grow to 40% by the year 2030 and more than 50% by the year 2050, coupled with growth in national population, this housing shortage will increase year by year. Hence India may require huge numbers of urban housing and related infrastructure, which is more than the double of the present strength. This will require huge resources like, land, construction materials, water, energy, labour, money and whole set of logistics. The associated issues like transportation, livelihood, schools, hospitals, markets, recreation zones, water, sewerages, solid waste management, electricity, air, etc., will also needs careful considerations and meticulous planning. The amount of primary energy & water required and associated global warming issues also needs a careful consideration as the new development may have serious consequences on environment.

The typical lifespan of Indian houses, in a composite climate is about 60-75 years, and amount of primary energy required to construct these houses is known as initial embodied energy, further these houses also require frequent maintenance in terms of re-plastering, re-painting, re-flooring, re-terracing, re-joinery and re-wiring and re-plumbing. The primary energy required in maintenance of these houses in its life time is known as recurring

embodied energy. The amount of recurring embodied energy is sometime more than the amount of initial embodied energy. The amount of energy required during operational stage of these houses is also very high as lifespan of these houses is about 60-75 years and these houses requires lots of energy on lighting, cooling, heating, HVAC and uses lots of electrical & electronic gadgets during their life time and this primary energy is known as operational energy. The energy required in demolition & recycling of these houses is generally very less compared to initial, recurring embodied energy and operational energy during life cycle of these houses. Further these energies have associated embodied carbon footprints as generally primary energies come from burning of fossil fuels. The sum of all these energies is known as life cycle energy of these houses (LCE). The total amount of energy (LCE) usages in Indian houses is quite high and it is estimated to be about 30-40% of total annual energy consumption at national level. The associated carbon & GHGs potential of Indian houses is also very high and needs to be reduced to control global warming.

The future Indian houses have to be affordable, sustainable, functionally efficient, resilient, walkable and thermally comfortable for which, we need to find innovative physical planning, modern construction materials, efficient building envelop, efficient micro-climate and efficient electrical & plumbing fixtures. The plinth area and carpet area ratio of these houses has to be very efficient (preferable in the range of 1.2 to 1.35 in low rise 1.3-1.6 in high rise construction) to

minimize wastage of usable areas & resources (high rise construction uses more cement and steel due to more wind pressures, earthquake forces and gravity loads) and to gain maximum carpet area within allowed FAR. It is seen that in low rise construction, plinth area- carpet area ratio is quite low, hence these houses are very economic, as lots of circulation areas are not required in these constructions. The houses have to be climate sensitive, disaster resilient and flexible to adopt to the changing requirements of future generations (the life of the houses are generally 60-75 years and one generation changes in 25-30 years with different functional requirements).

The national carbon reduction target of 100% by the year 2070 can be achieved by reduction of carbon in housing construction, operation and maintenance. The old housing also needs green retrofitting to save on energy consumption and to harness renewable energy. There are few construction materials like cement, steel and fired clay bricks, which are highly energy & carbon intensive and weigh more than 75% of energy consumption in Indian affordable housing. The energy consumption in these houses can be suitably reduced by efficient alternative construction materials, planning, designing and construction of low-rise houses. There are several options of alternative sustainable construction materials, which are NBC of India compliant and have been used throughout India in many housing constructions. Similarly, operational energy of Indian affordable housing can be reduced by efficient building envelop, micro climate and



efficient electrical & plumbing fixtures coupled with renewal energy harnessing. It is estimated that overall, 50% LCE of Indian affordable housing can be reduced by these alternative construction materials, envelop design and efficient plumbing & electrical fixtures without increasing construction cost.

The modern physical planning is pushing for TOD (Transit Oriented Development), where FAR/FSI is quite high and low-rise construction will not be feasible, hence high-rise construction is the only option, where initial and recurring embodied energy along with operational energy is going to be quite high in conventional construction, but there is no other option to utilize this high FAR/FSI in TOD based planning other than high-rise construction. Here innovative and new construction materials like LG steel, Volumetric Concrete, Pre-fab Construction, GFRG, EPS, Rapid wall, RCC printing based construction, etc., based

housing will be the future. The lifespan of these housing is also high and associated carbon footprint is also low, which makes them more affordable & sustainable. Now Geopolymer based cement and recycled high strength steel along with manufactured sand & aggregates are also gaining ground in India and these are quite affordable & sustainable construction materials.

BMTPC (Building Materials & Technology Promotion Council) an organization of MoHUA, GOI had invited bids from all over the world for best housing practices and have done few demonstrative housing constructions in India, using best of these construction materials and technologies. The construction cost of these houses cannot be compared with traditional housing construction technologies as the current scale of construction is very low and these are new technologies, but the quality of construction and lifespan of these houses is quite

high. The indoor comfort and LCA/LCE of these houses will be available in due time and then real analysis will be possible. However traditional Indian houses are known for their vernacularity and labour-intensive practices, which will not be possible in this supplier driven housing technologies. The repair and maintenance of these houses will also need to be studied. Hence, we need to promote local construction materials and vernacular construction technologies in compliance with NBC of India, along with creation of livelihood, where we need to develop a model, where high-rise construction is possible with locally available construction materials along with local labour.

The best solution in these situations will be to provide affordable housing with new construction materials & construction techniques in conjunction with vernacular construction materials along with development of new towns and



cities, where water, air, waste, greens, amenities and industry are planned together (mixed land use). The potential of land needs to be assessed for such development and then climatic, disaster, socio-economic and physical planning should be done. The construction materials and energy in construction as well as energy in operations have to be either neutral or negative (harnessing of renewable energy is more than the current energy consumption), so that we can achieve the targets of providing affordable & sustainable housing along with livelihood, recreation, social infrastructure to all within the city with the objective of making India carbon neutral.

Disclaimer: The views presented in this paper are personal and the organization/s where the author represents may or may not subscribe to these views.

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Sick Building Syndrome in Office and Residential Buildings



Chandan Ghosh *

Abstract
Sick building syndrome (SBS) is the name given to a cluster of non-specific complaints; irritated eyes, nose or throat, headache, fatigue, difficulty concentrating and dry or itchy skin, that occupants associate with time spent in a particular building, in the absence of any single confirmed illness or contaminant. It is conceptually distinct from building-related illness (BRI), in which a specific pathogen or exposure, such as Legionella colonisation of a cooling tower, can be identified. Because urban Indians now spend the great majority of their time indoors, the seasonal behaviour of a building, how it is ventilated, cooled, heated, drained and cleaned through summer heat, monsoon humidity, winter closure and dusty pre-monsoon winds, is a public-health question as much as an engineering one. This treatise brings together two lines of technical work for the building industry: a hazard- and standards-based review of Indian climatic drivers, HVAC failure modes, Internet-of-Things (IoT) indoor air

quality (IAQ) monitoring, and a practice-oriented account of how a suspected SBS complaint should actually be investigated, corrected and verified by engineers. It proposes a single diagnostic and mitigation framework: recognise, investigate proportionately, correct sources and moisture, ventilate adequately, and verify under comparable seasonal conditions which will be supported by indicative reference values drawn from the National Building Code of India 2016/2026, ASHRAE 62.1/62.2, the Bureau of Energy Efficiency's Eco Niwas Samhita, World Health Organization and United States Environmental Protection Agency guidance. Moreover, sensors and dashboards are treated as investigative aids that help locate and confirm the correction of a defect; they do not by themselves certify a building as healthy or diagnose SBS. A phased implementation route; a bounded pilot, procurement safeguards, and integration into BMTPC's demonstration-housing and training programmers, is proposed for both office and

residential contexts across India's climatic zones.

Keywords: sick building syndrome; building-related illness; indoor air quality; HVAC; ventilation; monsoon dampness; VOC; IoT monitoring; National Building Code of India

1. Introduction

The term "sick building syndrome" entered technical use after the World Health Organization's 1983 description of workplaces in which an unusually large share of occupants reported acute discomfort while inside a building, without a single diagnosable illness or contaminant being found. More than four decades later, the underlying problem has not gone away; if anything, tighter building envelopes, deeper floor plates and heavier reliance on mechanical conditioning have made the ventilation and moisture performance of a building, rather than its architecture alone, the decisive factor in occupant comfort. Because most urban areas, whether office workers or residents of

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apartment blocks, now spend the large majority of each day indoors, indoor environmental quality (IEQ) has become as material to public health as outdoor air quality, and arguably more so for the population that never sets foot near a monitoring station.

1.1 Indoor Environmental Quality in Construction Policy

For BMTPC, this places IEQ alongside affordability, durability and resource efficiency as a criterion for evaluating construction technologies. A completed building must go on performing through summer heat, winter closure, dusty winds and prolonged rainfall, and its subsystems interact in ways that are easy to overlook at design stage: an envelope retrofit that reduces air leakage to save energy can just as easily strip out the incidental ventilation that occupants had been relying on, and an oversized cooling unit can deliver an uneven, clammy space rather than a comfortable one. Building performance is therefore something that has to be checked after occupation, under the conditions in which people

live and work, not only inferred from equipment specifications at handover.

This document is addressed to planners, architects, facility managers and public-health officials promoting BMTPC and Ministry of Housing and Urban Affairs (MoHUA) programmes; including demonstration housing, PMAY, GRIHA and smart-city initiatives and treats office workplaces and residential dwellings together, since both are exposed to the same climatic extremes even though they differ in HVAC type, occupancy pattern and regulatory oversight. The recommendations that follow are proposals for practice and pilot evaluation; they are not an issued BMTPC policy, and the current ministry name is used throughout even where earlier source material referred to the former Ministry of Urban Development.

1.2 Scope and Evidence

What follows is a practice-oriented narrative synthesis of official health guidance, building-engineering standards and BMTPC-relevant materials. It does

not estimate the prevalence of SBS in India, and the illustrative photographs and trend charts referenced later are simulated for explanatory purposes only. They depict typical exposure situations and hypothetical operating patterns, not surveyed buildings or measured outcomes.

2. Defining SBS and Building-Related Illness (BRI)

Four features are generally used to identify SBS: no single causative agent is found despite a reasonably thorough investigation; symptoms are non-specific and tend to cluster among occupants sharing the same space; complaints intensify during occupancy and ease within hours of leaving the building; and critically, SBS is distinguished from building-related illness, in which a specific pathogen or contaminant, such as Legionella in a cooling tower or an allergenic response to humidifier contamination, can be identified as the cause. This distinction matters operationally: a SBS complaint is investigated through building inspection and proportionate measurement, whereas a suspected BRI, or any presentation involving fever, chest pain, marked breathlessness, collapse, suspected carbon monoxide exposure, or several people becoming unwell together, calls for urgent medical or emergency action rather than routine environmental scoring. Heat illness should likewise be triaged separately from ordinary thermal discomfort.

2.1 Symptom Classification

Reported SBS complaints are conventionally grouped into four broad categories; mucosal and respiratory irritation (eyes, nose,

Conceptual Framework: External & Internal Drivers of Sick Building Syndrome

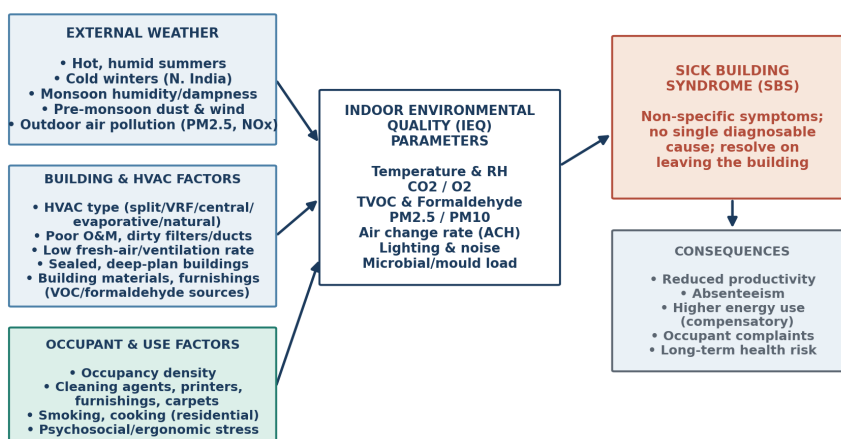


Figure 1. Conceptual pathway from external climate and building/HVAC design, through occupant behaviour, to indoor environmental quality and reported SBS-type complaints. The diagram is a planning aid, not a causal model validated against Indian surveillance data.

throat), general and neurological symptoms (headache, fatigue, difficulty concentrating), skin complaints (dryness, itching), and a residual category of odour- or comfort-related annoyance. This classification helps an investigator narrow down probable causes during a walkthrough: mucosal irritation points more often toward particulates, VOCs or low humidity, while general and neurological symptoms correlate more with ventilation adequacy and elevated CO₂ as a proxy for poor air exchange. The classification is a starting hypothesis, not a diagnostic test. The same symptom can arise from lighting, noise, ergonomics, stress or an illness unconnected with the building, and these competing explanations must be checked before a building cause is accepted (Fig. 2).

3. Recognising and Investigating a Suspected Case

An association between symptoms and a particular room, work period or occupancy episode, especially one that improves once the person leaves the

building; is what usually triggers an investigation. Because, the symptoms themselves are non-specific, this timing supports a working hypothesis; it does not prove that any single measured pollutant caused the complaint, and a structured, stepwise process is needed to move from a cluster of complaints to a verified correction.

3.1 A Practical Occupant Record

A short, voluntary daily record room or zone, arrival and departure times, symptom category and severity on a simple 0–3 scale, onset time, whether symptoms ease away from the building, any odour or visible dampness, and relevant activity, gives an investigation a denominator as well as a numerator: recording total occupants and participation alongside complaints turns anecdote into a complaint proportion that can be tracked over time. Diagnostic labels should be avoided in this record, and personal health details should be kept out of any building-level dashboard.

3.2 Evidence to Collect, by Setting

Evidence categories for an SBS walkthrough investigation, adapted for office and residential contexts is given in Table-1.

3.3 A Stepwise Investigation and Closure Procedure

A joint walkthrough by the building manager, maintenance team and an occupant representative should precede any broad chemical sampling campaign: air paths, leaks, drains, materials and recent changes are checked first, and monitoring is matched to a specific question; does CO₂ rise when a meeting room fills, does a particulate peak follow cooking, does dampness recur after rain? Where the inspection and targeted measurement support a working diagnosis, corrective action follows, and the occupant record and key measurements are repeated afterward under comparable occupancy, weather and operating conditions, so that the closure confirms the original defect was corrected rather than merely that a sensor reading changed. A single low reading on one visit does not close a complaint, and where symptoms persist after verified repairs, the investigation should be extended and occupational or environmental health advice obtained.

4. Climatic and Seasonal Drivers of Indoor Air Quality (IAQ)

India's climatic range means that the dominant IAQ stressor changes through the year, and a fix designed for one season can be actively counter-productive in another. The clearest example being that additional cooling is not a remedy for a humid building. Condensation forms whenever a

Classification of Sick Building Syndrome Symptoms

Mucosal / sensory irritation ● Eye redness or dryness ● Nasal irritation and sneezing ● Dry or sore throat ● Itchy or watery eyes	General / neurological symptoms ● Headache ● Fatigue and lethargy ● Difficulty concentrating ● Dizziness and irritability
Skin symptoms ● Dryness or itching ● Rash or irritation ● Static-shock sensation (low humidity, dust)	Respiratory & other symptoms ● Dry cough and hoarseness ● Chest tightness or wheeze ● Sensitivity to odours ● Nausea or flu-like malaise

Symptoms are non-specific, often occur in clusters, intensify during occupancy and typically improve soon after leaving the building. In building-related illness (BRI), a specific causative agent is identified.

Figure 2. Four broad categories of SBS-type symptoms commonly reported in office and residential walkthrough surveys, used here as an investigative aid rather than a clinical classification.

