HOUSING IN INDIA

Challenges & way forward

INDIAN NATIONAL ACADEMY OF ENGINEERING
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A Report by

INAE Forum on Civil Infrastructure

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FOREWORD

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The Indian National Academy of Engineering, established in 1987, currently has 890 Fellows, 94 Foreign Fellows and 128 Young Associates, who are amongst the most eminent engineers, having a marked track record of achievements. Over the years, consistent with its mission, the Academy has made significant contributions towards developments in Engineering and Technology in India. It has recognized and honored individuals with outstanding achievements, and, encouraged excellence by awarding worthy projects amongst students and young engineers. Another very important endeavor of the Academy has been to address engineering challenges relevant to National development, through studies of the same, and, by thus recommending actionable solutions.

Habitat is one of key elements for sustenance of the human kind. More precisely, Civil Infrastructure touches the lives of millions, and thus the reduction or removal of its deficiencies create an enormous challenge. The Academy therefore set up the Forum on Civil Infrastructure in January 2017 to address the issues of Traffic & Transportation, Housing and Water in the context of National Development. The study on Housing problems in India contained in this report has been carried out by authors with considerable experience and expertise in the subject domain drawn from within the INAE Fellowship as well other eminent experts. The report contains an analysis of the challenges faced and their possible solutions and, contains a set of actionable recommendations. It is noteworthy that before its finalization, an extended executive summary based on the draft was shared with a select group of stakeholders in the domain, and also discussed subsequently in an online meeting, wherein besides invited experts, officials from the Ministry of Housing & Urban Affairs, Government of India, also participated. The comments from the stakeholders, experts and officials served as valuable inputs for finalizing the report and helped in making it more meaningful and relevant.

Prof. Prem Krishna and his colleagues, who have authored this report *"HOUSING IN INDIA – Challenges & Way Forward"*, have put in exemplary effort and done a commendable job in bringing out this volume, which has the promise of contributing towards improved solutions for the problem of housing, so vital for the wellbeing of the society and relevant to the ongoing efforts in the '***Housing* for All**' initiative of the Government of India. I place on record my sincere appreciation for their noteworthy efforts in conduct of the study and preparation of a comprehensive report with meaningful actionable recommendations.

Sincerely,

Indranil Manna

(Indranil Manna)

PREFACE

Housing in India – Challenges & Way Forward, is the report of a study undertaken by the *INAE Forum on Civil Infrastructure.* In the background to this are the ideas put forth in the INAE document, "Vision, Mission, and Values 2037", which was prepared a decade ago in order to envision the future engineering scenario of the country and to draw up a road map of future activities of the INAE. It is easy to see that Civil Infrastructure, being a major concern for National development, emerged as one of the important areas to be addressed. The *Forum on Civil Infrastructure* was thus set up. It had been envisaged that the Forum will undertake to study three areas of concern, namely, *Traffic & Transportation, Housing and Water*, in that sequence. A report on *Urban Transportation* was released at the INAE Annual Convention in December 2019 at Jaipur. This document marks the completion of the study of second of these areas.

The problem of housing is perennial globally, and India is no exception. The equation between demand and supply has always shown housing being deficient and besides often being wanting in quality as well. Continued efforts by the Governments in position since India attained independence in 1947, and increased impetus in the last few years, have brought the country into a much-improved situation. However, there is still a lot to be done before each of the families of the country has housing of desirable standard.

The study carried out by the members of the Forum, which is constituted by domain experts from within as well as outside the INAE, reviewed the developments of the past, assessed the present situation, and, on this basis, made a series of actionable recommendations, related to policy, economic concerns, technology of construction and materials. The undersigned herewith records his appreciation of all these colleagues, who attended a number of meetings to deliberate upon the subject, for their time, effort and support.

An Extended Executive Summary based on the draft report was shared with a select group of stakeholders to seek their comments and suggestions. Subsequently this was also shared with stakeholders invited to participate in an online *Discussion Meeting* held on 09 December, 2021, with a similar objective. The salient features of the report were presented. The participants were also addressed by Sri Durga

Shankar Mishra, Secretary, Ministry of Housing & Urban Affairs, GOI, and Professor Indranil Manna, President INAE. Comments received on the Executive Summary and deliberations at the Discussion Meeting were generally complimentary, and the valuable suggestions made have been duly accounted for in finalising the report.

Last but not the least, the undersigned wishes to place on record the support received from Lt. Col. (retd.) Shobhit Rai, Deputy Executive Director, INAE, and his team at the INAE office, particularly Mrs Pratigya Laur, who helped in coordinating this activity.

2nd October 2022

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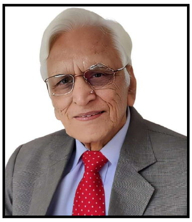

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Abbreviations & Acronyms

Abbreviation	Details
AAC	Autoclaved Aerated concrete
AC	Alliance Contracting
AHP	Affordable Housing in Partnership
AR	Augmented Reality
ARCS	Autonomous Robotic Construction System
ARHC	Affordable Rental Housing Complex
ASHA	Affordable Sustainable Housing Accelerator
B.C.	Before Christ
BHK	Bedroom-Hall-Kitchen
BIM	Building Information Modelling
BIS	Bureau of Indian Standards
BLC	Beneficiary-Led Construction
BMTPC	Building Materials & Technology Promotion Council
BSUP	Basic Services for Urban Poor
C&D	Construction & Demolition
c3DP/DCP	3D Construction Printing
CASTRA	Centre for Application of Science and Technology to Rural Areas
CBRI	Central Building Research Institute
CC	Contour Crafting
CCSS	Credit-cum-Subsidy Scheme
CEEF	Cost-effective, Energy-efficient, Environment-Friendly
CLC	Cellular Lightweight Concrete
CLSS	Credit Linked Subsidy Scheme
CNA	Central Nodal Agency
CNC	Computerized Numerically Controlled
COVID-19	Corona Virus Disease 2019
CPWD	Central Public Works Department
CREAM	Construction Research Institute of Malaysia

CSIR	Council of Scientific & Industrial Research
CTI	Construction Technology India
CVC	Central Vigilance Commission
DDA	Delhi Development Authority
DHP	Demonstration Housing Project
DU	Dwelling Unit
EPC	Engineering, Procurement and Construction
EPS	Expanded Polystyrene System
ERP	Enterprise Resource Planning
EWS	Economically Weaker Section
FAR/FSI	Floor Area Ratio / Floor Space Index
FC	Freeform construction
FCB	Fibre Cement Board
FICCI	Federation of Indian Chamber of Commerce & Industries
FIDIC	FédérationInternationale des Ingénieurs – Conseils-International Federation of Consulting Engineers
GCC	General Conditions of Contract
GDP	Gross Domestic Product
GFRG	Glass Fibre Reinforced Gypsum
GGBFS	Ground Granulated Blast Furnace Slag
GHTC	Global Housing Technology Challenge
GI	Galvanized Iron
GIC	General Insurance Corporation
GoI	Government of India
GST	Goods and Services Tax
HDFC	Housing Development & Finance Corporation
HFA	Housing for All
HIG	High Income Group
HIMI	High Impact Molded Inserts
HUDCO	Housing & Urban Development Corporation
IAY	Indira Awas Yojana
IBS	Industrialised Building System
ICI	Indian Concrete Institute
IEC	Information, Education & Communication