Table 1: Evidence categories for an SBS walkthrough investigation, adapted for office and residential contexts

Evidence to collect	Office workplace	Residential setting
Time and place	Workstation, meeting room, shift pattern, HVAC start and cleaning times	Bedroom overnight, cooking periods, bathroom use, time away from home
Recent building changes	New partitions, fit-out, increased occupancy, altered operating hours	New furniture, painting, window replacement, roof or plumbing leakage
Exposure pattern	Compare affected and unaffected zones performing similar tasks	Compare rooms and sleeping arrangements; include outdoor sources
Competing explanations	Lighting, noise, ergonomics, workplace stress, illness outside work	Sleep, smoking exposure, allergies, combustion appliances

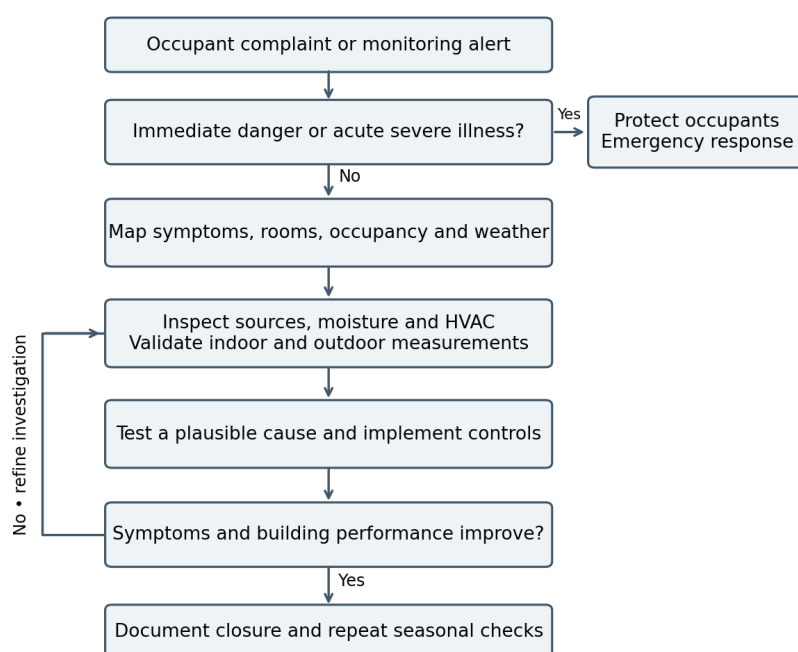


Figure 3. Proposed pathway from an SBS-type complaint to a verified, closed-out correction. Severe illness or an immediate hazard is routed to emergency procedures outside this pathway; the remaining steps combine building investigation with clinical referral where indicated

surface falls below the local air's dew point: air at 26°C and 70% relative humidity has a dew point of roughly 20°C, so an exposed pipe or diffuser surface at 18°C will sweat even though the room itself feels comfortable. This is a building-physics problem calling for continuous insulation and vapour control around cold services, adequate drainage, and latent (dehumidification) cooling capacity, which is not simply a lower thermostat setting.

Each situation in Figure

4 implies a different next step rather than a shared remedy. Sunlit glazing calls for a check of shading, radiant temperature and cooling distribution, not an inference of pollutant exposure from discomfort alone. Dust at a window is a possible entry pathway warranting a comparison of indoor and outdoor particulate levels and an inspection of seals and intakes, without eliminating the outdoor air the room still needs. Staining and peeling surfaces call for a moisture survey of roof, façade, plumbing

and cold surfaces, stopping the water entry and removing unsalvageable porous materials rather than simply repainting. Paints, adhesives, furniture and cleaning products after a renovation warrant a materials inventory and, if needed, targeted VOC testing, with low-emission products specified and adequate airing time before reoccupation. Cooking aerosol requires capture close to the source and discharge outdoors; recirculating room air alone is not sufficient.

5. HVAC Systems, Building Design and Their SBS Failure Modes

Cooling capacity and ventilation capacity are different specifications, and a room can feel comfortably cool while pollutants and bio-effluents accumulate in it. Indian offices and homes use a wide mix of systems — from simple window or split air-conditioners and evaporative coolers in homes, small offices and hot-dry, budget-constrained contexts, through to VRF/VRV and central chilled-water plant in large commercial buildings — and each has a characteristic vulnerability that a maintenance programme needs to target specifically.

Table 2: Seasonal drivers of indoor air quality across Indian climatic conditions and the corresponding priority response, synthesising engineering practice with season-specific facility actions

Season / condition	Mechanism and clues	Priority engineering response
Summer heat	Solar gain, hot roof and crowding; windows kept shut for AC; discomfort strongest near glazing or on top floors	Shade and reduce envelope heat gain; verify cooling capacity and outdoor-air provision; clean AHU coils, filters and condensate drains
Winter / overcooled indoors	Closed windows, local cold drafts, cold surfaces; condensation may appear at thermal bridges	Maintain minimum outdoor-air ventilation despite closure; correct diffuser throw; service heaters; improve envelope detailing
Pre-monsoon, windy and dusty	Wind drives uncontrolled infiltration and pressure changes; dust and traffic emissions enter through openings	Repair uncontrolled leakage; upgrade or clean intake filtration (e.g. MERV 13 / ISO ePM1 grade); operate openings according to outdoor conditions
Monsoon and humid coastal climates	Wind-driven rain, roof and façade leaks, humid infiltration and blocked condensate drains; mould or musty odour	Stop water entry; drain and dry affected materials; keep relative humidity below about 60%; inspect false ceilings, carpets and wall cavities
Mild / shoulder weather	Natural ventilation can be effective, but wind and outdoor pollution remain variable	Use mixed-mode operation where outdoor air and security conditions permit; verify airflow is actually reaching occupied rooms



Figure 4. Six representative exposure situations: summer overheating, overcooling and drafts, wind-driven dust intrusion, monsoon dampness and mould, renovation-related chemical sources, and cooking/combustion aerosol. (Illustrative only; invisible pollutants cannot be identified from a photograph, and no single image should be read as a diagnosed SBS case).

Table 3: HVAC system types commonly deployed in Indian offices and residences, their characteristic SBS-relevant vulnerability, and the corresponding response. (Abbreviations: AHU- air handling unit; DOAS- dedicated outdoor air system; HRV/ERV- heat/energy recovery ventilator; VRF/VRV- variable refrigerant flow/volume)

System	Common vulnerability	Design or maintenance response
Natural ventilation and fans	Wind is variable and crossflow paths get blocked; fans move room air without supplying outdoor air	Provide usable, shaded air paths; account for pollution, rain and security constraints
Evaporative cooler	Adds moisture; dirty wetted media perform poorly and are unsuitable in humid weather	Use only where climate permits; maintain clean water and media; provide an exhaust path and seasonal shutdown
Window or split AC	Usually recirculates room air only; dirty filters or blocked condensate drains	Provide a separate, verified ventilation path; clean coils and drains; check filter fit
Multi-split / VRF-VRV	Good zonal temperature control can conceal an absence of designed outdoor-air provision	Pair with designed outdoor-air treatment; coordinate operating schedules and humidity control
Packaged, ducted or rooftop units	Outdoor-air damper faults; intake sited near an exhaust; duct leakage	Measure intake airflow directly; inspect separation of intake/exhaust, filter bypass, drainage and controls
Central AHU with chiller	Poor balancing, wet coils, dirty drain pans; low airflow at part-load	Commission at occupied conditions; verify minimum outdoor air is maintained under variable-airflow operation
DOAS with HRV/ERV	Core leakage or condensate faults; heat/energy recovery does not purify the air	Select by climate; assess cross-contamination and frost/drainage risk; maintain filters

5.1 Building Design and House-keeping Factors

- Deep-plan, heavily glazed buildings with limited operable windows and high reliance on mechanical ventilation.
- Synthetic furnishings, adhesives, paints and laminates that off-gas VOCs and formaldehyde, particularly in newly fitted-out offices and homes.
- Overcrowding relative to design occupancy, common in shared or co-working offices and in multi-generational Indian households.
- Inadequate housekeeping of pantries, restrooms, waste points and printer or photocopier rooms, which act as localised VOC and bioaerosol sources.

Cooling towers require their own water-management programme, and their well-known Legionella risk should not be generalised to every room air conditioner; conflating the two leads to wasted remediation effort on low-risk equipment while a

genuine cooling-tower hazard goes unmanaged.

6. Indoor Air Quality Parameters and Reference Thresholds

Objective assessment of SBS risk requires comparing measured IAQ parameters against reference values drawn from the National Building Code of India (NBC) 2016 Part 8 (Building Services, Section 3: Air Conditioning, Heating and Mechanical Ventilation), ASHRAE Standards 62.1 and 62.2, CPCB ambient guidance as a reference for infiltrating outdoor pollutants, and WHO indoor air quality guidance. It is important to be precise about what these numbers can and cannot do: they are indicative planning and investigation triggers, not universal clinical pass/fail thresholds, and a single mid-day reading within range does not exclude an intermittent problem, just as a single elevated reading does not, on its own, prove that a symptom was caused by that pollutant.

7. Mitigation Hierarchy for Offices and Residences

Because SBS is multi-causal, an effective mitigation programme follows a hierarchy (Fig 5): broad, low-cost, preventive measures at the base — source control and moisture management supported by increasingly targeted ventilation, filtration and monitoring interventions, with policy and occupant engagement providing the enabling environment at BMTPC/MoHUA level.

7.1 Controlling Sources and Water Entry First

Low-emission paints, adhesives, sealants and composite wood products should be specified with supporting test evidence; a low-VOC-content label alone does not establish low emissions after installation. Chemicals should be stored away from occupied rooms, cleaning methods chosen to minimise unnecessary fragrance, renovation work isolated from occupied areas, and odour-masking avoided as a substitute for actual source control; targeted

Table 4: Indicative indoor air quality parameters and reference values compiled from NBC 2016, ASHRAE 62.1/62.2, and WHO and EPA guidance. (Values are indicative, planning and investigation triggers; the cited standards should be consulted for space-specific, legally applicable limits)

Parameter	Indicative reference value	Interpretation and limitation
Carbon dioxide (CO ₂)	Below roughly 1,000 ppm above outdoor baseline, occupied space	A ventilation-adequacy indicator, not a toxicological or ASHRAE health limit; investigate persistent unexpected elevations rather than isolated peaks
Total VOCs (TVOC)	Sustained departure from a documented local baseline (indicative guideline range 300-500 µg/m ³)	Mixture-dependent signal; there is no universal TVOC health threshold, and low-cost sensors cannot identify individual compounds
Formaldehyde	WHO 30-minute guideline of 0.1 mg/m ³ (100 µg/m ³)	A compound-specific value; use a validated method to confirm any low-cost sensor indication
PM _{2.5} (indoor)	Indicative 24-hour range of roughly 15-35 µg/m ³ , context-dependent	Tracks particle mass; humidity and aerosol composition affect optical sensor response, and it provides no gas-phase information
Relative humidity	EPA guidance: below 60%, ideally 30-50% where feasible	Moisture-management guidance rather than a mould-clearance test; adapt to local climate and condensation risk
Ventilation / outdoor-air rate	At or above the applicable NBC 2016 /2026, ASHRAE 62.1 or 62.2 minimum per occupant or area	Directly dilutes bio-effluents, VOCs and CO ₂ ; commission by direct airflow verification rather than assumption
Air changes per hour (ACH)	As specified for the space type in NBC tables	Determines dilution and removal rate of contaminants; recheck after partition changes or at reduced fan speed

ventilation and adequate curing or airing time should accompany any reoccupation decision. Leaks should be repaired before repainting, and water-affected materials dried promptly, ideally within 24 to 48 hours where feasible, with contaminated or persistently wet porous materials assessed for removal. Remediation must address the moisture source itself, not just the visible growth, and extensive contamination, sewage involvement or HVAC contamination should be referred

to competent specialist assessment with occupant protection in place.

7.2 Ventilation Matching and Filtration to the Pollutant

Ventilation dilutes many indoor-generated pollutants, though outdoor air may itself require treatment during dusty or humid periods. Properly sized particle filters (upgraded to MERV 13 / ISO ePM1 grade where the system can tolerate the added resistance) and portable HEPA cleaners can reduce airborne

particles, sized to an appropriate clean-air delivery rate and an acceptable noise setting; particle filters do not remove CO₂ and are not a general VOC remedy. Suitable sorbent media can remove selected gases, with performance dependent on media quantity and replacement schedule, and ozone-producing air cleaners should be avoided in occupied spaces.

7.3 Averting a New Problem While Solving the First

A higher-efficiency filter can restrict airflow if the fan cannot overcome the added resistance; more exhaust can draw garage fumes indoors or cause combustion back drafting; and additional outdoor air can overload dehumidification capacity during the monsoon. Any contractor implementing a fix should be required to demonstrate airflow, pressure and moisture performance after the change, and lifecycle cost, maintenance access and occupant acceptance should be weighed alongside energy consumption when selecting the

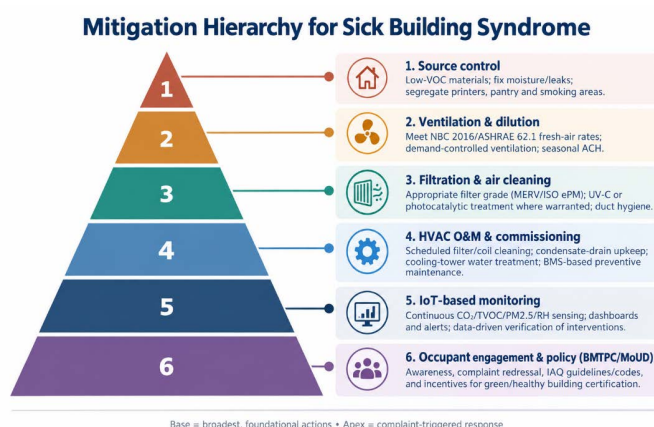


Figure 5. Recommended mitigation hierarchy for Sick Building Syndrome in Indian buildings, moving from source control and moisture management at the base to ventilation, filtration, monitoring and governance measures above it.

Table 5: Season-specific mitigation priorities and responsibility for office and residential buildings

Season	Priority action	Responsible party
Summer	Verify fresh-air damper operation; clean AHU coils and filters; check condensate drains	Facility O&M team
Monsoon	Control RH below 60%; inspect for leaks and dampness; increase exhaust in bathrooms and kitchens	Facility O&M / housing society
Winter	Maintain minimum ACH despite reduced natural ventilation; service heaters	Facility O&M team
Pre-monsoon / windy	Upgrade or clean intake filters; monitor PM2.5 at intakes	Facility O&M team

Table 6: Complementary office and residential mitigation actions

Office actions	Residential actions
Verify ventilation in meeting rooms and after partition changes; coordinate AHU schedules with actual attendance	Check bedrooms during overnight occupancy; provide a planned air path when windows remain shut
Separate printing, chemical storage and renovation zones; keep return and supply grilles clear	Capture cooking emissions outdoors; use bathroom exhaust with replacement air and a suitable run time
Maintain coils, drains, filter seals and dampers; inspect concealed wet insulation	Maintain AC condensate drainage, bathroom seals, roof outlets and kitchen grease filters
Offer a transparent reporting route and an alternative workspace while a serious problem is investigated	Protect children, older people and those with respiratory conditions during intrusive works; use a clean alternative room where appropriate

final remedy.

8. Implementation Programme for BMTPC

BMTPC could incorporate an indoor-environment module into demonstration housing, technology appraisal and professional training, documenting how a system controls rainwater, heat, moisture and pollutant entry throughout its service life. A successful demonstration would show maintainable details and measured occupied performance, rather than relying on equipment labels alone.

8.1 A Proposed 90-Day Pilot

- Days 1–15: appoint a coordinator; select an office and a residential cluster representing different climate and ventilation conditions, not only premium

centrally conditioned buildings; obtain voluntary participation; map occupancy and maintenance responsibilities; inspect for immediate hazards.

- Days 16–30: commission a small, validated monitoring network; collect occupant records and establish baseline operating performance; review drawings and verify actual air paths; use specialist sampling only where the inspection supports a clear exposure question.
- Days 31–60: implement prioritised repairs, source controls, airflow corrections and moisture measures; record installed cost, staff time, energy implications and operational disruption; provide residents and maintenance staff with simple instructions in locally appropriate

languages.

- Days 61–90: repeat comparable measurements; document remaining complaints; issue a performance report; and schedule summer, monsoon and winter follow-ups, since a 90-day programme alone cannot establish year-round performance.

This timeline is an implementation framework for BMTPC's own evaluation purposes, not a proposed regulatory schedule.

9. Recommendations

- Incorporate mandatory minimum outdoor-air ventilation rates, aligned with NBC 2016/2026 and ASHRAE 62.1/62.2, into building byelaws for new commercial and multi-family residential construction.
- Promote IoT-based IAQ monitoring as an optional or incentivised compliance pathway under green-building and smart-city guidelines, with data reporting to a central BMTPC/CPWD dashboard for large public buildings, alongside a named responsibility chain for acting on alerts.
- Develop simplified, low-cost IAQ sensor and demand-controlled-ventilation retrofit packages suitable for existing government office buildings and PMAY housing stock.
- Issue seasonal HVAC operation-and-maintenance advisories; pre-summer, pre-monsoon and pre-winter to CPWD, state PWDs and housing societies.
- Support training of facility managers and building engineers in SBS investigation procedure and in interpreting IAQ standards correctly, including their limitations.
- Encourage low-VOC, certified

building materials, paints, adhesives, boards, in government procurement specifications.

- Confirm the applicable edition and local adoption of every cited code or standard for each project: an international standard, or a draft code, should never be presented as an automatically binding Indian requirement.

Designers should in every case consult the applicable National Building Code provisions for lighting, natural ventilation, air conditioning, heating and mechanical ventilation, together with locally adopted building bye-laws and state energy code requirements; the Bureau of Energy Efficiency's Eco Niwas Samhita and commercial code resources provide complementary energy and envelope guidance.

10. Conclusion

Sick building syndrome is best understood as a preventable, management-driven problem rather than an inevitable cost of modern construction. Its prevention rests on keeping pollutant sources controlled, building assemblies dry, and occupied spaces adequately ventilated and comfortable through India's changing seasons, summer heat, monsoon humidity, winter closure and dusty pre-monsoon winds each demand a different priority response, and a fix suited to one season can be counter-productive in another. IoT-based measurement adds real value when it helps locate a defect and verify that a correction has worked; it does not, by itself, diagnose SBS or certify a building as healthy. BMTPC and the Ministry of Housing and Urban Affairs are well placed to mainstream a coordinated

approach, joining construction-technology assessment with post-occupancy evidence, clear maintenance responsibility, and practical training through building codes, green-building incentives and public-building demonstration projects, improving occupant health, comfort and productivity across both office and residential buildings in India's built environment.

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Understanding and Minimising the Air Pollution Contribution of Construction and Demolition Activities



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Construction & Air Pollution

India's urban population is projected to more than double, while the urban land cover will increase by over 5 times. To accommodate this growth, several infrastructural development projects are underway across the country, such as roadways, railways and metro systems, airports and ports, industrial zones, and civic utilities. Additionally, 700-900 millions square meters of real estate (residential and commercial) will need to be added annually by cities, equivalent to the entirety of Chicago, USA's 3rd largest city.

As a result, the construction sector, which already contributes 9% of the country's GDP and employs 71 million people, is the third largest in the world. It will also indirectly enable cities to boost their contribution to the GDP, which already exceeds 60%; and have cascade economic effects on over 250 other industries with which it maintains forward and backward linkages.

While construction is a critical driver of India's economic growth, its environmental impacts—es-

pecially air pollution—also need attention. Activities such as demolition, excavation, hammering, crushing, transport and mixing, release several pollutants, most commonly particulate matter (PM10 and PM2.5) associated with dust generation. According to the Central Pollution Control Board, dust resuspension—including from construction—can contribute up to 58% of total particulate matter emissions. <https://hsph.harvard.edu/environmental-health/news/air-pollution-in-india-linked-to-millions-of-deaths/>.

These emissions directly affect the health of personnel on site,, as well as residents and workers of nearby areas, triggering a range of pulmonary and physiological illnesses. This also lowers the overall air quality of cities, resulting in the spread of adverse health impacts across wider regions. <https://hsph.harvard.edu/environmental-health/news/air-pollution-in-india-linked-to-millions-of-deaths/>

Current Policy Responses

The National Clean Air Programme (NCAP), provides a framework for 131 'non-attainment cities' to pursue policies and projects with the objective of reducing

particulate matter emissions by 40% by 2026. City-level Clean Air Action Plans formulated through NCAP typically provide measures for monitoring and mitigation of air pollution emissions across various source sectors. These are further reinforced by Graded Response Action Plans (GRAPs) that enforce a cascade regime of mitigation measures during episodic rises in pollution levels.

Construction activities are a key focus of these plans. Several cities, through their respective Urban Local Bodies (ULBs), have prepared and notified guidelines that mandate dust mitigation measures to be adopted across construction sites. While these guidelines differ across locations, they can broadly be said to cover the following actions:

1. Erecting metal barricades along the peripheries of project sites to prevent leakage of dust to external areas.
2. Use of high-density fabrics to enclose active construction areas, activities like cutting and grinding, and stockpiles of loose materials, to reduce exposure to wind and limit the spread of

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dust generated.

3. Deployment of sprinkling or misting, including through anti-smog guns, to increase local moisture content and encourage settling of dust.
4. Regulating the speed of vehicles inside the site to reduce tyre-led dust resuspension and ensuring their proper cleaning before exiting asite.

For monitoring and enforcement, a growing number of cities are mandating the installation of the following technologies on project sites:

1. Low-cost sensors (LCS) that measure PM10 and PM2.5 levels in real-time to enable faster mitigation action on sites.
2. Close circuit television (CCTV) cameras that can provide video evidence of compliance with mitigation measures.
3. Online self-audit portals that project proponents must mandatorily fill at regular intervals to ensure compliance.

ULBs typically undertake inspections of sites to ensure compliance. Sites with inadequate implementation of prescribed mitigation measures are then subjected to penalties such as fines or work-stop orders.

In addition to such guidelines, some cities have also included construction-specific measures in their GRAPs. These measures typically include intensification of mitigation measures such as sprinkling as overall air pollution levels rise. During severe episodes, certain construction activities are banned until air quality recovers.

Gaps and Challenges

While the construction sector is rapidly adopting dust mitigation practices, several knowledge,

technology, and enforcement gaps remain.

A general lack of awareness regarding air quality management affects the proper interpretation and implementation of the policies and guidelines:

1. Project proponents typically deploy mitigation measures to meet compliance requirements alone, and do not understand how they can be strategically targeted at dust sources on sites. This not only lowers their air pollution reduction potential but leads to wastage of materials and resources. Additionally, pressures such as timely delivery and ensuring financial profitability of the projects contribute to reduced emphasis on air quality control.
2. ULB officials may benefit from additional support and guidance on air quality issues and practical logistics of deployment of mitigation measures at construction sites. This will enhance their ability to make informed monitoring and enforcement decisions. Further, not all construction sites may fall under their purview, with some being managed by other government departments or located outside their jurisdictions but still contributing to local air pollution. At present, channels for inter-departmental coordination in such situations remain limited.

Dust mitigation practices prescribed and adopted in India emphasise basic measures such as covering, sprinkling, and cleaning. Such measures, when implemented properly, can bring down the site's contribution to PM significantly. However, they have several limitations:

1. They do not apply to the entirety of the construction process, with critical elements like preliminary site planning or finishing and handover remaining under emphasised.
2. Existing guidelines focus largely on 'typical' real estate development, while guidance and mitigation frameworks for infrastructure-oriented projects are under-emphasised.
3. Prevalent mitigation measures remain technologically primitive when compared to the rapid changes in construction systems, and practices adopted in other countries. This is further compounded by the sector's lack of awareness of and access to newer mitigation technologies such as pressure-controlled construction tents and industrial-grade dust suction equipment, and general apprehensions about cost and staff training required for their deployment.

Although several sites comply with LCS, CCTV, and self-audit mandates, these processes are not sufficiently leveraged for monitoring and enforcement:

1. Data from all three is typically not co-related by either project proponents or ULB officials.
2. Technical specifications that can facilitate such coordination are absent as well. This leads to ad hoc deployment of mitigation measures and inspection visits, leading to concerns about resource wastage and accountable governance.

These gaps undermine the construction sector's investments in dust mitigation measures. Materials and equipment purchased for compliance are not utilised to their full air pollution reduction potential; ULBs continue to rely on

labour-intensive manual enforcement procedures; and periodic bans have an adverse impact on the livelihood of labourers, project timelines, and the finances of both builders and buyers. In the National Capital Region (NCR), for instance, construction bans can often last the entirety of the winter season, despite the region having a long history of mandating dust mitigation and monitoring protocols.

Recommendations for the Construction Ecosystem

Policy frameworks and basic guidelines regarding dust mitigation at construction sites are already in place. Looking ahead, there is a need to both optimise existing processes and enable technological shifts that can together minimise the sector's air pollution contribution.

Knowledge gaps in the ecosystem may be addressed through two strategies:

1. Stakeholders such as builders, technicians, and enforcers can collaboratively develop detailed guidelines, technical specifications, and deployment manuals that can enable correct interpretation and implementation of dust mitigation measures.
2. Systematic capacity building can help ensure that all levels of construction project staff and enforcers can adequately understand guidelines and mandates.

Identifying and encouraging newer dust mitigation solutions to fill technology gaps may benefit from the following approaches:

1. Investing in domestic research and entrepreneurship, in partnership with technical institutions and industry bodies, to encourage innovators towards

developing, demonstrating, standardising, and scaling new dust mitigation solutions as well as new construction systems that are less dust-intensive.

2. Identifying global best practices that can be customized to the Indian context by testing through pilot projects, validation by local experts, and dissemination to the industry through expos and other means.

Enforcement can be enhanced by enabling a shift to a data-led compliance framework:

1. Integrated dashboards that collate LCS, CCTV, and self-audit data and automate their validation can greatly ease the resource burden on ULBs and build transparency and accountability.
2. Protocols for deployment of LCS and CCTV alongside tools for evidence validation can motivate builders towards proper implementation of mitigations and streamline decision-making for enforcement agencies.
3. Research on dust emissions from various construction activities is required to arrive at detailed emission inventories and monitoring of efficacy of mitigation actions. Partnerships between Governments and technical institutions can help build these evidences and scientific frameworks, and inform future policies.

Mindset Shifts Needed

As with health, safety, and sustainability, the construction industry should prioritise air quality. Instead of treating it as a standalone compliance requirement, the sector should place dust mitigation at the centre of planning, execution, and monitoring of projects. It may

be noted that the industry already invests in procuring and deploying mitigations. Proactively sensitising staff towards their proper implementation and documentation, and emphasising maximal impact of mitigation purchases are simple shifts with which the industry can be better placed to not only lower pollution contribution, but emerge as sustainability leaders, at minimal additional cost.

Enforcement agencies should also recognise and leverage the benefits of data-led systems that can not only enhance monitoring and enforcement for their own departments, but ease coordination with other agencies to ensure widespread compliance with dust mitigation guidelines. Further, they can play a pioneering role in motivating the construction industry by facilitating knowledge and learning platforms, promoting new technologies and solutions, and incentivising good-performers with appropriate exemptions and/or recognition.

Conclusion

The construction industry needs to both reduce its air pollution contribution, and remain resilient in the face of disruptions caused by severe pollution episodes. A proactive and systematic approach towards complying with mitigation mandates and maximising efficiency can help negate any perceived cost and time burdens of dust control. Enforcement agencies can play a complimentary role by co-creating robust guidance, monitoring frameworks, and creating collaborative platforms that incentivise the industry.

(Views expressed by the authors are personal.)

Greening Adequate Housing for All



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Abstract: Adequate housing is often treated as a social-policy outcome. It is also an economic asset and a long-lived infrastructure investment. This article argues that affordability, adequacy, climate resilience should be considered together when India plans and finances its next generation of housing. Using the latest available evidence from NITI Aayog, NFHS-5, CEEW, UNEP, PMAY and GGGI's work on low-carbon buildings, it examines the housing deficit, climate exposure, gender and inclusion, and the market barriers that stand between policy intent and implementation.

1. Introduction

Housing is a fundamental human right under international law. However, in most cases housing policies primarily revolve around 'access and availability', i.e. number of houses required and who can afford them. But a house is also a long-lived asset, and its sustainability is often depicted in the choices we make today.

The UN Committee on Economic, Social and Cultural Rights

AT A GLANCE

- 5–7 crore: Estimated housing deficit across metro, urban and semi-urban India.
- 60.3%: Indian households living in pucca houses, according to NFHS-5 (2019–21).
- 80%: India's population living in districts highly vulnerable to extreme hydro-meteorological disasters.
- 57%: Indian districts at high or very high heat risk, home to 76% of the population.
- 37%: Global CO₂ emissions associated with buildings and construction.
- 1.20 crore: Employment opportunities estimated through PMAY-U's forward and backward linkages across 21 sectors.

defines adequate housing on seven elements: security of tenure, availability of services and infrastructure, affordability, habitability, accessibility, location and cultural adequacy. For India, this broader definition matters more significantly because a house can be pucca and yet still be poorly located, unaffordable, thermally uncomfortable or inadequately serviced. Additionally, with the global temperatures surpassing 1.5 degree centigrade – housing or the building ecosystem overall is becoming of utmost significance not just for basic human rights but also for climate action.

UNEP and the Global Alliance for Buildings and Construction report that buildings and construc-

tion represent 11 to 13% of global GDP and around 9% of global employment. The sector also accounts for about 37% of global CO₂ emissions driven primarily by the rise in electricity consumption driven by cooling demand. The 2025–26 report also notes that half of the buildings that will exist globally in 2050 have yet to be built or renovated¹.

For India this opportunity is particularly essential as more than half the building stock it will need by 2050 is yet to be built. Therefore, the buildings we invest in today, translate to long term durability and security rather than pay later to retrofit with older

¹ Global Status Report for Buildings and Construction 2025-2026 | UNEP - UN Environment Programme

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building leaving smaller margin for sustainable solutions, as most economies now face. Section 6 of this article highlights some of the case studies undertaken by GGGI in India and highlight the main learnings from them.

2. Can Everyone Afford Adequate Housing?

Three concepts should be kept distinct: a pucca house, an affordable house and an adequate house. The National Family Health Survey - 5 (NFHS-5, 2019-21)² reports that 60.3% of Indian households lived in pucca houses in 2019-21. However, this statistic does not necessarily present as a measure of adequacy because structural quality alone does not capture affordability, services, accessibility, location or climate performance. Only 28.4 % of Indian households qualify nationally if we go by the true measure of adequacy (60.6 % urban, 13.3 % rural)³. **The 31.9% gap is the size of India's hidden adequacy deficit: households that are counted as housed in structural terms but are not adequately housed in any functional sense.**

This distinction is particularly important in understanding India's housing affordability challenge. A recent NITI Aayog assessment estimates a housing shortage of approximately 5-7 crore units across metro, urban and semi-urban areas. Its analysis also illustrates how the gap varies across settlement types⁴.

Table 1: NITI Aayog Estimate of Housing Shortage by Settlement Type (Dec 2025)⁵

Segment	Households (crore)	Liveable houses (crore)	Shortage (crore)
Metro	5.0	2-3	2-3
Other Urban	3.8	1.8-2.3	1.5-2
Semi-Urban	4.8	3.0	1.5

NITI Aayog identifies several structural constraints that influence whether adequate housing can be delivered at a price households can afford. Land is a major cost driver, accounting for an estimated 10% of housing costs in rural areas but up to 63% in metropolitan areas. At the same time, nearly one crore urban houses are estimated to be vacant even as housing demand remains unmet, highlighting challenges in rental markets, including low rental yields, tenancy risks and litigation concerns.