IHSDP	Integrated Housing and Slum Development Programme
IHTM	Indian Housing Technology Mela
IIT	Indian Institute of Technology
IPD	Integrated Project Delivery
ISSR	In Situ Slum Redevelopment
IT	Information Technology
JIT	Just in Time
JnNURM/JNNURM	Jawaharlal Nehru National Urban Renewal Mission
LGSFS	Light Gauge Steel Framed Structure
LGSS	Light Gauge Structural Steel
LHP	Light House Project
LIC	Life Insurance Corporation
LIG	Low Income Group
LPP	Land Pooling Policy
LSAM	Large Scale Additive Manufacturing
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MGO	Magnesium Oxide
MHADA	Maharashtra Housing and Area Development Authority
MHUPA	Ministry of Housing and Urban Poverty Alleviation
MIG	Middle Income Group
MIS	Management Information System
MoHUA	Ministry of Housing & Urban Affairs
MoRD	Ministry of Rural Development
MP	Madhya Pradesh
NAREDCO	National Real Estate Development Council
NBC	National Building Code
NBO	National Building Organization
NEERI	National Environmental Engineering Research Institute
NERP	National Rural Employment Programme
NID	National Institute for Design
NITI Aayog	National Institute of Transforming India Aayog

NPCA	National Precast Concrete Association of USA
NPV	Net Present Value
NREP	National Rural Employment Programme
NSDP	National Slum Development Programme
NSS	National Sample Survey
NTSA	National Technical Support Agency
NURM	National Urban Renewal Mission
OLHS	One Lakh Housing Schemes
OSM	Off-Site Manufacturing
PACS	Performance Appraisal Certification Scheme
PCCon	Precast Concrete Construction
PCI	Precast/Prestressed Concrete Institute of USA
PEB	Pre-Engineered Building
PIRPoly	Isocyanurate
PMAY(G)	Pradhan Mantri Awas Yojana (Gramin)
PMAY(U)	Pradhan Mantri Awas Yojana (Urban)
PPGI	Pre-painted Galvanised Iron
PPP	Public Private Partnership
PPPP	Public Private People Participation
PQ	Pre-Qualification
PUF	Poly Urethane Foam
PVC	Poly Vinyl Chloride
PWD	Public Works Department
QCBS	Quality-cum-Cost Based Selection
R&D	Research & Development
RAY	Rajiv Awas Yojana
RBC	Reinforced Brick concrete
RBI	Reserve Bank of India
RC	Reinforced Concrete
RCC	Reinforced Cement Concrete
RERA	Real Estate Regulation Act
RICS	Royal Institution of Chartered Surveyors
RICS	RICS School of Built environment- Amity University [Royal Institute of Chartered Surveyors]

RLEGP	Rural Landless Employment Guarantee Programme
RRL	Regional Research Laboratories
SASH	Subsidies Aimed at Self Help Housing Scheme
SBM-G	Swacch Bharat Mission - Gramin
SC/ST	Schedule Cast/Schedule Tribe
SCC	Special Conditions of Contract
SCM	Supply Chain Management
SDG	Sustainable Development Goal
SECC	Socio Economic and Caste Census
SERC	Structural Engineering Research Centre
SoR/SOR	Schedule of Rates
TDR	Transfer of Development Right
TG	Technology Group
TIFAC	Technology Information, Forecasting & Assessment Council (India)
TNHB	Tamil Nadu Housing Board
TSM	Technology Sub-Mission
TVD	Target Value Delivery
UBS	Urban Basic Services
ULB	Urban Local Body
UN	United Nations
USA	United States of America
USD	United States Dollar
VAI	Vulnerability Atlas of India
VR	Virtual Reality
W.C.	Water Closet

CONTENTS

EXECUTIVE SUMMARY

The INAE document on VISION, MISSION & VALUES, 2037, brings out the fact that, areas such as Engineering Education, Energy, Infrastructure (with its various aspects), take centre stage, besides several other areas, and will continue to do so, for national development. The INAE, therefore, formed the Forum on Civil Infrastructure with the specific purpose of studying the subject areas of Traffic & Transportation, Housing and different aspects of Water. As its first task, the Forum carried out a study on the Urban *Traffic & Transportation* problems of the country, and a report thereon entitled, ***Urban Transportation: Challenges & Way Forward***, was released at the Annual Convention of the Academy, in December 2019, at Jaipur. The Forum has followed this up by taking a similar study on *Housing*. This subject area was also identified in the January, 2019 meeting of the DST – INAE Consultative Committee, for a study by the INAE.

The Forum is constituted by domain experts from within the INAE as well as outside it, and, the report has been authored by the members of this Forum.

The study reaffirms the fact that there exists a gap between demand and supply of liveable and affordable housing units as the number of dwelling units available are inadequate and further, even amongst the available units, a great majority are not up to the mark in terms of quality and their resilience to the natural hazards. Ever since the country attained independence, there has been continuous significant effort by the Government to address the problem of Housing shortage. This has been in addition to efforts by general public to cater for housing for themselves. In the last few decades, the private sector has also ventured into real estate to construct and deliver housing units. Despite these efforts, currently the gap runs into tens of millions in both rural as well as urban housing. Some of it will be filled by individual investment, but a larger proportion will require Public Sector inputs in terms of policy and planning, as well as investment. Furthermore, at least in the urban context, the concept of mass industrialised housing needs to be adopted. This may even be so, in the semi – urban and peri-urban as well as the rural context if the size of the project is large enough to justify its application. However, the concept of mass industrialised housing, which is the major focus in this study, is generally an unlikely application in the rural context, because the rural population is scattered.

For providing additional rural housing in a time-bound manner, the need is to upgrade and modernise conventional technologies, so as to become responsive to the changing ethos and aspirations.

The Housing Mission launched by the Government of India in 2015 and 2016 for urban and rural areas, so as to provide housing for all by 2022, the 75th year of our independence, has brought great impetus for the housing sector. The multi-pronged approach and a laudable effort in the last few years has enabled a clearer identification of a set of technologies for this purpose. Effort is also on to gain a deeper working understanding of some of these technologies by deploying them in what is being described as **"Demonstration Housing Projects"** and **"Light House Projects."** Most of these efforts are still in a nascent stage, except the technologies based on Aluminium formwork systems, Precast concrete construction and Pre-engineered building, for which a reasonable degree of experience does already exist. The technologies to enable faster delivery of housing stock along with sustainable development are also being highlighted through these missions.

There is an obvious need to make a critical analysis of the scenario and the ongoing efforts, in order to be able to make possible improvements in technologies being used, related engineering issues, as well as any policy interventions that could prove to be useful to the housing industry. This study is expected to add value to the ongoing efforts in the housing sector and also for future interventions required in developing housing stock at the required pace. The study gives an overview of the housing scenario in India for an assessment of demand and supply, as well as examines the prevalent and emerging technologies for housing. In view of the current level of housing shortages, Industrialised Building Systems (IBS) replacing cast-in-situ RCC framed construction hold a real promise to meet the demand in a given time frame. There is an attempt to identify the various problems faced with government schemes, ranging from issues related to, existing procurement policies especially tendering systems, unreasonable contract conditions, excessive taxation and even lack of standardisation, which are required to be duly attended to for mass housing schemes to be promoted using IBS or any other emerging technology. The report suggests the way forward for dealing with the prevailing housing scenario and ways to bring smooth technology transition to ensure faster delivery of sustainable quality housing stocks. The report is divided into chapters entitled, *Introduction*, *Housing Scenario in India, Concepts and Technologies for Housing*, *Industrialised Building Systems, Recommended Technologies for IBS*, *Enablers for Implementation of Emerging*

Technologies, Standardisation in Housing and The Recommended Way Forward.

The chapter-wise highlights are given in the sections below.

Housing Scenario

The importance of housing is accepted globally. This was evident when on 25 September 2015, the Member Countries of the United Nations agreed on 17 Sustainable Development Goals (SDGs) on Development Agenda, out of which SDG11 states, *Sustainable cities and communities - Make cities and human settlements inclusive, safe, resilient and sustainable, and aims at ensuring access for all to adequate, safe and affordable housing and basic services and to upgrade slums*, and also at providing *universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and those with disabilities*. Arising from the position of housing shortages in India, concerted efforts by the Government for its supply become very pertinent, even more so in view of the trends of increasing urbanization. By 2050, two-thirds of all humanity - 6.5 billion people will be living in urban areas. Urban population of India has already increased from 285.3 million in 2001 to 377 million in 2011, and is expected to reach 533 million in 2025.

Sustainable development cannot be achieved without significantly transforming the way we build and manage our urban spaces. Making cities sustainable means creating career and business opportunities, safe and affordable housing, and thus building resilient societies and economies. It involves investment in public housing and infrastructure, creating green public spaces, and improving urban planning and management in participatory and inclusive ways. Housing being key to accelerate the pace of development, investment in housing industry, like any other industry, has a multiplier effect on income and employment, which in turn leads to the overall development of the economy. The investment in housing impacts more than 200 sectors directly or indirectly fuelling employment besides helping livelihood, transport, skill development, landscape development etc. The demand and supply scenario today, in the wake of concerns such as climate change, is further influenced by the dire need of providing houses which are sustainable, resilient, climate responsive and can be quickly constructed.

As urban development takes place, a growing concern for India's urban planners is the massive urban housing shortage plaguing the country. Add to this, the rather disconcerting fact that the growth of slums in India has been at least three times higher than the growth of urban population, leading to a huge proportion of urban population living in the slums. Furthermore, despite the rise in the trends in urbanisation, more than half of India's population is still projected to be rural by 2050. Thus, there is need to create a balance between urban and rural schemes, as the growth and development of rural and urban economies and the population residing there are key to overall inclusive development of the country. According to the 2011 census, the housing shortage in India was, 17.4 million in rural areas and 9.1 million in urban areas. Other surveys give differing figures in the demand – supply equation. This may well be attributed to different yardsticks, procedures used for the survey and modelling used by the different organisations making these assessments.

In the last few years, with tax exemptions, single window clearances, formulation of innovative micro mortgage lending models, affordable housing being given infrastructure status, and Pan India housing programmes taken up in Mission mode by the Central and State Governments, the much-needed fillip has been provided to affordable housing development in the country. These policy level interventions could encourage public, private and people's participation. Also, the introduction of Real Estate Regulation Act (RERA) aims to protect the interests of buyers/ consumers and bring in more transparency into the sector.

Likewise, in the Post COVID-19 situation, the Government of India announced development of Affordable Rental Housing Complexes (ARHCs). This initiative is being taken up for the first time in the country to improve living conditions of the urban migrants/poor and to obviate their need of staying in slums, informal settlements or peri-urban areas. Also, in order to check the reverse migration which was realized in the wake of COVID-19, policy level interventions are contemplated to provide onsite housing facilities for workers during construction, which can later be converted to permanent housing for urban poor and maintenance/ domestic workers and security persons in future projects.

The measures above, though in their initial stages, are expected to bring about a welcome improvement in the housing scenario of the country.

Concepts & Technologies for Housing

India being a vast country having different geo-climatic regions, varying demography and multi-hazard vulnerability, has different types of existing housing based on local materials and local skills. However, with the advancement in the area of building materials, slowly the traditional housing types are being replaced by masonry construction and RCC framed construction both in rural and urban areas. Of late, with the increasing demand of housing, especially in urban areas, emerging construction systems based on prefabrication and precast technologies are being preferred.

Rural housing is greatly influenced by the vernacular architecture, traditional practices, local building materials and local skills available, but is mostly non-engineered. Houses in rural setup are designed to meet the essential and functional requirements of the households. On the other hand, urban housing is influenced by the size of its population and industrial and commercial developments. Urban areas are essentially expected to have infrastructural facilities for healthy living, such as protected water supply, electricity, and sewerage; and also the opportunities for education, employment and health. To meet the housing requirement of the ever-growing population, cities have been expanding both vertically and horizontally. With increasing industrialization, socio – economic and demographic changes are occurring on a large scale. Old patterns of society and family structure are also undergoing great changes. The joint family system is breaking up and number of individual or nuclear families is on the rise. Thus, family units and households are increasing, which in turn demand more housing accommodation.

The cities are classified as class I, II and III based on the population, infra-structural growth and services, where the land-use pattern is controlled by municipality, town-planning or urban development departments, through statutory master plan or regional development plan with zoning regulations. Building byelaws, town & country planning regulations and standards control the growth of buildings for various uses, to maintain an orderly development. The type of housing in urban areas varies widely. There are row houses, bungalows and multi-storied apartments. Gated communities, condominiums and suave housing societies are also in vogue with excellent amenities inside the premises. Houses are mostly strong and durable as these are constructed using sound engineering principles and good construction materials.

The most commonly used building materials for construction are stone, stone aggregates, sand, cement, steel, aluminium, brick, timber, glass, plastics, ceramics, etc. However, the lack of availability of these materials for the construction industry poses a problem for the housing sector. All these materials depend directly or indirectly, on a finite natural resource base which is fast depleting, and creating an imbalance in the demand and supply equation for materials.

The direct consequence of an increased demand would be the increasing price due to shortage of supply, leading to the increased cost of housing. The indirect consequence would be rapid and irrationally managed finite natural resources, enhanced use of top fertile soil, use of timber and fossil fuels, river dredging, lime quarrying etc. leading towards GHG emissions and environmental degradation.

On the other hand, factory made materials such as cement, steel, aluminium etc. demand high energy inputs for their production. Greater demand would also be made on the transport networks for the purpose of transporting raw materials and finished products, thus enhancing the cost per unit of output. Enhancing the supply of these conventional materials would not always be feasible nor recommended under the given circumstances. Therefore, there is a need to adopt appropriate technologies either by upgradation of traditional technologies using local resources or applying modern construction materials and techniques with efficient inputs leading to economic and sustainable solutions. In the context of the large volume of housing to be constructed in both rural and urban areas, the consideration of limitations in the availability of resources such as building materials, besides skilled/ experienced manpower and finance has become a most relevant aspect.