These pressures also have a spatial dimension. Housing that is cheaper to acquire but located far from employment, education, healthcare and public transport can impose significant costs on households through longer commutes and higher transport expenditure. For low-income households in particular, affordability is therefore not determined by the price of the house alone. It is shaped by the combined cost of housing, energy, transport and essential services.

For low-income and middle-income households, this creates an important opportunity. **Climate-responsive design should therefore not be treated as an additional premium added to affordable**

housing. It should be considered part of what makes housing affordable over its lifetime.

3. India's Climate Vulnerability Index

The affordability of a home cannot be separated from where it is located and the climate risks it faces. A house may be affordable to acquire but still be inadequate if it is repeatedly exposed to flooding, extreme heat, cyclones or other climate hazards. Climate resilience therefore needs to be considered from the point of site selection and planning through design, construction and operation, rather than being treated only as a post-disaster concern.

The urgency is growing alongside India's rapid urbanisation. India's urban population is projected to almost double to 951 million by 2050, while more than 144 million additional urban dwelling units will be needed between 2022 and 2070. At the same time, urban expansion is increasing exposure to climate risks. The World Bank reports that intense heat and urban heat island effects are already causing city-centre temperatures to rise by more than 3-4°C compared with surrounding areas, while the expansion of built-up areas is reducing the capacity of cities to absorb stormwater and increasing flood risks⁶.

India's climate vulnerability is not uniform. CEEW's 2021 Climate Vulnerability Index (CVI) assessed exposure, sensitivity and adaptive capacity to extreme hydro-meteorological events and found that 27 of 35 states and Union Territories were highly vulnerable, with more

² NFHS

³ How many Indians live in a pucca house with basic amenities? » CEDA

⁴ A_Comprehensive_Framework_to_Promote_Affordable_Housing.pdf

⁵ Source: NITI Aayog, A Comprehensive Framework to Promote Affordable Housing, December 2025.

⁶ India has a critical opportunity to drive resilient urban development, says new World Bank report

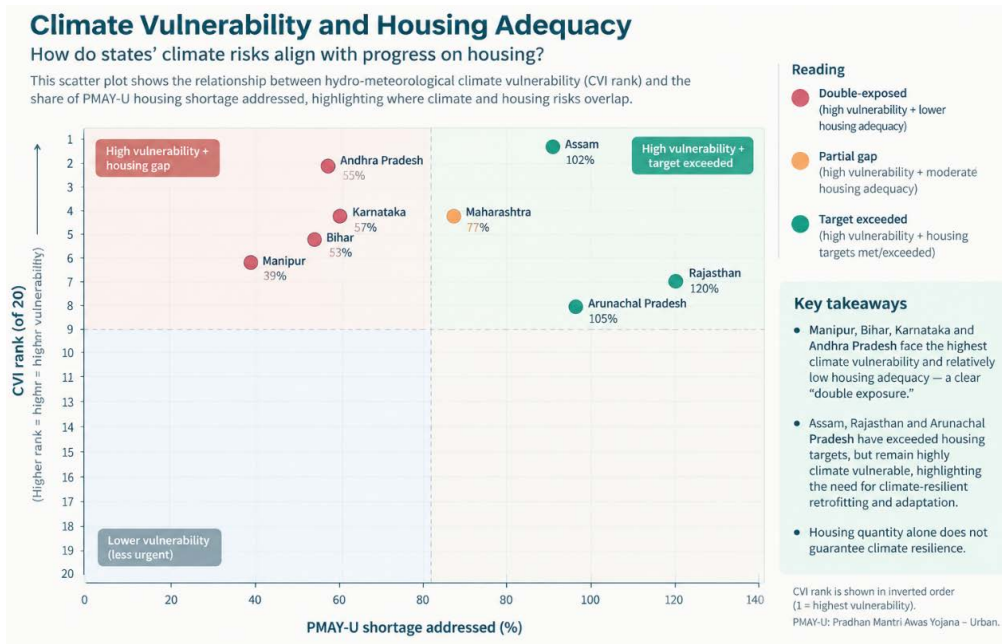


Figure 1: CVI and PMAY - Status for Selected States

than 80% of India's population living in districts highly vulnerable to extreme hydro-meteorological disasters. **Assam, Andhra Pradesh, Maharashtra, Karnataka and Bihar** ranked among the most vulnerable states.⁷

One of the recent pressing concerns now is the rising ‘heat’ leading to thermal discomfort. CEEW's 2025 district-level assessment of 734 districts found that 417 districts, or about 57%, were at high or very high heat risk, covering 76% of India's population. The assessment also shows that heat risk is shaped not only by rising temperatures, but by population and building density, loss of green cover, humidity and underlying health and socio-economic vulnerabilities.

This becomes particularly important when climate vulnerability is considered alongside housing delivery. The state-level CVI and PMAY-U data presented in the **Figure-1** show that several highly

climate-vulnerable states also have relatively low completion against their original PMAY-U targets. Bihar, Andhra Pradesh, Karnataka and Manipur, for example, combine high CVI scores with comparatively lower PMAY-U completion rates in the dataset. This points to a potential **double exposure**, where the need for housing and the need for climate resilience overlap.

4. Impact of Improper Housing on Vulnerable Communities

Housing inadequacy does not affect all households equally. For women, particularly those in low-income and climate-vulnerable households, inadequate housing can magnify the impacts of extreme heat, flooding, water stress etc. Women often carry a disproportionate share of unpaid care and household responsibilities⁸. When climate shocks disrupt water supplies, increase indoor temperatures or damage homes, the time and effort required to manage these impacts can increase, reduc-

ing the time available for paid work, education and other economic opportunities. Housing therefore becomes both an equity issue and an economic issue.

Additionally, Low-income (LIG) and lower-middle-income (MIG) households generally have less financial flexibility to absorb higher electricity, maintenance or transport costs. For LIG households, even relatively small

increases in recurring expenditure can affect spending on other essentials. For MIG households, rising operating costs can gradually erode the affordability of a home that appeared affordable at the point of purchase.

Housing programmes can also influence who has access to housing assets. Under PMAY-U, houses are promoted in the name of an adult female member of the household or jointly with another household member. Under PMAY-G, houses are similarly sanctioned in the name of the woman or jointly with her husband, with provisions for women-only ownership in specified circumstances.

The scale of this approach is significant. Under PMAY-G, around 73% of completed houses were owned solely or jointly by women as of December 2024⁹. PMAY-U has also reported that around 80%¹⁰

⁷ ceew-study-on-climate-change-vulnerability-index-and-district-level-risk-assessment.pdf

⁸ working-paper-the-climate-care-nexus-en.pdf

⁹ 2.68 Crore Rural Houses Completed under PMAY-G Scheme, Women Ownership at 73 Per Cent - Elets eGov

¹⁰ 80% houses given under Prime Minister Awas Yojana are owned by women: Modi | Current Affairs News National - Business Standard

of houses were owned or jointly owned by women, a milestone reported in 2021. While ownership alone does not guarantee economic empowerment, a formal stake in a household asset can strengthen women's position within the household and provide a foundation for greater economic security.

A truly adequate home should provide a secure asset while also reducing exposure to heat and other climate risks. For LIG and MIG households, better design and building performance can also reduce the recurring costs of keeping homes comfortable. Women's ownership, climate resilience and affordability can therefore reinforce one another, allowing housing policy to contribute to social protection, adaptation and economic inclusion.

5. The Need for Affordable, Low-Carbon Houses

India's housing challenge is unfolding alongside rapid urbanisation and rising demand for cooling and electricity. This makes the quality of new construction an economic question as much as an environmental one. India now has a policy architecture that can support better building performance, including the India Cooling Action Plan (ICAP) and the Energy Conservation and Sustainable Building Code (ECSBC).

The case for acting at the design stage is particularly strong because buildings can remain in use for decades. Decisions made during planning and construction can lock in thermal performance and energy requirements for the lifetime of a building. Poor design can create long-term costs for

households, while retrofitting occupied homes later can require additional capital and may be technically or financially difficult.

The priority should therefore be to incorporate climate-responsive measures from the outset. Passive cooling, shading, natural ventilation where appropriate, reflective and efficient building envelopes, suitable materials and climate-resilient construction can reduce heat exposure and energy demand before mechanical cooling is required. Efficient appliances and renewable energy can complement these measures where active cooling is necessary.

6. Case Studies: Climate Friendly Living

6.1 Asia Low Carbon Buildings Transition (ALCBT) Project¹¹

Launched under the guidance of the Ministry of Housing and Urban Affairs (MoHUA), Government of India and funded by the International Climate Initiative (IKI) the Asia Low Carbon Buildings Transition (ALCBT) Project is a five-year initiative that aimed to facilitate the nationwide transition towards Low Carbon Buildings (LCBs) and meet the urge in cooling-driven peak electricity demand

directly for existing and upcoming buildings. Led by Global Green Growth Institute (GGGI) the project is targeting the reduction of 0.76 Mt CO₂e GHG emissions primarily driven by the rising demand for cooling through standardizing tools and systems, policy interventions, and building capacities of key public and private stakeholders. As of 2026, the project has developed a comprehensive buildings registry now covering 1,687 buildings across its 3 pilot implementation states of Kerala, Haryana, and Uttar Pradesh of which 302 have already been assessed on a whole-life-carbon basis using the Building Emission Assessment Tool (BEAT)¹², also developed under the project. Moving forward the project and is planning to deliver sustainable-cooling retrofit pilots across 60 Indian buildings alongside its partner Energy Efficiency Services Limited (EESL). The project has also built the technical capacity for more than 3,000 government officials, architects, engineers, developers, building owners and financiers on LCB across India and conducted University Gap Assessment to incorporate Low Carbon Buildings into its syllabus. In April 2026, the project officially launched the

¹² Introducing BEAT: Building Emission Assessment Tool - Asia Low Carbon Buildings Transition

¹¹ [Home - Asia Low Carbon Buildings Transition](#)



Figure 2: Energy Audit (Chillar - Buildings)



Figure 3: Capacity Building Trainings with CII

Green Finance Network (GFN)—India, convening over 25 financial institutions, developers, and regulators to close the financing gap for LCBs identified in Section 6. The implementation is also overseen by the Building Material and Technology Promotion Council (BMTPC) in India, Government of India.

6.2 Cool Roofs for Indian Residential Buildings¹³

GGGI's current demonstration project addresses thermal comfort directly for the vulnerable communities where cooling demand and heat-health risk are most acute. Implemented across 20 residential, community and Anganwadi¹⁴ centres in Haryana and Andhra Pradesh using solar-reflective roof coatings, it is projected to deliver 150–250 kWh of energy savings per building annually and reduce indoor temperatures by 4–6°C aligned with the India Cooling Action Plan (ICAP) and with city-level Heat Action Plans. The project pairs the physical intervention with capacity-building for around 60 stakeholders and the development of technical guidelines, standard operating procedures, and a replication roadmap intended for uptake by state agencies beyond the pilot sites. The project illustrates a wider principle that climate-resilient housing does not always require expensive technologies. Through this pilot demonstration GGGI aims to scale up the offtake of cool roof paints across more residential and commercial buildings in India especially promoting LCB houses under PMAY – U.

¹³ Advancing Thermal Comfort and Energy Savings through Cool Roofs in Indian Residential Buildings — Global Green Growth Institute

¹⁴ Anganwadi - Wikipedia



Figure 4: Cool Roof Completed Projects

6.3 Technical inputs to Pradhan Mantri Awas Yojana—Urban (PMAY-G)

GGGI's technical team has provided inputs and developed a framework for supporting the integration of low-carbon, energy-efficient, and climate-resilient building practices into PMAY-G, working alongside the broader effort to align the country's largest housing programme. This initiative supported in incorporating green perspective in Government's flagship rural housing scheme and providing safe and secure houses for the most marginalized sections of the society. In line with the technical standards set out in the ECSBC and ICAP, embedding sustainable practices and solutions at the point of design and construction rather than as a later retrofit is the lowest-cost way to ensure that upcoming housing stock, delivered at a scale of over a crore unit, does not itself become the next generation's retrofit liability.

7. From Solutions to Scale

From the implementing experience of these solutions GGGI learned that the challenge for offtake of low carbon buildings and houses is not simply a lack of viable technologies or approaches. Many low-carbon building measures can improve thermal comfort, reduce energy use and lower lifetime costs, but their adoption remains limited by gaps across the market. These include uneven awareness and skills, limited access to reliable building-level information, difficulties in preparing investment-ready projects, and financing constraints.

Some of the highlights of the learnings include:

- **Building-level data:** During the development of the buildings registry database under the ALCBT project, it was revealed that India till date lacks the necessary and reliable information on the existing building stock, materials especially Bill of Quantities (BoQ) data, energy performance. This becomes difficult for lenders, policymakers and project developers to price risk or prioritise investment. Therefore, strong emphasis was placed on the development of a nationalized repository to further streamline the implementation of LCBs in the country.
- **Low Awareness:** The knowledge of LCBs is still low amongst the individuals with fragmented knowledge amongst Architects, Engineers, Building Owners, Developers, Government and Financial

Institutions. Through dedicated and voluntary capacity building programs for LCBs, over 3,000 individuals across the buildings ecosystem of India have been engaged. Of which 90% of the participants self-assessed their willingness to apply the necessary skills and knowledge gained from the training programs to their jobs and around 80% of the participants gained the necessary skills and knowledge from the training programs. Through similar replication approaches across public and private sectors, the nationwide transition towards LCBs can be facilitated.

- **Missing Links in Education:** India's higher education system operates at a scale few nations can match, encompassing thousands of engineering colleges and more than 362 architecture school's¹⁵ from which thousands of engineers and architects graduate each year. However, the university gap assessment conducted across selected universities in Kerala, Haryana and Uttar Pradesh revealed that several universities have not yet shifted their focus to dedicated green/lifecycle carbon courses a potential fall back for the upcoming population in India. Based on the recommendations some of the universities went further to agree to present the findings in front of Board of Studies for formal deliberation. The summary below highlights the findings from GGGI's gap assessment:

- **Availability of Tools and**

¹⁵ https://coa.gov.in/architectural_institutions.php

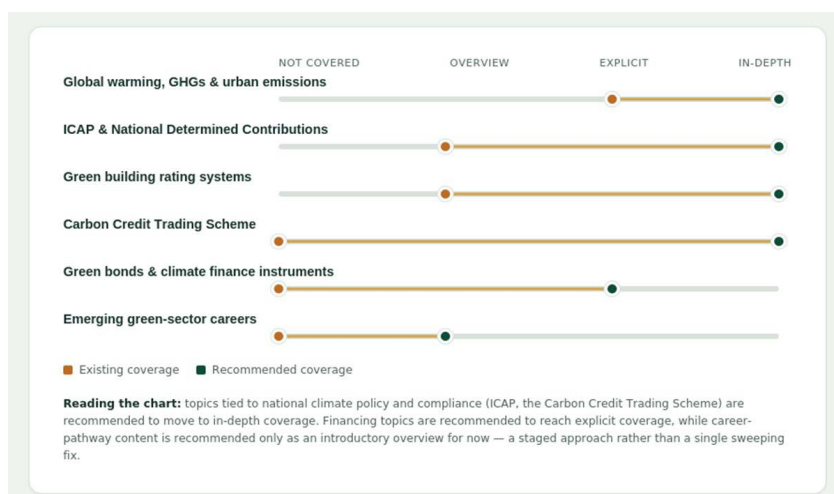


Figure 5: Gap Assessment Recommendations

Systems: Developers, households and financiers need credible information on building performance, lifecycle costs and climate risk. At present, free and available tools for accounting embodied and operational carbon is not available in the market. The Building Emission Assessment Tool (BEAT) offers a standardized, bottom-up methodology for assessing building-level emissions, enabling consistent evaluation across diverse building types. Its use supports informed decision-making by providing granular insights into energy use patterns and carbon hotspots, helping identify opportunities for emissions reduction. Furthermore, the building registry, together with BEAT-based assessments, should be embedded into urban planning and climate action policies to align with broader sustainability goals. Institutionalizing energy and carbon assessments within planning frameworks will strengthen regulatory enforcement, enhance

transparency, and accelerate the development of low-carbon, energy-efficient urban infrastructure.

- **Finance and project preparation:** Low-carbon measures can involve higher upfront costs even when they reduce operating costs over time. Financial institutions also need investment-ready projects, clear performance information and appropriate financial structures. GFN-India is designed to improve this gap rather than act as a financing facility itself.

7. Way Forward

'Adequate housing for all' is therefore not a choice between social policy and climate policy. It is an investment challenge that brings together affordability, infrastructure, resilience, energy use, finance and inclusion.

For India, the opportunity is to ensure that the homes built over the coming decades improve living standards without creating a new generation of high-cost, high-energy and climate-vulnerable assets.

Table-2: State-wise PMAY-Urban Housing Shortage Addressed

State	Beneficiaries identified	Houses completed	Completed/ Identified
Andhra Pradesh	20,50,000	11,19,901	55%
Arunachal Pradesh	8,000	8,405	105%
Assam	1,40,000	1,43,230	102%
Bihar	3,75,000	1,98,204	53%
Chhattisgarh	3,00,000	2,61,995	87%
Delhi	79,000	31,670	40%
Goa	4,845	3,174	66%
Gujarat	7,65,000	9,63,217	126%
Haryana	1,50,000	72,749	48%
Himachal Pradesh	13,000	11,887	91%
Jammu & Kashmir	79,331	34,954	44%
Jharkhand	2,20,000	1,64,854	75%
Karnataka	7,00,000	3,98,070	57%
Kerala	1,30,000	1,38,779	107%
Madhya Pradesh	8,50,000	8,94,215	105%
Maharashtra	13,50,000	10,37,844	77%
Manipur	55,000	21,439	39%
Meghalaya	6,000	2,750	46%
Mizoram	40,000	33,813	85%
Nagaland	35,000	30,120	86%
Odisha	1,80,000	1,68,437	94%
Punjab	1,15,000	1,01,895	89%
Rajasthan	2,20,000	2,63,048	120%
Sikkim	1,500	219	15%
Tamil Nadu	7,15,000	6,19,003	87%
Telangana	2,25,000	2,25,346	100%
Tripura	92,000	81,606	89%
Uttar Pradesh	17,00,000	17,16,677	101%
Uttarakhand	50,000	48,444	97%
West Bengal	5,50,000	5,02,051	91%

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Table-3: CVI for India's Top 20 States

Rank	State	CVI score	Category
1	Assam	0.616	High
2	Andhra Pradesh	0.483	High
3	Maharashtra	0.478	High
4	Karnataka	0.465	High
5	Bihar	0.448	High
6	Manipur	0.424	High
7	Rajasthan	0.423	High
8	Arunachal Pradesh	0.408	High
9	Sikkim	0.370	Medium
10	Odisha	0.368	Medium
11	Nagaland	0.365	Medium
12	Tamil Nadu	0.339	Medium
13	Himachal Pradesh	0.329	Medium
14	Jammu & Kashmir	0.328	Medium
15	NCT Delhi	0.290	Medium
16	Gujarat	0.280	Medium
17	Uttar Pradesh	0.269	Medium
18	West Bengal	0.257	Medium
19	Tripura	0.250	Medium
20	Kerala	0.226	Medium

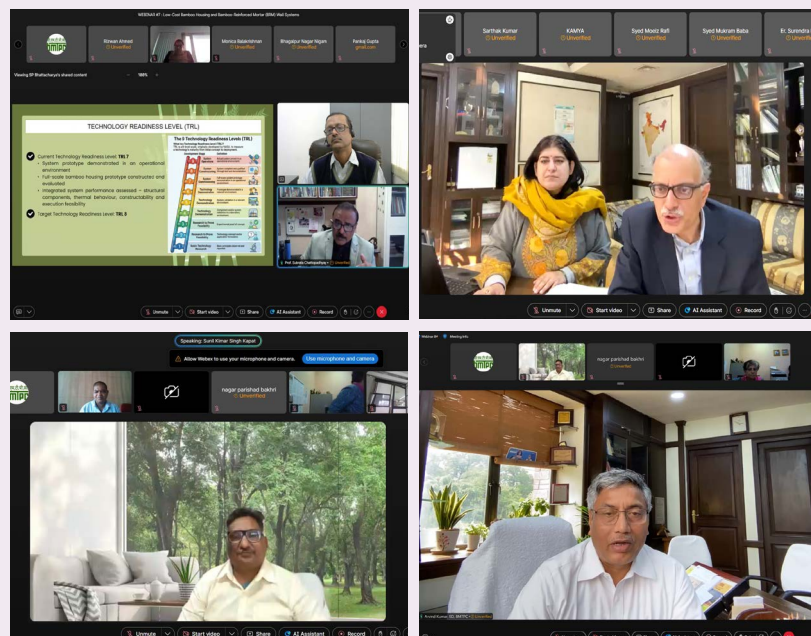
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BMTPC Webinar Series on “Innovative Building Materials and Technologies for Thermally Comfortable Green Buildings”



To promote the use of modern, green and innovative building materials and technologies for sustainable and quality housing under PMAY-U 2.0, the Building Materials & Technology Promotion Council (BMTPC) has launched a webinar series on “Innovative Building Materials and Technologies for Thermally Comfortable Green Buildings.”

The webinar series aims to create awareness about cutting-edge building materials, sustainable construction solutions and emerging technologies that contribute to improved thermal comfort, energy efficiency and environmental sustainability in modern green buildings. The series also highlights innovative approaches for enhancing the resilience of buildings against natural hazards, thereby promoting safe, sustainable and climate-responsive housing.

The series is designed to benefit a wide range of stakeholders, including State Government officials, architects, engineers, developers, professionals, students and other stakeholders engaged in housing policy, planning, design and implementation. It also provides valuable knowledge and insights to PMAY-U stakeholders and implementing agencies for adopting innovative and sustainable construction practices.

Eight webinars have been organised so far, covering various aspects of innovative building materials, technologies and sustainable construction practices. Through this initiative, BMTPC continues to facilitate knowledge sharing, capacity building and wider adoption of innovative technologies for sustainable, resilient and thermally comfortable housing in the country.

Transforming Agro-Industrial By-Products into Sustainable Construction Materials and Modular Housing Systems in India



Dr. Rahul V. Ralegaonkar¹



Dr. Sanchita Nawale²

The vision of “Adequate Housing for All” requires the development of housing systems that are affordable, resource-efficient, environmentally responsible, thermally comfortable, and capable of rapid construction. The increasing demand for infrastructure and housing has intensified the consumption of natural resources and energy, while conventional cement-based construction continues to contribute significantly to environmental pollution and greenhouse-gas emissions. Simultaneously, the generation of agricultural residues and industrial by-products has increased, creating challenges related to storage, disposal, and land contamination. These concerns highlight the need to develop alternative construction materials that can convert locally available residues into value-added products while reducing dependence on conventional raw materials.

This research investigated the potential of agro-industrial by-products, particularly sugarcane bagasse ash (SBA) and biomass

ash (BA), for the development of sustainable construction materials and innovative housing technologies. The study focused on material characterization, mix development, mechanical and functional performance, environmental assessment, and practical implementation through modular construction. Sugarcane bagasse ash was investigated as a pozzolanic and cementitious constituent for producing building bricks and low-density construction blocks. Comprehensive physical, chemical, mineralogical, and microstructural characterization was undertaken to evaluate its suitability for construction applications. The development of SBA–Quarry Dust–Lime (SBA-QD-L) bricks and cellular lightweight SBA bricks demonstrated the potential of agricultural residues to replace or reduce the use of conventional raw materials. The developed products were assessed in terms of compressive strength, durability, density, thermal properties, and environmental performance. The results indicated that the incorporation of SBA can contribute to the production of

lightweight construction materials with satisfactory engineering performance. The lower thermal conductivity of the developed materials, compared with conventional construction products, indicated their potential to improve indoor thermal comfort, particularly in hot climatic regions. Experimental housing models further demonstrated the possibility of reducing indoor temperatures through the use of thermally efficient walling materials. Such performance can contribute to reduced cooling requirements and improved living conditions, particularly in affordable housing projects and for economically vulnerable communities.

In addition to brick and block production, biomass ash obtained from the co-combustion of coal and biomass in industrial boilers was evaluated as a precursor for alkali-activated concrete. A regional survey supported by the Maharashtra Pollution Control Board identified industrial residues generated from boiler operations in the Nagpur region of Maharashtra. The selected biomass ash was

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subjected to physical, chemical, mineralogical, and morphological investigations to establish its suitability for alkali activation. Based on the characterisation results, different mix proportions were developed for producing M30-grade alkali-activated concrete. The study examined the effects of sodium hydroxide molarity, sodium silicate-to-sodium hydroxide ratio, fly ash-to-biomass ash ratio, and alkali-activator solution-to-dry-mix ratio on the fresh and hardened properties of concrete. Commercial sodium hydroxide and liquid sodium silicate were used as activators, and the mix parameters were developed with reference to the relevant provisions of IS 17452:2020.

The research was further extended to the development of self-compacting alkali-activated concrete (SCAAC) under ambient curing conditions. Ground granulated blast-furnace slag was incorporated to improve setting behaviour and facilitate ambient curing. The fresh properties of the concrete were evaluated in accordance with the EFNARC 2002 guidelines, including filling and passing abilities. The optimised mix achieved a compressive strength of 38.12 MPa, satisfying the target requirement for M30-grade concrete. The corresponding flexural and split tensile strengths were 4.12 MPa and 3.95 MPa, respectively. The material also demonstrated favourable thermal characteristics, including lower thermal conductivity than conventional concrete. These findings establish the potential of agro-industrial by-products to produce structurally adequate, thermally efficient, and environmentally responsible

construction materials.

The environmental performance of the developed alkali-activated concrete was assessed through embodied-energy analysis and life-cycle assessment. The results indicated a 7.37% reduction in embodied energy compared with conventional cement concrete. Under the assessed conditions, the contribution to Global Warming Potential was approximately 29% for the alkali-activated concrete, compared with 42% for conventional concrete. These findings highlight the environmental benefits of replacing conventional cement-based systems with appropriately designed alkali-activated materials. They also demonstrate the importance of evaluating construction materials not only through mechanical strength but also through energy consumption, environmental impact, durability, and long-term performance.

To validate the practical applicability of the developed materials, biomass-ash-based alkali-activated concrete was used in the construction of a full-scale three-dimensional volumetric modular pod. Casting and on-site erection were completed within seven days, while the overall time assessment indicated an approximately 50% reduction in construction duration compared with conventional construction methods. Although the cost of producing a single modular unit was higher than that of a conventional unit, the economic assessment indicated improved cost-effectiveness with large-scale production. The manufacturing cost per unit was expected to decrease as production volume increased, with potential economic viability identified for mass produc-

tion beyond 100 units.

Overall, the research demonstrated an integrated approach combining waste utilization, sustainable material development, thermal efficiency, alkali-activated technology, life-cycle assessment, and modular construction. The use of SBA, BA, fly ash, GGBS, quarry dust, and other agro-industrial residues can support the development of bricks, blocks, paving units, lightweight products, concrete, and prefabricated components. For effective implementation in India, region-specific mapping of ash sources, reliable collection and processing systems, quality-control mechanisms, and collaboration among research institutions, government agencies, and industry are required. Pilot projects under affordable housing and sustainable habitat programmes can support field validation under different climatic and construction conditions. Compliance with relevant Indian Standards, long-term durability assessment, and performance-based approval will be essential before large-scale structural application. The conversion of agro-industrial residues into construction resources can therefore contribute to circular-economy practices, low-carbon development, improved housing quality, and the broader objective of “Adequate Housing for All.”





3D Volumetric Alkali activated pods



3D printer Partition Cabin



Pre-fabricated Guard Rooms



The CLW-BBA brick construction resulted in 34% reduction in Dead load, 24% Cost Savings and 6% less temperature control compared to Fly ash brick construction



Development of 3D Sustainable Volumetric Pods & Application Thereof



Vivesvaraya National Institute of Technology, Nagpur,
India

Civil Engineering Department

Prologue

The construction sector is a key contributor to economic growth and is currently experiencing various disruptions, including the adoption of offsite construction methods. The increasing construction activities have exploited the conventional raw materials. This study presents the development of 3D sustainable volumetric toilet pod using cement free self compacting concrete (SCAAC) using agro-industrial by-products and sodium based alkali activators (AAS). The fine aggregates were replaced with 10% CFBA. The end-product was tested for physico-mechanical, and functional properties. The developed concrete successfully met the specified compressive strength requirement for M30 grade concrete, achieving a value of 38.12 MPa. The developed 3D volumetric pod gained 95% of its strength within 7 days, requires 7.55% less embodied energy, 35% reduction in peak cooling load, and contributes 13% less to the GWP as compared to cement-based concrete.

Raw Material – Feasibility Analysis

Agro-Industrial wastes – CFBA (co-firing rice husk and coal in the boilers of a paper mill industry), Fly ash and Ground granulated blast furnace slag (GGBS).

Various physical and material characterisation properties were conducted on CFBA such as Scanning electron microscopy (SEM), X-Ray diffraction (XRD), X-Ray fluorescence (XRF), and other related tests. It was proved to be suitable as a substitution for fine aggregate in concrete making.



Experimental Study

Different mix compositions were tried with varying molarity of NaOH. For passing and filling abilities, the properties of fresh SCAAC were assessed in accordance with the guidelines of EFNARC (2002). Optimum mix were finalised based on the testing parameters such as density and compressive strength. Furthermore, other mechanical (tensile and flexural) and functional (thermal conductivity) property tests were performed, and the end product was found to be suitable as a sustainable alternative to cement-based M30 grade concrete.

Table: Fresh Concrete properties as per EFNARC Guidelines

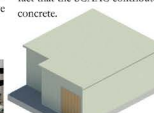
Tests	Values	Acceptable Values	Units
Slump Flow	680	650-800	mm
V Funnel	11.05	8.0-12.0	sec
L Box	0.82	0.8-1	(h ₂ /h ₁)
J ring	2	0-10	mm

Table: Hardened concrete properties

Mix	Density (kg/m ³)	Compressive Strength (MPa)	Tensile Strength (MPa)	Flexural Strength (MPa)	Thermal Conductivity W/(m.K)
Optimum Mix	2350	38.12	2.72	3.44	1.247

Computational Study

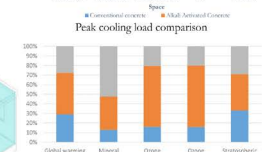
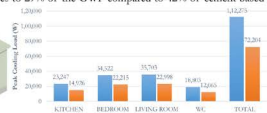
Optimal building design was carried out for a real-scale structure with developed end-products with the BIM based computational tools. From the energy perspective, 7% reduced embodied energy and around 35% reduced peak cooling loads were observed on comparison with cement based concrete. The life cycle impact assessment confirms the fact that the SCAAC contributes to 29% of the GWP compared to 42% of cement based concrete.



Prefab Model



Energy Model



On-field application

The demonstration of technology (Full scale toilet pod) was done under the Ministry of Housing and Urban Affairs (MoHUA) pre-incubation support, the mentorship of CSIR-CBRI, Roorki and CSIR-NEIST. The dimensions of toilet unit were considered as per Swachh Bharat Abhiyan guidelines. The product is ambient-cured, saving an immense amount of water required for curing in the case of cement based concrete. The time study observes a 50% reduced total duration when the volumetric construction technique was preferred over conventional technique. The developed 3D volumetric pod gained 95% of its strength within 7 days, requires 7.55% less embodied energy, 35% reduction in peak cooling load, and contributes 13% less to the GWP as compared to cement-based concrete.