Market forces are consequently creating demand for cost-effective technologies. However, the alternate technologies and materials are not widely accepted in the construction sector and require enabling eco-system for its absorption and mainstreaming. Cost-effective building materials and construction technologies developed by the various research and development bodies in the country, namely Central Building Research Institute (CBRI), Structural Engineering Research Centre (SERC), Centre for Application of Science and Technology to Rural Areas (CASTRA), National Environmental Engineering Research Institute (NEERI), Building Materials & Technology Promotion Council (BMTPC) and some others are time-tested, proven and readily available. These technologies have proved to be appropriate and viable in the context of low-income group housing and are being used in many regions of the country, but could not find wider acceptability and replication at a larger scale. Some of the appropriate technologies based on walling material, roofing types, doors, windows and other elements are described in the report.

India has a history of recurrent disasters leading to irretrievable losses to lives and properties. With 26 percent of land areas exposed to earthquake hazard in zone IV and V, 18% of land vulnerable to High Wind Velocity (55 and 50 m/s), 7% of land vulnerable to Floods, 12.6% of land vulnerable to landslides in hilly regions, the coastal belt (especially eastern coast) to Tsunami, the housing stock of the country is vulnerable to multitude of natural hazards of varying degrees. Realising the obvious need to mitigate destruction and losses due to these hazards, the traditional 3 Rs (Rescue, Relief and Restoration) are slowly albeit surely being replaced by 3 Ps (Prevention, Preparedness and Proofing). Several Acts enacted by Govt. of India towards this end are a good augury for meeting these objectives, and in addition the Vulnerability Atlas of India 2019, prepared by BMTPC, deserves to be mentioned as a very useful tool for this exercise.

The world over, building construction has shifted to quite an extent from 'on site' to the 'off site' mode, whereby building components are manufactured partially or fully in the factory under controlled conditions and then transported to the site for their erection, assembly and finishing. This has given rise to fast track construction systems with much improved structural and functional performance, better durability, low life-cycle cost, resource-efficiency, with minimum wastages, air and land pollution than the cast-in-situ RCC construction. It is notable that, the provisions to use new construction technologies including those certified by BMTPC have now been introduced in the National Building Code (NBC), 2016 and CPWD's Schedule of Rates. The need of bringing emerging construction systems has also been well documented by vision documents by TIFAC, NITI Aayog and CSIR. Further, within the ambit of the overarching PMAY (U), a Technology Sub-Mission (TSM) was set up to facilitate the adoption of new, innovative, sustainable, green and disaster-resilient technologies and building materials for low-cost, speedier and quality construction of houses. MoHUA therefore, conceptualized a Global Housing Technology Challenge-India (GHTCIndia) to enable this paradigm shift in the construction sector. This resulted in identifying 54 new technologies grouped into six broad categories namely, *Precast Concrete Construction System - 3D Precast volumetric; Precast Concrete Construction System – Precast components assembled at site; Light Gauge Steel Structural System & Pre-engineered Steel Structural System; Prefabricated Sandwich Panel System; Monolithic Concrete Construction; and Stay-in-Place Formwork System.* Some of these technologies are being implemented and the latest position is reflected in the report. Furthermore, in a parallel exercise for further adaption and adoption of these technologies, and for finding ways of improvement, the Government of India has launched a Light House Project. These LHPs are promoted as Live Laboratories for learning, facilitating transfer of technology to the field and its further replication.

Ministry of Housing & Urban Affairs, Government of India had organized Indian Housing Technology Mela (IHTM) as part of New Urban India Conference cum Expo during October 2021 in Lucknow, Uttar Pradesh. 84 innovative technologies/systems/ products/materials were identified for use in low and mid-rise construction from this exercise. These are listed in the report.

An online drive for Enrolment of Technograhis under GHTC-India: Light House Projects has also been launched. Technograhis are the Change Agents of innovative and sustainable technologies which will bring about technology transition in the construction sector for its adoption and replication in the country. These are expected to act as catalysts to transform the urban landscape for new urban India to fulfil the vision of Aatma Nirbhar Bharat.

Industrialised Building Systems

The Industrialised Building System (IBS) is 'off site' construction which involves the repetitive construction of standardised units, utilising standardised components, automation and mass production concepts, with minimal wastage, maximum efficiency and best quality possible. This necessarily involves thorough prior planning, employing appropriate designs, prefabricating various standardised components under controlled factory environment, transporting them to the site where required, erecting and assembling them at the site using minimal, but efficient interventions. The systems for the joints and connections between the various components become especially important to ensure desired functional and structural performance. The system also implies an aspiration for the least cost possible, leveraging mass production principles, automation, and standardisation. A typical example is the popular precast concrete construction. Apart from complete buildings, IBS may also be applied to parts of buildings, where efficient construction systems are adopted. With ongoing developments, this definition may need further modification to include 3D printed housing depending on how well it evolves over time.

IBS applications can generally be classified as, precast concrete construction using linear framing, planar Panels and slabs and three- dimensional Box Systems, cast in-situ concrete work using system formwork, frames and blockwork systems, tilt-up construction, lift slab construction, etc., possibly also including 3D printed concrete, structural steel systems- frameworks, expanded steel systems with cover boards, prefabricated timber framing system, etc.

In order to meet rapidly rising demands for good quality housing as quickly as possible and considering the several advantages of IBS, many countries around the world have taken steps to promote IBS. However, it is reported that some of these countries also faced several issues while promoting IBS, such as lack of stable demand for precast construction, lack of adequate standardisation, lack of widespread expertise in design and manufacturing, higher initial costs, high costs of transportation, limitation on the sizes of elements due to transportation difficulties, incompatibility between elements supplied by various manufacturers, inter-communication issues between the various agencies involved, perception of bad performance of buildings, etc. These issues are required to be studied in the Indian context, so that steps to ameliorate these difficulties can be taken during the planning stage. While doing so, the soaring demands for housing have to be kept in view. Accordingly, the reported issues for India are, lack of large and steady demand for IBS projects, inadequate policy support from Government for sustaining IBS as a preferred solution for mass housing projects, lack of adequate standardisation/ standards/ Handbooks, lack of familiarity and required skills for both design and construction leading to high learning cycles, lack of involvement of smaller contractors, lack of adequate good quality road networks, jointing quality issues, higher initial costs, unfavourable taxation and payment terms, etc.

Many other countries have realised the advantages of IBS and have overcome the initial problems in good measure. Thus, one notices much higher levels of use of IBS in these countries compared to India.

Recommended Technologies for IBS

The housing problem of India is a rather complicated issue considering the huge variations in socio-economic characteristics of the heterogenous population, the variations in climatic conditions across the country, the large variations in the prevalence of locally available materials and locally appropriate technologies, the rural versus urban dichotomies, local preferences for particular types of housing, etc. In view of this, it is rather difficult to identify particular technologies for adoption across the country and prescribe the same for adoption and implementation on the large scales required. However, looking at the huge scale of the demand, the urgency associated with the need to address this demand rapidly and the prior proven experiences in the country, some common technologies can still be identified to serve the needs of housing fairly judiciously. These have been grouped earlier as, *Precast Concrete Construction System - 3D Precast volumetric; Precast Concrete Construction System – Precast components assembled at site; Light Gauge Steel Structural System & Pre-engineered Steel Structural System; Prefabricated Sandwich Panel System; Monolithic Concrete Construction; Stay-in-Place Formwork System.*

The technologies which can be recommended for mass housing should be easy to adapt and adopt for wider application, and, should be readily available from many producers and constructors of the technology for a variety of climatic and seismic/ wind loading conditions across the country. These should be economical in cost and speed, be environment friendly to a reasonable extent, suitable for urban and rural applications as well as both for low-rise and high-rise structures, etc.

Considering the above factors, it will be advantageous and expeditious if at this stage preference is given for adoption in housing for mass applications, mainly to the following two technologies, which are already being practiced quite widely in the country by many agencies.

1. Precast Concrete Construction (PCCon) using either (i) framed structure components with in-fill precast blockwork walls/ precast wall panels and precast slab panels (including precast half-slabs) or precast Hollow Core Slab units with screeding on top, or (ii) precast wall and slab panels, and (iii) 3D volumetric construction.
2. Monolithic in-situ construction using standard pre-designed formwork plates in metal (mainly Aluminium) or plastic, which can be shifted up from floor to floor with easy erection and dismantling, popularly known as Aluminium formwork construction.

Nevertheless, there are other technologies, with substantial merits, in different stages of development, and, for which, as mentioned above too, pilot projects have already been initiated to assess their suitability, or to determine how these can be made more acceptable for use in the mass housing programme of the country.

Enablers for Implementation of Emerging Technologies

In order to provide affordable housing, various stakeholders, such as the Central Government, State Governments, real estate and infrastructure developers, financial institutions, urban planners and, most importantly, beneficiaries have to work together. In this context, both the public as well as the private sectors have to play their part. In an ideal PPP scenario, the public sector could look into aggregating land for projects, providing single-window and time-bound clearances, redrafting the local development bye-laws to suit the requirements of affordable housing projects and reviewing the taxes and levies from the perspective of reducing cost of home ownership for the target segments. Private sector entities can leverage core competencies such as planning and design, project development, best technology practices, project financing, human resources, sales and marketing.

To achieve the objective of 'housing for all' and based on the schemes run by Central and State Governments, policy level interventions that are needed to remove constraints, such as lack of ready access to finance from formal financial institutions for IBS projects; long-drawn out and multi-level approval system in urban areas in a large majority of municipal jurisdictions; delays even where a single window system has been introduced; limited private sector participation in affordable housing schemes in urban areas; predominance of conventional construction practices that result in delayed progress in urban areas and the limited use of prefabricated and pre-engineered materials; limited access to suitable land banks for affordable housing projects; insufficient number of trained masons and skilled workmen; capacity constraints in urban local bodies (ULBs) to formulate and design mass housing projects; and high levels of taxation leading to non-viability.

Contract formats and conditions have a considerable impact on the choice of technology, time and cost of completion, functionality and even the very feasibility of adoption in new schemes. These have to be properly administered centrally, in a globally accepted and holistic manner to ensure uniformity and equity to all concerned agencies and for rapid realisation of the objectives in the most efficient and economical manner. Also, there is urgent need to create a pool of architects, engineers and above all contractors and artisans specializing in these new building systems.

Standardization in Housing

In all infrastructure developments including housing, it is necessary to prescribe appropriate quality benchmarks so that the huge investments made for the purpose result in assets which are truly functional, safe and sustainable. In the field of housing, this would involve specifying standards for planning aspects and space norms, building materials and components, as well as for design and construction. The Town and Country Planning Act/ Development Act, Municipal Corporation/Municipality Act and Local Building Bylaws/Regulations are some of the instruments which are used by the state/urban local bodies for regulating the building construction activities within their jurisdiction. The Bureau of Indian Standards (BIS) is responsible for formulation of Indian National Standards. The Indian Standards are voluntary in nature but may become mandatory through a contract, or through legislation. For the sake of uniformity in concepts, understanding and implementation, it is necessary to have standardisation across the various activities and the BIS Standards serve this purpose.

For housing and other building types, the BIS has formulated a series of standards on building materials and components, test methods for evaluating the same, basic loading codes, design and construction codes of the good practices for various material streams, guidelines for the management of construction projects and standards for various building and constituent services. These have also been duly interwoven for ease of understanding and implementation in the National Building Code of India (NBC). In addition, NBC gives administrative provisions for regulating building construction, apart from focusing on ensuring accessibility for persons with disabilities and the elderly, and also for sustainability and management of built asset/facility. In order to support the cause of promoting PCCon-based industrialized building systems, it would be required to develop IS 15916 as a further detailed and elaborate standard, and also to publish a separate detailed Design and Construction Handbook.

The Recommended Way Forward

This Chapter contains *the recommended way forward* based on the study described in the preceding seven chapters, for consideration by the policy–makers, engineering & technology establishments, the industry, financial institutions, and, various stakeholders generally, all of whom face the challenge of providing adequate good quality housing for the entire population of India.

The suggested strategies to overcome the constraints for adequate supply of affordable housing given below are grouped into five categories, namely, *Financial Issues, Efficient Land Use, Appropriate Technologies for Construction, Mainstreaming of Technologies and Developmental Studies.*

- **Financial Issues**

  There is an obvious need for creating a robust institutional framework for a financial mechanism to ensure access by the needy for getting the loans, and earmarking funds for affordable housing through Government resources as well as extra budgetary resources. Also, reducing regulatory complexities and introducing single window clearance are essential for bringing in new financial models such as 'rental-cum ownership housing'.

  Further, in order to reduce the overall cost, *life cycle cost* approach should be adopted instead of the *initial cost* basis alone, and utilization of waste based recycled materials and products need to be promoted. The latter is also an environmental need to ease out the waste disposal issues and improve sustainability.

- **Efficient Land Use**

  A data bank should be created for the appropriate land lying idle within the public sector domain of the central/ state governments, to encourage its possible utilization for housing, partly or as a whole. In addition, there is a need to introduce urban governance reforms, such as, removing the need to obtain permission for non-agricultural use in the case of land that has been earmarked for residential purposes in master plans. Also, all relevant permits and approvals should be secured a priori.

- **Appropriate Technologies for Construction.**

  In keeping with the need of industrialised mass housing, it is required to introduce state-of-the-art technologies for safer and disaster resilient housing, which are affordable and sustainable ensuring faster delivery. These will also improve the quality of construction in a cost effective and environment friendly manner across states/ regions and achieve economies of scale in urban areas.

  Besides this, there is a need to continually work upon and bring about innovation in the conventional technologies deployed in rural housing, such that the housing thus created meets the challenge of the rising aspirations of the rural population while satisfying the requirements of changing environment in a better manner.

- **Mainstreaming of Technologies**

  -New Technologies

  As brought out in the report, there is considerable ongoing effort for developing or adopting new technologies suited to speedier and good quality construction of housing. However, in order to achieve due success, the following specific suggestions may be noted:

1. Adoption of EPC contract system for which Procurement Policy needs to be encouraged. Adoption of appropriate contract conditions such as, povisions of additional mobilization advance (for example, 20% in place of existing 10%) to the contractors to facilitate setting up of the manufacturing plant/ production of components, etc is also important.

2. Policy level interventions are also important for adoption of new technologies through a high-level committee of experts representing technical and financial departments to best mitigate and manage the risks perceived by policy makers and technocrats. Creation of a capable Nodal Agency to steer the various initiatives through the various stakeholders is very important.