3D Volumetric Toilet Pod



Implications



Time Saving



Quality & Waste Management



Energy efficient



Sustainability



Value to the Society

Publications

1. Lanjewar, B. A., Chippagiri, R., Dakwale, V. A., & Ralegaonkar, R. V. (2023). Development of bio-based blended ash and fly ash based alkali activated concrete. *Magazine of Concrete Research*, 1-29. <https://doi.org/10.1680/jmagr.22.00251>
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Patent

- Indian patent "Composition for M30 Grade Alkali Activated Concrete Prepared Using Agro-Industrial Wastes" Granted 20/11/2023 (No-470442)

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From Adequate to Future-Ready Housing

Connecting Resilience, Performance, Finance and Delivery



Dr. Priyanka Kochhar *

Adequate Housing in a Changing World

Housing has traditionally been discussed in terms of supply: how many homes are needed, where they should be built, and how they can be made affordable. These questions remain fundamental. But as cities confront climate change, environmental stress, rising costs and increasingly complex patterns of vulnerability, another question is becoming equally important: what makes a home adequate over time?

The question is particularly relevant in 2026, when World Habitat Day is being observed under the theme “Adequate Housing for All.”¹ UN-Habitat’s World Cities Report 2026² places adequate housing within a wider framework of sustainable urban development, linking housing with access to services, health, economic opportunity, inclusion, climate action and urban resilience.

A home may be structurally sound yet increasingly expensive to operate as temperatures rise. It may meet construction require-

ments yet remain exposed to flooding or other hazards because of where it is located. A well-designed dwelling may still leave its occupants vulnerable if roads, water, electricity or other essential services fail around it. For lower-income households, where the home may also be a place of work, care or livelihood, such disruption can have consequences far beyond physical damage.

Adequacy, therefore, cannot

be treated as a static attribute of a housing unit. It is increasingly a question of performance over the life of the home.

This suggests a shift in the way the housing challenge is framed. The question is not only how to provide more housing, but how to ensure that housing remains affordable, safe, healthy, resource-efficient, accessible and resilient as conditions change.

Figure 1 — Dimensions of Adequate Housing:
From a Dwelling to a Sustainable Housing Outcome



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The challenge is not simply to add more requirements to an already complex housing system. It is to connect affordable housing, sustainable buildings, disaster resilience, housing finance, infrastructure and delivery capacity in ways that governments, developers, financial institutions and households can act upon.

1. Rethinking What Makes Housing Adequate

The idea of adequate housing has never been limited to the physical structure of a dwelling. It encompasses affordability, habitability, accessibility, security, services and location.³ What is changing is the context in which these dimensions have to be sustained.

Climate change makes this particularly evident. The effective cost of occupying a home extends beyond rent, purchase price or housing finance to include energy, water, maintenance, transport and the costs associated with disruption or damage. A dwelling may therefore be affordable at the point of purchase but expensive over its lifetime.

Similarly, habitability cannot be separated from changing environmental conditions. Thermal comfort, indoor air quality, water availability and protection from hazards increasingly influence whether a dwelling remains healthy and functional. Resilience is therefore not an additional feature that can simply be attached to a building after design has been completed; it is part of the adequacy of the home itself.

This suggests that “adequacy” needs to become both multidimensional and dynamic. It should encompass four interconnected

questions:

Is the home affordable?

Not only at the point of purchase or construction, but over its lifecycle.

Is it safe and healthy?

Including protection from structural, environmental and climate-related risks.

Does it perform?

In terms of energy, water, thermal comfort, resource efficiency and other relevant parameters.

Can it remain functional and recover from disruption?

Taking into account the dwelling, its location, surrounding infrastructure, essential services and the capacity of households and institutions to respond.

These questions do not replace existing definitions of adequate housing. Rather, they highlight an important evolution: environmental performance and resilience increasingly determine whether the other dimensions of adequacy can be sustained over time.

That takes the discussion beyond the individual building.

2. From Resilient Buildings to Resilient Housing Systems

A common way of approaching housing resilience is through the physical building: stronger structures, safer materials, hazard-resistant construction and compliance with relevant codes and standards.⁴

India already has an important institutional foundation for this systems approach. The Building Materials & Technology Promotion Council (BMTPC), under the Ministry of Housing and Urban Affairs,

works at the interface of building technologies, disaster-resistant construction, vulnerability assessment and capacity building. Its Vulnerability Atlas of India translates hazard information into an understanding of housing vulnerability and risk, illustrating how resilience can move from a general aspiration towards context-specific housing decisions.

These remain essential. But they are only one part of the equation.

A resilient building is not necessarily a resilient housing outcome.

The distinction becomes apparent when we consider how households actually experience climate and disaster risks.

A house can remain structurally intact during a flood while the surrounding road network is inaccessible, electricity is disrupted and water services are unavailable. A dwelling can meet structural requirements while becoming dangerously hot because of its orientation, envelope, ventilation or surrounding urban conditions. A technically sound home may be difficult to repair if appropriate materials and skilled workers are unavailable locally.

For many households, the consequences extend further. If the home is also a place of work, a small business, a rental asset or a site of home-based care, disruption to the dwelling can affect household income and financial security.

Housing resilience therefore has to be understood at the intersection of building, place and people.

This broader perspective is increasingly reflected in the re-

silience discourse. CDRI's current work on resilient housing similarly frames housing together with basic services and allied social infrastructure as part of a wider habitat system. Its Community of Practice on Resilient Housing, established in 2026, is explicitly examining resilience across formal and informal settlements and the roles of financing, technology, community participation, governance and traditional knowledge. Its scope covers new housing, retrofitting and post-disaster recovery.⁵

This suggests that housing resilience can be considered across at least five interconnected layers:

1. **The dwelling:** Structural safety, thermal performance, materials, energy and water efficiency, accessibility and maintainability.
2. **The site and neighbourhood:** Exposure to hazards, land-use patterns, drainage, mobility, public space and access to essential services.
3. **The infrastructure and service system:** Water, sanitation, electricity, transport, communications and other systems that allow a dwelling to function as a home.
4. **The household:** Affordability, tenure, livelihood dependence, capacity to invest in improvements and ability to prepare for and recover from shocks.
5. **The institutional and delivery ecosystem:** Planning systems, regulations, financial institutions, technical professionals, construction workers, material supply chains, local governments and community organisations.

The significance of this framework is that weaknesses at any one level can undermine resilience at the others. A technically resilient house may not be sufficient if the household cannot afford to maintain it; a well-financed programme may not deliver resilient outcomes if local contractors lack the necessary skills; and a strong building code may have limited effect where implementation capacity is weak.

This is why the resilience challenge cannot be addressed solely through stronger building standards. It requires a shift from thinking about resilient buildings to thinking about resilient housing systems.

There is another important implication. Resilience cannot be completely standardised.

The risks facing a coastal settlement are different from those facing a heat-stressed inland city or an earthquake-prone hill settlement. Construction practices, household incomes, tenure arrangements, available materials, institutional capacity and local knowledge also differ.

The objective, therefore, should not be to create one universal checklist for resilient housing. Instead, the sector needs a common architecture of assessment that can be adapted to local risk, climate, housing typology and socioeconomic conditions.

This raises the next question: if adequate and resilient housing is multidimensional and context-specific, how do we know whether a particular home or housing project is actually performing well?

That is where measurement becomes critical.

3. Making Housing Performance Visible

If adequate housing is multidimensional and resilience is context-dependent, a fundamental question follows: how do we know whether a home or housing project is actually performing well?

Housing markets already contain substantial information—project specifications, certifications, regulatory disclosures and sustainability claims—but it is often fragmented, presented in different formats and difficult to compare. The result is an information gap between the characteristics of a home and the decisions made by those who buy, finance, develop or regulate it.

But an important distinction must be made: disclosure is not performance.

Recent work on residential sustainability illustrates both the opportunity and the complexity. The Square Yards Green Living Index (SYGLI), for example, was developed to analyse publicly available project disclosures through a standardised framework, making sustainability information more accessible and comparable to consumers. Its framework considers resource efficiency, health and comfort, safety and resilience, and connectivity and mobility.

The significance of such an approach extends beyond helping a prospective homebuyer compare properties. Structured information can potentially create a common language between different participants in the housing ecosystem. Developers can understand how sustainability attributes are being communicated; consumers can compare projects; policymakers

can see patterns across the market; and financial institutions can begin to access structured information about housing characteristics.

But this is where an important distinction needs to be made.

Disclosure is not the same as performance.

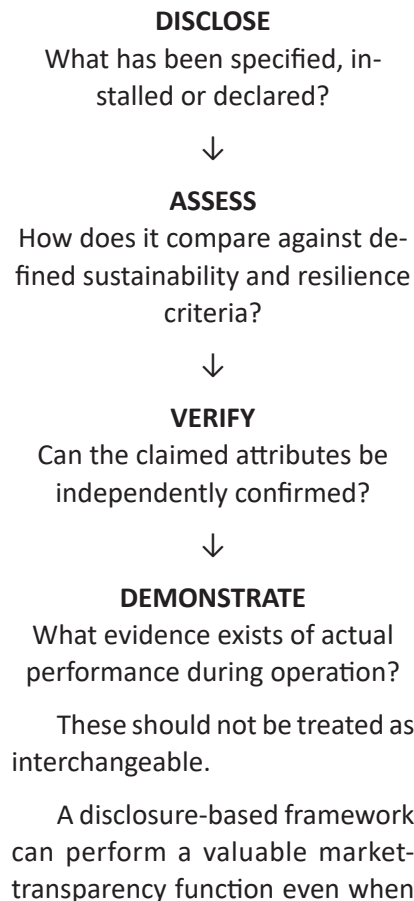
A housing project can disclose that it incorporates efficient fixtures, passive cooling measures, water-management infrastructure or other sustainability features. An assessment framework can then organise these disclosures and evaluate them against defined criteria. But neither necessarily tells us how the building will perform once occupied.

The current SYGLI methodology is disclosure-based: it assesses publicly available information and therefore captures documented design intent and specified features rather than verified post-occupancy performance.⁶

It also currently applies a uniform national scoring approach and does not fully account for regional differences in climate risks, water stress and environmental conditions.

This distinction is important not because disclosure-based assessment has little value, but because it clarifies what different forms of information can legitimately tell us.

The housing sector could increasingly benefit from a hierarchy of information:



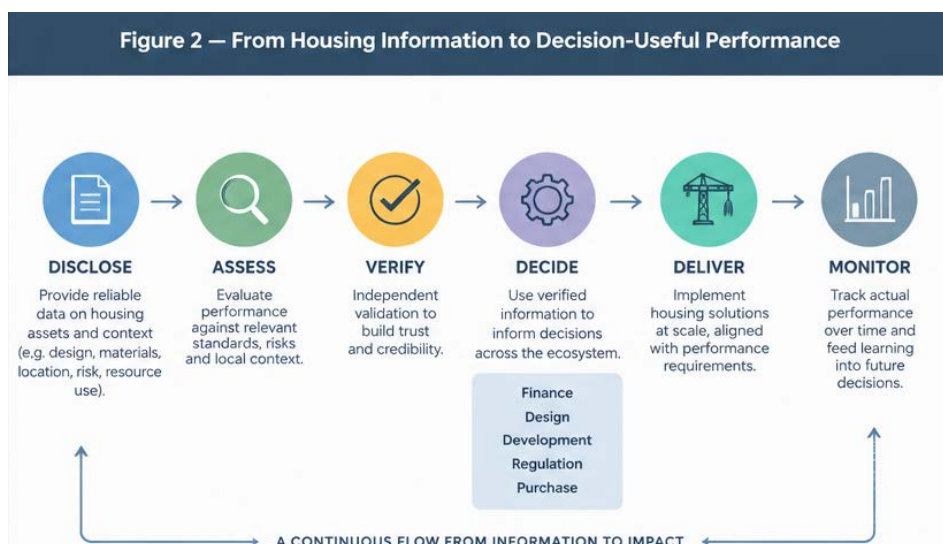
post-occupancy data are unavailable. It can establish a baseline, reduce information asymmetry and create incentives for more consistent disclosure. Over time, however, the ambition should be to move progressively from information about features towards information about performance.

This also means that housing assessment cannot remain entirely location-neutral.

A sustainability feature that is valuable in one climatic or risk context may be less relevant in another. Heat, water stress, flooding, seismic risk and other hazards vary considerably across India. Future housing-performance systems will therefore need to combine standardised indicators with the ability to reflect local conditions.

The objective should not be to create an increasingly complicated scoring system. It should be to create a usable information layer: one that is sufficiently standardised to enable comparison, sufficiently contextual to reflect local risks, and sufficiently transparent to allow users to understand what the information actually represents.

This becomes particularly im-



portant when housing performance begins to intersect with finance.

Because information does more than influence what consumers see. It can influence what developers build, what financial institutions finance and what investors consider an eligible or lower-risk asset.

The next frontier, therefore, is not simply better sustainability information.

It is turning housing-performance information into information that can support decisions.

4. Making Housing Performance Financeable

The existence of a technically better housing solution does not automatically make it a financeable one.

For a household, developer or financial institution, the relevant question is rarely simply whether a building is “green” or “resilient”. The questions are more practical: *What will it cost? What will it save? What risks will it reduce? Who bears the upfront cost? Who receives the benefits? Can those benefits be demonstrated? And how should they influence a financing decision?*

This is where the conversation about housing performance meets the conversation about finance.

India’s housing-finance ecosystem has already begun to explore this intersection. Financial institutions have introduced green home-loan products linked to recognised building-performance or certification criteria, while development-finance institutions have supported the growth of green affordable housing. In 2021, for example,

IIFL Home Finance introduced a Green Home Loan offering an interest-rate discount for homes in projects pre-certified by IGBC or GRIHA.⁷ IFC has also supported green affordable housing finance through investments and advisory programmes with housing-finance institutions, including initiatives aimed at lower-income borrowers and self-built housing.⁸

These developments point to an important shift: environmental performance is beginning to enter the architecture of housing finance rather than remaining solely a matter of building design.

India’s public policy architecture is also beginning to create a performance language for residential buildings. The Bureau of Energy Efficiency’s Eco Niwas Samhita (ENS) establishes minimum energy-performance requirements for residential buildings, including requirements relating to the building envelope, heat gain and heat loss, natural ventilation and daylighting. The framework is important not only as an energy-efficiency code, but because it translates aspects of residential building performance into parameters that can be specified, assessed and incorporated into mainstream housing practice. The evolution of ENS, including its provisions for residential building services and renewable-energy systems, points towards a broader opportunity: performance criteria can increasingly become part of the ordinary language of housing delivery rather than remaining an optional sustainability attribute.⁹

But the connection is still evolving. A financial institution does not need to know every technical detail of a building; it needs information that can inform decisions about

eligibility, affordability, risk, cash flow and the credibility of claimed performance.

The challenge, therefore, is not simply to produce more information about sustainable housing. It is to create an application layer between housing performance and financial decision-making.

Certification can help establish eligibility, but it is not the same as financial value. The more important questions are whether better performance reduces operating expenditure, improves resilience, lowers future retrofit requirements, improves asset quality or otherwise changes the economics or risk profile of the home—and whether those benefits can be evidenced sufficiently to influence finance.

IIFL Home Finance’s publicly documented Green Value Partner mechanism provides one example of this interface. It connects developers with technical expertise and certification agencies and supports the process from initial assessment through pre-certification, monitoring and final certification. The wider lesson is not the particular institutional model, but the need to translate technical complexity into a form that can work within the financing ecosystem.

This interface becomes particularly important in affordable housing. The households that may benefit most from lower operating costs and greater resilience may also have the least capacity to absorb additional upfront costs. Financing therefore needs to consider the lifecycle economics of the home rather than transferring the cost of better performance directly to the borrower.

The same principle applies across different forms of housing. New formal housing may require green eligibility criteria and performance-linked finance; existing housing may require small-ticket retrofit finance and aggregation; self-built and incremental housing may require simpler technical solutions, accessible advice and proportionate verification.

The future of housing finance will therefore not be defined by a single “green housing loan”. It will require different financial and technical pathways for different forms of housing production and improvement.

Public and concessional finance can help establish emerging markets, but durable scale requires institutional and market infrastructure alongside capital. The objective is not simply:

finance → green building

but:

performance information → assessment → financial eligibility → appropriate financing → delivery → verification → learning.

Measurement and finance therefore need to evolve together.

Ultimately, the question is not whether housing can be labelled “green” or “resilient”. It is whether better housing performance can be translated into information that households, developers and financial institutions can use to make better decisions.

That is the foundation for moving from isolated green-finance products towards a housing market in which resilience, resource efficiency, affordability and long-term performance become integral to how housing is designed, financed

and valued.

And yet, even the most appropriate financing mechanism cannot deliver better housing on its own.

5. The Missing Middle: Building Delivery Capacity

Between housing policy and the finished home lies a delivery ecosystem of people, skills, materials, institutions and technical knowledge. This is often the missing middle in discussions on adequate housing. A technology may be proven, a performance requirement may be defined and finance may be available, yet adoption can remain limited if the actors responsible for design, procurement, construction, inspection and maintenance cannot translate these requirements into practice.

India has considerable experience in building such delivery capacity. BMTPC, for example, has played an important role in promoting innovative, cost-effective and disaster-resilient building technologies through technology demonstration, training, capacity building and field-level dissemination. Its role under the Technology Sub-Mission of PMAY-U, and in the Global Housing Technology Challenge-India (GHTC-India) and Light House Projects, illustrates an important principle: technology becomes transformative only when it can be demonstrated, understood, adopted and replicated within the housing delivery system.

The experience also points to the importance of an institutional pathway between innovation and scale. Demonstration projects can establish technical feasibility; training and knowledge dissemination can build practitioner confidence; standards, approvals and procure-

ment mechanisms can reduce uncertainty; and finance can create the conditions for wider adoption. These functions need to reinforce one another rather than operate as separate interventions.

The same principle applies to housing performance and resilience. Designers and developers need practical specifications and tools. Local authorities need appropriate assessment and approval mechanisms. Contractors and artisans need skills to implement new technologies correctly. Financial institutions need sufficiently reliable information to incorporate performance into lending decisions. Households need to understand not only the initial cost of an intervention, but its implications for comfort, utility expenditure, maintenance and resilience.

This is particularly important because the delivery ecosystem is not uniform across India. Formal developer-led housing, government-supported housing, self-built homes and incremental additions operate through very different institutional and financial arrangements. A technology or performance requirement that is straightforward to implement in a large formal development may require a completely different support mechanism in a self-built or incrementally constructed home.

The policy challenge, therefore, is not simply to promote better technologies. It is to build the institutional and market infrastructure that allows appropriate solutions to move reliably from knowledge → demonstration → capacity → adoption → scale. This includes strengthening local technical capacity and developing practical guidance.

6. Different Homes, Different Pathways

The framework becomes more useful when applied to different housing pathways. There is no single route to adequate housing, and the appropriate combination of performance criteria, finance, technical assistance and verification will vary.

New housing

For new construction, performance and resilience can be embedded before design and procurement decisions become difficult or expensive to change. Site selection, orientation, passive design, materials, envelope performance, water and energy systems and climate-risk considerations can therefore form part of the fundamental project proposition. The Light House Projects under GHTC-India provide an Indian illustration of how alternative technologies can be demonstrated under different geographical and climatic conditions.¹⁰

This is also the stage at which national programmes can embed performance requirements at scale. PMAY-U 2.0, launched in 2024,¹¹ with an outlay of ₹10 lakh crore to deliver one crore homes for EWS, LIG and MIG households over five years, offers exactly this kind of leverage point — as does the Bureau of Energy Efficiency's Eco-Niwas Samhita, which already sets minimum envelope and electro-mechanical performance requirements for new residential buildings above a defined plot-size threshold. Aligning large public housing programmes with such performance requirements from the design stage can avoid the technical and financial challenges

of retrofitting compliance later.

Existing housing and retrofit

For existing housing, the challenge is different. Improving adequacy requires interventions to buildings that may have limited technical documentation, fragmented ownership and small investment requirements. Retrofit therefore needs simple assessment, accessible finance, aggregation where appropriate and evidence of savings or risk reduction. India's emerging residential retrofit guidance across climatic contexts points towards the importance of treating existing housing as a major performance-improvement opportunity.¹²

Self-built and incremental housing

For households constructing or improving homes incrementally, conventional project-level certification may be less practical. More useful may be a sequence of affordable interventions—shading, ventilation, roof and wall treatments, efficient appliances, water management, structural safety and locally appropriate materials—supported by accessible technical advice and finance. Information needs to reach households and local builders at the point when construction decisions are being made.

Post-disaster reconstruction.

Reconstruction presents both an urgent need and an opportunity to reduce future vulnerability. The objective should not simply be to replace damaged structures, but to address location, land and tenure, access to services, construction capacity, materials, livelihoods and future hazard exposure. Housing, settlement planning and infrastruc-

ture recovery therefore need to be considered together, an approach reflected in BMTPC's work on disaster mitigation, vulnerability and risk reduction, and retrofitting and reconstruction.¹³

Odisha's experience after Cyclone Fani (2019) illustrates this. With over five lakh houses damaged, reconstruction was linked to cyclone-resilient house designs developed by the Central Building Research Institute, incorporating column foundations, grade beams and roof-bracing details engineered to withstand wind speeds of up to 200 km/h, delivered through enhanced assistance under PMAY-Gramin. The episode shows how post-disaster reconstruction can double as an opportunity to institutionalise better technical standards rather than simply replace what was lost.¹⁴

Across these pathways, one principle emerges: common outcomes do not require identical processes. A useful housing-performance framework should establish a common language for adequacy while allowing the pathway, evidence requirements, financing mechanism and technical support to vary according to context.

The question is therefore not only whether a house meets a particular standard, but whether the housing system has the capacity to define, measure, finance, deliver, verify and learn from performance.

7. Conclusion / Action Agenda

From Adequate Housing to Future-Ready Housing

The 2026 World Habitat Day theme, *Adequate Housing for All*, provides an opportunity to expand the definition of adequacy

in response to a changing climate, rising costs and evolving patterns of vulnerability.

Adequacy cannot remain a static threshold. A home that is technically adequate today may become increasingly expensive to operate, uncomfortable during heat events, vulnerable to flooding or dependent on infrastructure that is itself under stress. The challenge is therefore to make the benefits of better performance and resilience visible, financeable and deliverable.

The housing sector does not lack individual solutions. What remains less developed is the connective tissue between affordable housing, resilient construction, building performance, finance, infrastructure and delivery. That connective tissue needs to operate across a simple housing-performance cycle:

DEFINE → MEASURE → FINANCE → DELIVER → VERIFY → LEARN

with risk, equity and local context embedded across every stage.

Six priorities follow.

1. Define adequacy as a lifecycle outcome

Housing policies and programmes should consider not only access to a dwelling, but its continuing affordability, safety, health, environmental performance, resilience, accessibility and connection to essential services.¹⁵ The question should increasingly be: Does this housing remain adequate over time?

2. Build a common but contextual performance language

Housing performance needs to

become easier to understand and compare without losing sensitivity to climate risk, water stress, housing typology, household characteristics and local infrastructure. The objective is not another layer of reporting, but decision-useful information.

3. Translate performance into financial language

Energy savings, thermal comfort, water efficiency and resilience need to be connected, where evidence permits, to operating expenditure, affordability, asset quality, risk exposure, financing terms and long-term value. Technical performance should not sit outside the financial architecture of housing.

4. Create delivery mechanisms, not just standards

Standards have limited impact if the skills, technical services, products and institutional arrangements required to implement them are absent. Future housing programmes should therefore invest in the delivery ecosystem—professionals and contractors, advisory capacity, simplified tools, standard specifications, local institutions and implementation partnerships.

5. Design differentiated pathways

New construction, retrofit, self-built housing and post-disaster reconstruction require different combinations of technical assistance, finance, standards and verification. A common definition of adequate housing should therefore be accompanied by multiple pathways to adequacy.

6. Establish a learning loop

Housing interventions need to generate evidence about what actually works. The sector should

move progressively from design intent and compliance towards verification of outcomes—what occupants experience, what households spend, how buildings perform, how infrastructure responds during shocks and whether financial assumptions materialise.

The opportunity is therefore larger than making individual homes greener or more resilient. It is to build a housing ecosystem in which adequacy, performance, resilience and finance reinforce one another.

India already possesses many of the building blocks of such a system—from hazard and vulnerability knowledge and technology demonstration to residential energy-performance frameworks, housing delivery programmes and emerging performance-linked finance. The next challenge is not necessarily to create another framework, but to connect the frameworks, institutions, data, finance and delivery mechanisms that already exist.

Adequate housing for all is therefore not simply a housing target. It is a systems challenge—and an opportunity to connect the knowledge, institutions and capital already working across the housing sector into a more coherent pathway towards future-ready homes.

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Figure 3 — The Housing Performance Cycle: From Adequacy to Action

A continuous process for resilient, inclusive and low-carbon homes



*A resilient, inclusive and low-carbon housing future is a shared responsibility
and a continuous process.*

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नवरीति: NAVARITIH – e-Certificate Course on Innovative Construction Technologies

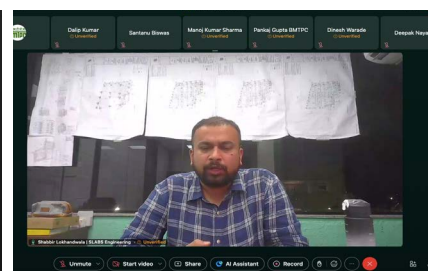
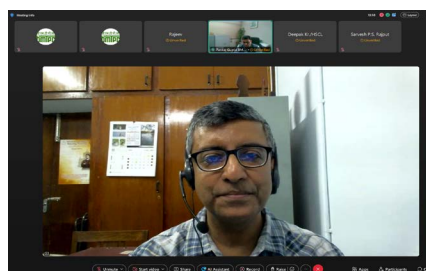
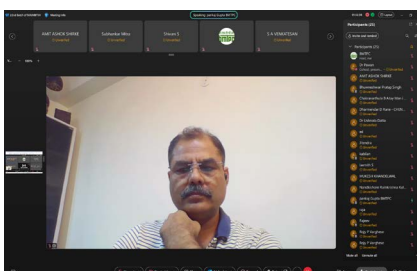
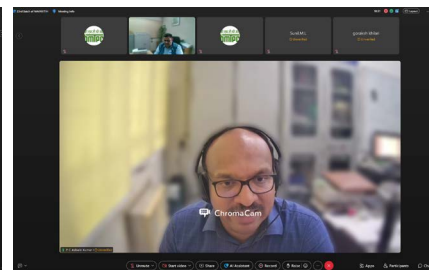
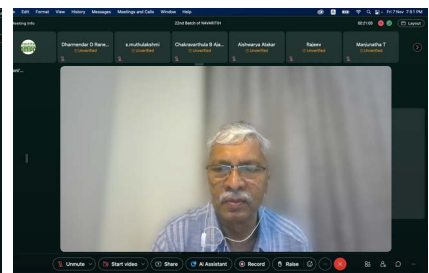
In order to build capacities amongst building professionals about the new and emerging building materials and technologies for housing and building construction, the Ministry of Housing and Urban Affairs in collaboration with BMTPC and School of Planning & Architecture (SPA), New Delhi is implementing a Certificate Course on Innovative Construction Technologies namely NAVARITIH (New, Affordable, Validated, Research Innovation Technologies for Indian Housing) to build capacities of engineers and architects including students in the area of industrialised building systems. It is of paramount importance that building professionals learn about the new and emerging building materials and technologies for

housing and building construction.

The NAVARITIH Certificate Course was launched by Hon'ble Prime Minister on January 1, 2021 during the foundation stone laying ceremony of six Light House Projects under Global Housing Technology Challenge - India – Pradhan Mantri Awas Yojana (Urban) through video conferencing by releasing the resource material in form of a Book for NAVARITIH. The objective of the Certificate Course is to (a) Familiarise the professionals with the latest materials and technologies being used worldwide for housing, (b) Provide an awareness of the state of art of materials and technologies in terms of properties, specifications, performance, design and

construction methodologies so that professionals can successfully employ these in their day to day practice and (c) Provide exposure to executed projects where such materials and technologies have been implemented. Subsequently, first batch of NAVARITIH was inaugurated by then Secretary (HUA) in 2021.

The Course has received overwhelming response and so far in 23 batches conducted so far, 1468 participants comprising of civil engineers, architects, faculty & students from various engineering and architectural colleges have been successfully trained. The resource faculty for the Course are from SPA, BMTPC, IITs, CBRI & Industry.



Demonstration Housing Projects

– propagation of sustainable emerging construction systems under PMAY-U & PMAY-U2.0

BMTPC is mandated to promote use of new / alternate building materials & technologies in housing through identification, evaluation, standardization, certification, capacity building, training and field level application by demonstration construction.

Under Technology Sub-Mission of PMAY(U), MoHUA has taken an initiative to construct Demonstration Housing Project (DHP) through BMTPC using emerging construction systems shortlisted through GHTC-India. These DHPs are pilots which help build confidence and create enabling environment for the large scale adoption of such innovative materials & technologies suiting to different geo-climatic regions of the country, thus making housing more affordable and sustainable.

BMTPC has so far completed DHPs at (i) Bhubaneswar (Odisha); (ii) Lucknow (Uttar Pradesh); (iii) Biharshariff (Bihar); (iv) Nellore (Andhra Pradesh); (v) Hyderabad (Telangana); (vi) Panchkula (Haryana); (vii) Agartala (Tripura); (viii) Bhopal (Madhya Pradesh); (ix) Ahmedabad (Gujarat), (x) Tiruppur (Tamil Nadu); (xi) Ayodhya (Uttar Pradesh); (xii) Bhalwal, Jammu (J&K); and (xiii) Dimapur (Nagaland). The Demonstration Housing Project at Guwahati, Assam is at advanced stage of completion.

Based on the learnings from the implementation of PMAY-U, MoHUA has revamped the scheme and launched PMAY-U 2.0 'Housing for All' Mission to support one crore additional eligible beneficiaries in urban areas across the country. The Technology Sub-Mission of PMAY-U has also been expanded into Technology & Innovation Sub-Mission (TISM) under PMAY-U 2.0. The CSMC in its 6th meeting 23rd February, 2026 approved construction of Demonstration Housing Projects (DHPs) at Alwar (Rajasthan), Villianur (Puducherry) and Ratanpur (Chhattisgarh). The work for construction of DHPs have been awarded.

The Urban Improvement Trust (UIT), Alwar has allotted a plot of land measuring 1,900 sq. m at Alwar, Rajasthan, for construction of DHP intended for mixed social purposes. The project is planned in G+3 configuration, comprising two blocks with 40 dwelling units having two rooms, kitchen, bathroom, WC and balcony along with other requisite provisions. The project will be constructed using Stay-in-Place PVC Wall Form Technology.

For construction of a Demonstration Housing Project at Ratanpur, Chhattisgarh the Nagar Palika Parishad, Ratanpur has allotted land measuring 3,664.40 sq. m for DHP to be used as a Night Shelter. The 40 units are planned in G+2

configuration across three blocks, providing two rooms, pantry, bath, WC and balcony, besides other essential provisions. Construction is proposed using the Light Gauge Steel Frame (LGSF) System with agro-waste straw panel/fibre cement board technology.

The Puducherry Housing Board has allotted 1,720.00 sq. m of land at Villianur, Puducherry for construction of Demonstration Housing Project to be used as a Working Women Hostel. The DHP is planned in G+3 configuration, comprising 40 units with a room, pantry, toilet and balcony, along with other necessary provisions. The project will be constructed using the Light Gauge Steel Frame (LGSF) System.

The construction of demonstration housing projects in different parts of the country aims to facilitate wide spread dissemination and adoption of existing proven, emerging and sustainable building materials and technologies replacing conventional construction. It further helps create enabling ecosystem for mainstreaming such materials & technologies in the construction sector & adapt them as future technologies for construction. During the construction of DHPs, training to professionals, artisans & students is also being imparted on regular basis in association with nearby academic institution.