3. Revisit pre-qualification criteria, especially the requirement of 'quantum of similar works' in tender documents to facilitate adoption of new technologies.

4. Demonstration of construction with new technologies at grass-root level required to showcase and educate all the stakeholders about the technologies. Awareness creation and construction of some public buildings to build confidence in

public and increase user acceptability would be useful.

5. Capacity Building & Skill Development. There is a need to create a pool of specialists since at present there are inadequate capacities at professional level. As there is paucity of contractors working with new technologies, there is a need to build a platform/panel of technology providers & contractors. Also, motivate existing developers/ builders to make use of emerging construction systems and utilize their plants & equipment, including capacities for "housing for all" mission.

6. Incentivizing innovation in construction through suitable reward or rebate could be a booster to new technologies.

7. Modular/standardized plans & design for different geo-climatic conditions to achieve appropriateness, speed and economy.

- **Industrialized Building Systems (IBS)**

IBS concepts have been developed to meet the needs for rapid and quality construction of buildings on large scales with good economy in cost. IBS concepts have many advantages, such as: speed, cost economy, high quality, standardization, high construction safety, less need for construction space at site and better managed facilities. However, certain logical prerequisites have to be met, such as,

1. Ensuring large and sustained demand to meet the higher initial capital costs, standardisation, equipment and labour with better capabilities and specific designs.

2. Promotion by giving incentives, such as: higher ranking for qualification, taxation benefits, preference in bidding, etc.

3. Adoption of appropriate systems, such as, the slab and wall panel system for Precast Concrete Construction (PCCon) in urban applications, and locally suitable technologies for rural applications, with effective architectural interventions to take care of functionalities, aesthetics, space utilisation, and standardisation.

4. Particularly, for PCCon systems, familiarising the Architects and Designers in PCCon concepts, developing standardisation for uniformity across the entire PCCon industry, developing guidelines and comprehensive handbook material for a shared approach between clients, designers and producers, setting up testing and certification institutions.

- **Developmental Studies**

  In the aforesaid section, certain recommendations have been made in order to face, in a more effective manner, the challenge of providing good quality housing for all in the country. The implementation of these recommendations by and large will need to be addressed by technological establishments besides a very committed substantial push by the policy makers. In addition, it is felt by the authors of this report that scientists, engineers and architects in academic and R&D establishments have a definite role to play in taking this laudable and challenging task forward. Areas that should be taken up as part of this endeavor (these are indicative and not inclusive) are:

  1. Innovative development related to Designs and Technologies for Rural Applications, with effective architectural interventions to take care of functionalities, aesthetics, space utilisation, and standardisation.
  2. Assessment of Material and Skilled Manpower Resources for meeting projected demand for development of housing over the next two decades, to bridge the gap between demand and availability (keeping in view also the competing demands from other sectors of civil infrastructure), and to identify measures to overcome deficiencies.
  3. Structural Health Monitoring Measures to be developed to enable the existing as well as upcoming housing stock to be utilised to the 'last mile', in order to economise on the use of financial resources.

INTRODUCTION

Light House Project at Chennai

Technology- Precast Concrete Construction System

1. INTRODUCTION

1.1 The Forum

The INAE Forum on Civil Infrastructure was formed to study the subject areas of Traffic & Transportation, Housing, and, different aspects of Water. As its first task, the Forum carried out a study on the *Urban Traffic & Transportation* problems of the country, and a report thereon entitled "Urban Transportation: Challenges & Way Forward" was released at the Annual Convention of the Academy, in December 2019, at Jaipur. The Forum has followed this up by taking up a similar study on *Housing*. This subject area was also identified in the January, 2019 meeting of the DST – INAE Consultative Committee, for a study by the INAE.

The Forum was constituted as follows:

Chairman - Prof. Prem Krishna & ***Members*** - Prof. Mahesh C. Tandon, Dr. Mangu Singh, Prof. P. K. Sikdar, Prof. S. K. Bhattacharyya, Prof. N. Raghavan, all FNAEs, Prof. Satish Chandra, Director, Central Road Research Institute (CRRI); Dr. S. K. Agrawal, Executive Director, Building Materials & Technology Promotion Council (BMTPC); Er. Sanjay Pant, Deputy Director General, Bureau of Indian Standards (BIS); and Er. K. Senou, Head, Precast Initiatives, Larsen & Toubro Ltd. (L&T). The Forum started work on the study in earnest in November, 2019. Er. Pankaj Gupta, Deputy Chief (I&D), BMTPC, joined the study as a special invitee.

1.2 Need for the Study

Need for shelter is as old as mankind. First need was food, which was provided for by nature, and, then it was shelter, which was either natural or created by the humans. Thus, the requirement for dwelling has always existed. In India, there has been a gap between demand and availability, from as far back as one would like to see. The gap exists because the number of dwelling units has been inadequate and further, even amongst the available units a great majority lack in quality and their resistance to the forces of nature.

Ever since the country attained independence, there has been a continuous effort to a larger or a smaller degree by the Government to address the problem of Housing shortage. This has been in addition to efforts by general public to build houses for themselves. In the last 2 – 3 decades, the private sector has also taken initiatives to construct housing Projects. In spite of all this, currently the gap runs into tens of millions in both rural as well as urban housing. Some of it is being filled by individual investments, but a large proportion requires Public Sector inputs in terms of policy and planning, as well as investment. At least in the urban context, the concept of mass industrialised housing needs to be adopted in earnest. This may even be so, in the semi–urban and peri-urban areas as well as in the rural context, if the size of the project is large enough to justify its application. Generally, though the concept of mass industrialised housing, which is the major focus in this study, is an unlikely application in the rural context because of scattered population and consequently a lower density as compared to that in the urban context. For providing additional rural housing in a time-bound manner, the need is to upgrade and modernise conventional technologies, so as to become responsive to the changing ethos and aspirations.

The mission launched by the Government of India in 2017 to provide housing for all by 2022, has brought great impetus to the housing sector. There has been multi-pronged approach and laudable efforts in the last few years, which has enabled the identification of a set of technologies for this purpose. Effort is also on to gain a deeper working understanding of some of these technologies by deploying them in what is being described as "Lighthouse Projects". Most of this effort is still in a nascent stage, except the technologies based on precast concrete construction, for which a reasonable degree of experience does already exist.

There is a need to make a critical analysis of the scenario and the ongoing efforts, in order to be able to contribute by recommending possible improvements in technologies being used, related engineering issues, as well as any policy interventions that could prove to be useful to the housing industry. The study should be expected to add value to the ongoing efforts for achieving the target. Also, it needs to be stressed that housing is a perpetual issue, which will continue to demand attention, if not for making up numbers to fill the gap between demand and availability, to also meet the need to upgrade the existing stock in quality, in order to meet rising aspirations for better habitats, to satisfy the demands of sustainability against the changing environment, and similar other issues. This report addresses the above issues and ideas for fulfilling the additional national needs related to housing in the coming years.

1.3 Objectives and Scope

The main objective of this report is to provide, in the first instance, an appreciation of the criticality of the housing demand in India, and furthermore to support the cause of achieving the laudable mission of providing housing to all, with a set of ideas related to technologies and policy initiatives. The report thus also embraces the issue of sustaining the process of maintaining and providing good quality housing for weaker sections of the society.

The scope of the study is to give an overview of the housing scenario in India for an assessment of demand and supply, as well as make a study of the prevalent and emerging technologies for housing. In view of the current level of housing shortages, Industrialised Building Systems (IBS) hold the real promise to meet the demand in a given time frame. The report describes some initiatives being taken to demonstrate the deployment of new technologies for industrialised building. The study also brings out various problems faced within government schemes like unreasonable contract conditions, excessive taxation or even lack of standardisation, which are required to be duly attended to for mass housing schemes to be promoted using IBS. The report suggests the way forward for dealing with the prevailing housing scenario and to extricate the society from the existing difficulties to a good extent.

1.4 Methodology Adopted

In studying this problem, the focus has been the housing shortage and its alleviation both in the urban as well as rural context. It was decided to first make a comprehensive study of the problem involving not only the engineering issues, but also other related ones such as the policy interventions needed. The assessment of gap between demand and availability of housing in the country as well as break-up of the gap state-wise have been brought out. Also, for this purpose, the various initiatives taken by the Government of India to overcome shortage of housing in the country, have been studied. The chapters that follow, namely, *Housing Scenario in India*, *Concepts and Technologies for Housing*, *Industrialised Building Systems*, *Recommended Technologies for IBS*, *Enablers for Implementation of Emerging Technologies*, *Standardisation in Housing*, *Recommendations & Way Forward*, have been prepared to cover different aspects of this study. These have been discussed in detailed deliberations in Forum meetings. Before finalisation, an extended Executive Summary covering the draft report has been widely shared with officials, academics and professionals who can relate to this domain (List at Appendix A), to seek their comments/suggestions. Subsequently, a discussion meeting was held online, with the extended Executive Summary having been shared with the invitees in advance of the meeting. The features of the draft report were presented at the meeting, and also the participants had the benefit of addresses by Sri Durga Shankar Mishra, Secretary, Ministry of Housing & Urban Affairs GOI, Professor Manna, President INAE. (The programme and the list of participants invited may be seen at Appendix B). Whereas the draft was generally appreciated, many valuable suggestions were made through the above two excercises and these have been duly taken into account in finalising the report.

1.5 The Report

The report that follows is based on the study of the problems faced by the country vis-à-vis Housing. This is contained in the Chapters 02 to 07, entitled, *Housing Scenario in India*, *Concepts and Technologies for Housing*, *Industrialised Building Systems*, *Recommended Technologies for IBS*, *Enablers for Implementation of Emerging Technologies*, *Standardisation in Housing.* The report then makes *Recommendations* for identifying the *Way Forward* to effectively meet the challenges of Housing in India.

HOUSING SCENARIO IN INDIA

Demonstration Housing Projects (DHPs)

Model housing projects containing up to **40 Houses each** with sustainable, cost and time effective emerging alternate housing construction technologies suitable to the geo-climatic and hazardous conditions of the region.

Nellore, Andhra Pradesh

Glass Fibre Reinforced Gypsum Panel System

Hyderabad, Telangana

Light Gauge Steel Frame System & Stay-in-place formwork - Coffor

Bihar Sharif, Bihar

Stay in Place - CR Steel Formwork System

Lucknow, Uttar Pradesh

Stay in Place - EPS Double Walled Panel System

Bhubaneswar, Odisha

EPS Core Panel Technology

Panchkula, Haryana Agartala, Tirupura

2. HOUSING SCENARIO IN INDIA

2.1 Existing Status of Housing - Rural and Urban

Housing being one of the basic needs after food and clothing, gets high priority in development schemes of any government. In India, therefore, arising from its position of shortages in housing, concerted efforts for its supply become very pertinent. The importance of housing is accepted globally. This was evident when on 25 September 2015, the Member States of the United Nations agreed on 17 Sustainable Development Goals (SDGs) on Development Agenda, out of which SDG11 states, "Sustainable cities and communities - Make cities and human settlements inclusive, safe, resilient and sustainable", and aims at ensuring "access for all to adequate, safe and affordable housing and basic services including upgradation of slums". It also aims to provide "universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities". The summary of SDG 11 is given in **Annexure 2.1**.

The quest towards a safe livable house has been as old as our civilization. The traditional people, who lived between 10,000 and 2,000 B.C. built their houses like pit dwellings, lake dwellings, huts, etc. primarily based on locally available materials. However, the importance of housing increased over the years due to fast pace of development in terms of industrialization and urbanization. Our ancestors gave importance to housing for protection against wild animals, natural calamities and also against enemies. The demand and supply scenario today, in the wake of concerns such as climate change, is influenced by the dire need of providing houses which are sustainable, resilient, climate responsive and can be quickly constructed.

The requirements of housing are growing on account of better understanding and gain of knowledge, changes in the demographic patterns and aspirational needs of the people as regards comfort, privacy, sanitation, consciousness about health, environment and infrastructural facilities. Housing is now considered a life-time requirement for safe and secure socio-economic life.

Furthermore, housing being key to accelerate the speed of development of the nation, investment in housing like any other industry has a multiplier effect on income and employment, which in turn leads to the overall development of the economy. The investment in housing impacts more than 100 different sectors directly or indirectly fueling employment besides helping livelihood, transport, skill development, landscape development etc. *(Source: Assessing Employment Generation under PMAY-Urban, National Institute of Public Finance and Policy, February 2019).*

The demand of housing is growing in most of the developing countries because of rapid pace of urbanization, largely through increased level of migration, especially from the rural areas to cities in search of livelihood (employment). Most of these countries are grappling with the mismatch between demand and supply of shelter and other services at affordable prices. This is further aggravated due to high cost of urban land parcels vis-à-vis income of people, leading to a non-sustainable situation. It is notable in this respect that India is fast urbanizing with 31% people living in urban areas as per Census 2011 which is projected to touch 40% by 2030 and 50% by 2050. Urban population of India has already increased from 285.3 million in 2001 to 377 million in 2011, *(Census of India, 2011, Provisional Population Totals, Ministry of Home Affairs, Government of India)* and was expected to reach 468 million in 2020 and 533 million in 2025 as per the projection based on the historical growth pattern of our population (1901-2001) *(Population Projection as per 1991-2001 Growth, by Census of India, Ministry of Home Affairs, Government of India)*. The rapid pace of urbanization owing to the rural–urban migration is putting a strain on the urban infrastructure in cities. As urban development takes place, a growing concern for India's urban planners is the massive urban housing shortage plaguing the country. Added to this, the rather disconcerting fact that the growth of slums in India has been at least three times higher than the growth of urban population, leading to sizeable proportion of urban population living in the slums. Cities and towns, which are thus expanding at unprecedented rate need to create and supply affordable housing at faster rate so that the gap between demand and supply can be checked to an extent.

In a country like India, this will not be possible unless there is public-private participation. The people themselves with their own resources construct majority of the houses in India, and therefore, the main role of the government at all levels is not to seek to build houses itself, but to act as a facilitator and make appropriate investments and create conditions where the poor people may gain and secure affordable housing of good quality. This has led towards impetus on encouraging private sector participation in affordable housing. However, there are issues that continue to persist with regard to land availability and its pricing, project approval processes including environment clearances and other aspects, which make low-cost housing projects unviable for private developers. Thus, barring a few States the results are not encouraging, and as things stand, affordable housing remains a challenging proposition for developers.