Bhubaneswar, Odisha



Biharshariff, Bihar



Lucknow, Uttar Pradesh

Demonstration Housing Projects under PMAY (U)



Panchkula, Haryana



Nellore, Andhra Pradesh



Hyderabad, Telengana



Agartala, Tripura



Ahmedabad, Gujarat



Bhopal, Madhya Pradesh



Dimapur, Nagaland



Ayodhya, Uttar Pradesh



Bhalwal, Jammu

Demonstration Housing Projects under PMAY (U)



Tiruppur, Tamil Nadu



Guwahati, Assam

Sensitization Programme on “Emerging Construction Technologies and Building Materials” at Jaipur

BMTPC in collaboration with the Rajasthan State Real Estate Development Council (RAJREDCO), organized a two-day Sensitization Programme on “Emerging Construction Technologies and Building Materials” on 18–19 December 2025 at the Rajasthan International Centre, Jaipur. The programme was aimed at sensitizing newly appointed civil engineers of Government departments in Rajasthan on innovative, cost-effective, environment-friendly, and disaster-resilient construction technologies promoted by MoHUA and BMTPC. The initiative focused on capacity building, knowledge dissemination, and encouraging adoption of modern construction practices in housing and infrastructure projects.

The programme was graced by Shri Jhabar Singh Kharra, Hon’ble Minister for Urban Development and Housing, Govt. of Rajasthan. More than 100 freshly recruited civil engineers of Rajasthan Housing Board attended the programme along with officials from State Government, Rajasthan Housing Boards, RAJREDCO and BMTPC.

The first technical session included a presentation on Pradhan Mantri Awas Yojana – Urban 2.0 (PMAY-U 2.0), outlining the scheme objectives, implementation framework, and the role of innovative construction technologies in achieving “Housing for All”. This was followed by an expert presentation by BMTPC on emerging technologies for



housing, wherein alternative and innovative construction systems, their performance, and successful implementation across the country were elaborated.

The session featured industry experts and technology providers, including representatives from Magicrete Building Solutions Pvt. Ltd., Biltech Building Elements Ltd., Elematic India Pvt. Ltd., and Knest Aluminium Formwork Systems, who showcased their respective technologies, case studies, and field experiences. The sessions provided valuable insights into precast construction, light gauge steel framing systems, sustainable walling solutions, and Aluminium formwork technologies.

The day concluded with presentations on integrated hybrid housing systems and earthquake testing facilities, followed by an Open House Discussion, where participants actively interacted with the speakers and clarified practical and field-related queries.

The programme witnessed active participation from civil engineers and officials, and successfully met its objectives of enhancing technical awareness and capacity building. The event received coverage in print and digital media, highlighting the initiative undertaken by BMTPC and RAJREDCO to promote modern building technologies.

Performance Appraisal Certification Scheme (PACS)



Performance Appraisal Certification Scheme (PACS), being operated by BMTPC (vide Gazette Notification No. I-16011/5/99 H-II in the Gazette of India No. 49 dated December 4, 1999), is a third party voluntary scheme for providing Performance Appraisal Certificate (PAC) to manufacturers or installers of a product which includes building materials, products, components, elements, systems etc. after due process of assessment giving independent opinion about fitness of its intended use in building construction sector.

Since the Scheme is operated for the products/systems where no relevant Indian Standards are available, it is required to first work out the desired specifications for Performance Appraisal. For the items where no Indian codes are available, international practices are also being referred. In few cases the specifications recommended by the manufacturers have to be modified based on global practices to improve the quality and performance.

Various States/UTs, its Housing & Urban Development Departments, Housing Boards and other concerned departments are also

promoting and using emerging technologies and materials for construction of mass housing in their States. As such PACS is proving to be an important tool for introduction of innovation in construction sector.

PACs Approved and Issued Till Date

Within the framework of power and functions of Technical Assessment Committee (TAC), Applications for appraisal of new building materials and construction technologies were received by BMTPC. Performance Criteria, based on National & International practices were framed in consultation with TAC members.

So far 20 meetings of TAC have been held and 88 PACs have been issued and out of these, 46 are emerging technologies/systems. The details of activities carried out recently under Performance Appraisal Certification Scheme (PACS) are highlighted below:

Approval of New PACs

PAC for the following four systems/products have been approved in the 20th meeting of TAC held on May 15, 2025.

1. Politerm Blu - Thermal Insulated

- EPS Beads Aggregates
2. Agrocrete Blocks and Bricks
3. Bed Joint Reinforcement (BJR)

The brief about these technologies are given hereunder:

1. Politerm Blu - Thermal Insulated EPS Beads Aggregates

Politerm Blu is a pre-additivated lightweight thermal insulated aggregate made from virgin closed-cell EPS (Expanded Polystyrene) beads of 2 mm to 5 mm dia size. The beads are treated with a special proprietary insulating chemical additive E.I.A. (Edilteco Insulating Additive), for use in preparation of light weight cement mortar and concrete mix of different densities, for thermal insulation and screed. The proprietary additive helps EPS beads bind with cement and water, preventing bead flotation, and ensuring uniform distribution within the mix. The density of EPS bead Aggregates ranges from 10 kg/m³ to 12 kg/m³ for different applications.

It may serve as an alternative to conventional lightweight Aggregates such as expanded perlite and vermiculite for insulation.

Salient features of the product include:



Politerm Blu- Thermal Insulated EPS Beads Aggregates

- a) Lightweight EPS bead-based insulating aggregate for cementitious mortars and screeds.
- b) Suitable for roof insulation, floor screeds, filling layers, and underfloor heating systems.
- c) Reduces structural dead load due to its low density.

2. Agrocrete Blocks and Bricks

The Agrocrete Solid bricks and Hollow Blocks are masonry units manufactured using crop residues, industrial by-products such as fly ash and alkali-activated-slag-based binders, reclaimed excavation soil, and stone crushing residue. These blocks are durable, thermally insulating, and are suitable for both load-bearing and non-load-bearing construction applications. The solid Agrocrete bricks are in regular red clay brick sizes (230mm x 100mm x 75 mm) while the hollow blocks have 400mm x 150 mm (length x height) with the block thickness/width varying from 100mm to 200 mm in 50 mm intervals.

Salient features of the product

include;

- a) Manufactured using agricultural residues and industrial by-products.
- b) Provides thermal comfort and energy efficient.
- c) Suitable for both internal and external wall applications, subject to design requirements
- d) Available as Solid bricks and Hollow blocks for application in buildings.

3. Bed Joint Reinforcement (BJR)

The Bed Joint Reinforcement (BJR) is a system used in Autoclaved Aerated Concrete (AAC) masonry walls. It is placed horizontally within the masonry mortar joints, as per the structural design requirements of the wall. The reinforcement is installed directly in these horizontal bed joints between successive AAC block courses; it is referred to as bed joint reinforcement. The reinforcement enhances the tensile strength of masonry and prevents in controlling diagonal and shrinkage cracks in AAC walls.

The bed joint reinforcement is a ladder-type wire mesh. It consists of multiple longitudinal high-carbon steel wire cords connected by transverse interwoven glass roving. Around each longitudinal wire cord, a pure Polypropylene (PP) yarn is woven to connect the steel

cords with the glass roving and to enhance bonding with mortar. The steel cords are protected against corrosion.

The number of longitudinal cords is selected based on the AAC block width. The bed joint reinforcement is provided at specified intervals and at critical locations such as above and below masonry openings, etc, in accordance with design requirements.

Salient features of the product include;

- a) Strength and Stability- Steel mesh masonry reinforcement is used to enhance the structural integrity of AAC block masonry, making it more resistant to tension and compression stresses. This is useful in earthquake-prone areas and for structures that need stability.
- b) Crack Control- Steel mesh masonry reinforcement helps in minimizing cracks (including above and below windows in a AAC block wall) that may occur due to various factors like thermal expansion, settlement, external forces etc. It ensures better distribution of loads, reducing the possibility of cracks.
- c) Ease of Construction- The Bed Joint Reinforcement (BJR) shall



Agrocrete Blocks and Bricks



Bed Joint Reinforcement (BJR)

be properly placed and fully embedded in the mortar bed joints. The Bed Joint Reinforcement (BJR) enables faster and simpler construction than conventional RCC bands, resulting in reduced construction time and labor.

PAC Renewed

The Performance Appraisal Certificate (PAC) issued under the Performance Appraisal Certification Scheme (PACS) is granted for a specified period. Renewal of PAC is required at the end of the validity period to ensure continued compliance with the approved performance criteria and conditions of use;

Based on receipt of Renewal applications along with requisite details, the following PACs were renewed;

1. **Concrewall - Reinforced EPS Structural Panels (RESP System):** Concrewall is a building system based on factory produced reinforced Expanded Polystyrene (EPS) panel as core & concrete sprayed on the both the side. The panels are used both for walling & slab purposes. The system can be used for load bearing structure upto G+3 Configuration. The system brings significant thermal insulation.
2. **Concrete 3D Printing Technology (C3DP):** Concrete 3D printing is the technology in which concrete layers are laid one over the other using an automated robotic system. The system consists of a pump and extruder along with a print head. The entire printing process is streamlined with the help of software integrat-

ing the machine & material parameters.

3. **PUF Sandwich Panel with Pre-Engineered Building Structure:** PUF Sandwich Panels with Pre-Engineered Building (PEB) structures combine a steel structural framing system designed as per relevant Indian Standards with PUF sandwich panels used for walling and roofing. The panels consist of a rigid PUF core sandwiched between colour-coated galvanized/galvalume steel sheets, offering high thermal efficiency, light weight, ease of installation, and cost effectiveness. The PEB steel system and PUF panels provide flexible design options, rapid construction & durable performance.
4. **Monolithic Formwork System – Tunnel Formwork:** Tunnel formwork is a mechanized system for constructing cellular structures, where two half-shell forms are joined to create a room or cell, and multiple cells form an apartment. Walls and slabs are cast in a single day, with construction divided into phases based on the floor area that can be poured daily. After positioning reinforcement and services, concrete is poured in a single operation, and the formwork is stripped the next morning and moved to the next phase. The forms are manufactured in a fully automated plant, enabling rapid and efficient construction.
5. **Quik Build Panels (Reinforced EPS Core Panels):** QuikBuild Panel System consists of a

polystyrene insulation core sandwiched within a welded wire space frame, with diagonal cross wires providing rigidity and truss-like behavior for composite strength. Steel trusses are integrated through the core and welded to the outer galvanized steel mesh to form rigid panels. Panels are manually erected on slabs, with provisions for doors, windows, and utilities and the walls are finished by shotcreting to form a monolithic structure. These panels are suitable for constructing load-bearing and non-load-bearing walls and floors in various types of buildings

6. **Integrated Hybrid Solution – ONE (IHS-ONE):** IHS-ONE (Integrated Hybrid Solution – ONE) is an Intermediate Building System (IBS) that integrates walls, floors/roof, and Ferro cement elements to construct a complete building. The walls use Hydraform prefabricated mortarless interlocking blocks made from cement-flyash or cement-soil. The floors/roof consist of mechanized precast R.C. planks and joists, which are partially precast and completed with in-situ concrete and a ferrocement layer, providing monolithic behavior and diaphragm action. Ferrocement elements include precast staircases, kitchen platforms, sunshades, lintel bands, and water tanks. The system allows construction of load-bearing structures up to G+3, and its floor/roof and wall systems can also integrate with R.C. framed or steel structures to provide a flexible, complete building solution.



The following new products/systems have been received from the manufacturers on the basis of which Detailed Application Forms (DAF) have been issued for submitting information along with other documents for processing the applications:

i. CLEANFLO- Inhibitor Solution Anti-Corrosive Coating of Reinforcement Bars

The inhibitor is used with inhibited cement slurry coating on reinforcement bars to provide corrosion protection to RCC structures and to reduce the repair cost of the structure.

ii. Bamboo Based Components / Technologies

a) Reinforced Wall Panel : The Bamboo Reinforced Wall Panel is a prefabricated walling system comprising treated bamboo elements used as reinforcement within a matrix of cementitious or earthen material. The panel typically consists of bamboo splits/mats/strips arranged in a grid or mesh form, integrated with plaster, mortar, or board materials to provide structural/non-structural walling functions.

b) Bamboo Column–Truss Component : The Bamboo Column–Truss Component comprises structural members made of treated bamboo, used for vertical (column) and roofing (truss) applications. The system utilizes bamboo poles as primary load-bearing elements, configured into columns and truss assemblies.

c) Bamboo Intensive Low Cost House : The Bamboo Intensive

Low Cost House is a complete building system utilizing bamboo as the primary construction material for structural and non-structural components, including walls, columns, beams, and roofing systems. Designed for low-cost, sustainable, and rapid construction, generally suitable for G / G+1 buildings

iii) GIB Cool Mix – Lightweight Thermal Insulation Premix

GIB Cool Mix is a lightweight, thermally insulating concrete using perlite-based GIB aggregates, ideal for energy-efficient, fire-resistant roof and deck applications. GIB (Glazed Iso Ball) is a manufactured lightweight aggregate derived from expanded perlite, with each particle sealed by a glassy coating making it lighter, more durable, and less absorptive than raw perlite.

iv) Circato Thermal Panels

Ui construction panels comprising of inner Grid made of waste plastic and outer layers are of cement fibre board for both walling & roofing.

v) Hedrad Composite Panels

Hedrad Panels are eco-friendly composite sandwich panels comprising a recycled kraft paper honeycomb core bonded between cement boards. The lightweight, load-bearing panels provide high structural strength, thermal insulation, and rapid construction, making them suitable for residential, commercial, and institutional buildings. They are used for external and internal walls, partitions, resorts, farmhouses, and acoustic applications. Manufactured using over 90% sustainable materials sourced in India, the panels generate minimal construction waste

and are designed for disassembly and reuse, offering an environmentally sustainable and cost-effective building solution.

vi) PEN Foundation (Pre-Engineered Foundation)

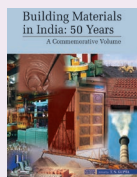
The PEN foundation consists of inclined nails/pins/micropiles along with a concrete head/node head, which may include one, two, three, or more nodes. These nodes comprise nails made of GI pipes with tungsten-carbide tips arranged in a specific configuration to resist loads. The combined action of the concrete head and the strategically positioned pins forms a soil-structure interaction system, thereby enhancing stability and load-bearing capacity under various soil conditions.

vii) Mould Release Oil

The mould release oils used in precast and conventional concrete applications. These mould release agents are provided to ease demoulding of concrete elements, improve surface finish, reduce blow holes and surface defects, and prevent concrete adhesion to steel, timber, aluminium, or plastic formwork. The products enhance shuttering life, minimize cleaning requirements, and improve productivity in precast construction and cast-in-situ concrete works

The above applications are being processed on the basis of data furnished by the firms, information available on their web sites, online inspection and testing of samples of the products/systems etc. before preparation of Performance Appraisal Certificates (PACs).

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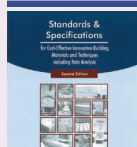
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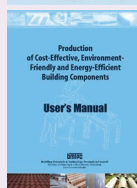
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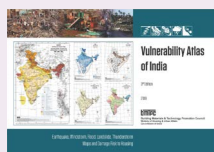
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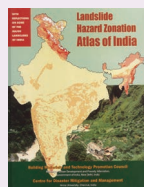
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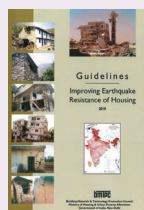
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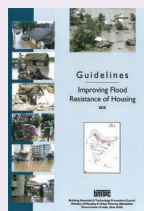
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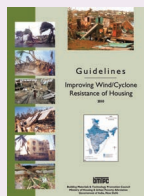
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Vision

“BMTPC to be world class knowledge and demonstration hub for providing solutions to all with special focus on common man in the area of sustainable building materials, appropriate construction technologies & systems including disaster resistant construction.”

Mission

“To work towards a comprehensive and integrated approach for promotion and transfer of potential, cost-effective, environment-friendly, disaster resistant building materials and technologies including locally available materials from lab to land for sustainable development of housing.”

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