In the last few years, with the introduction of GST, tax exemptions, single window clearances, formulation of innovative micro mortgage lending models, affordable housing being given infrastructure status, and Pan India housing programmes taken up in Mission mode by the Central and State Governments, there is a promise of enhanced affordable housing development in the country. The above initiatives could encourage public, private and people's participation.

India is predominantly a rural country with two third of its population and 70% workforce residing in rural areas, and contributing 46% of national income. Despite the rise of urbanisation, more than half of India's population is still projected to be rural in 2050. Therefore, there is need to create balance between urban and rural schemes, as the growth and development of rural and urban economies will only ensure the overall inclusive development of the country. Rural housing programme started in the country as early as immediately after independence with the rehabilitation of refugees.

2.2 Demand for Housing

As mentioned earlier, a large proportion of the Indian population is rural as well as poor. The poor people either do not have a house or live in a dilapidated kutcha house, and providing pucca house to households in rural areas is a major concern. On the other hand, as also mentioned earlier, the urban population in India has registered a decadal growth between 2001 and 2011, and, is expected to continue to grow. Given this scenario, it becomes critical to fill the existing gaps in the strained urban infrastructure and in particular, housing. Primarily, it would be important to address the need in the EWS (economically weaker sections) and LIG (lower income groups), which currently account for 95 percent of urban housing shortage in the country.

The housing shortage in urban and rural areas for India is presented in **Table 2.1**.

Table 2.1 : Housing Shortage (in millions)

Year	Rural	Urban	Total
1951	6.5	2.5	9.0
1961	11.6	3.6	15.2
1971	11.6	3.0	14.6
1981	16.3	7.0	23.3
1991	14.6	8.2	22.8
2001	13.5	8.9	22.4
2011	17.4	9.1	26.5

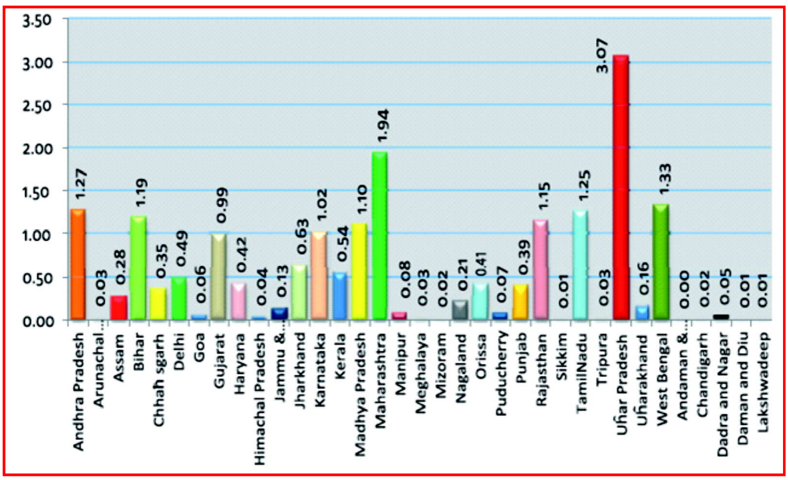
Source: Census of India 2011 as per 11th Plan (2007-12) Planning Commission, Govt. of India

2.2.1 Data from Government Source

Perpetual migration from rural to urban has resulted in an increase in the number of people living in slums and squatter settlements in urban areas. In addition, high land prices, lack of finance and expensive real estate market in urban areas have forced the poor and the economically weaker sections of the society to live in squatter settlements. Thus, with the fast urbanization, there is substantial housing shortage with a shortfall between demand and supply of housing, both in terms of quantity and quality.

There have been several attempts to project housing shortage in urban areas. As per the estimate of the Technical Group on Urban Housing Shortage (TG-12) (2012-17) constituted by NBO, Ministry of Housing & Urban Poverty Alleviation, at the beginning of the 11th Five Year Plan (2007-2012), the housing shortage was estimated to be 24.7 million in urban area. It is interesting to note that ten States contribute to three-fourths of the urban housing shortage as shown in **Figure 2.1**.

On an estimate based on Census & NSS 65th Round results on Housing conditions and Urban Slums (July 2008-June 2009) with usual inputs like obsolescence factor, congestion factor and homeless households, about nineteen million (18.78 million) households grapple with housing shortage in Urban India. Further, the shortage was distributed among the social economic categories, i.e. EWS, LIG and MIG & above. As per the report, the housing shortage are 56.18%, 39.44%, 4.38% for the EWS, LIG and MIG & above categories respectively. It is pertinent to mention here that EWS households are those with income up to Rs.5000 per month and LIG households are those with income between Rs.5001 and Rs.10000 per month. It is evident from the above that more than 95% housing shortage pertains to EWS and LIG categories.



Source: Report of Technical Group on Urban Housing Shortage (TG-12) (2012-17) constituted by NBO

Fig. 2.1: Housing Shortage *(in millions, statewise)*

2.2.2 Data from Non-Government Sources

Besides Government's estimation on housing shortages, there have been a few attempts by agencies like, KPMG, Knight Frank, RICS, NAREDCO on housing shortages. Some of the salient findings by these reports are reproduced hereunder and should be read in the context of the period in which these studies were carried out.

- **Brick by Brick - RICS and Knight Frank, 2019**

  In 2011, an initial assessment for housing shortfall was released by the then government which identified the need of 18.6 million houses in urban areas. This shortfall was however need based i.e. the estimated shortfall was drawn on the basis of certain normative standards of adequate housing. These estimates did not establish the willingness of a household to buy a house. The latest demand based assessment by the Ministry of Housing and Urban Affairs, which is based on an assessment of the number of houses which the households will choose to occupy given their preferences and ability to pay (at given prices), has pegged the affordable housing shortfall at approximately 10 million houses.

  With the target being to add 10 million houses, the focus of future missions should be on addressing the fundamental supply side challenges, to prevent the resurgence of the same problem in the future. Existence of the affordable housing market being well established in India, future programmes will have to focus on ironing out various issues in sub-markets comprising of leasing markets, sale markets, development markets, project finance and Housing Finance markets. This will facilitate development of a self-reliant and well-functioning affordable housing industry.

- **Funding the Vision: Housing for All by 2022 - KPMG-NAREDCO, 2014**

  India has a significant housing deficit, as almost a fifth of urban and rural households have access to limited housing facilities. To achieve the vision of 'Housing for all by 2022', it is estimated that India needs to develop houses at the rate of 30,000-35,000 units per day for the next 8 years (about nine crore houses including six crore of existing shortage). A majority of these houses need to be in the affordable segment requiring investment of more than US$2 trillion.

  The challenge is significant but not impossible, if this objective is supported by right policy mix, especially to improve institutional investment in the sector. The government announced new policy decisions in the recent Union Budget 2014-15, however, large scale development of affordable housing projects is still a challenging proposition for many private developers.

The report presents the housing demand as given in **Table 2.2** and **Table 2.3**.

Table 2.2: Housing demand– Urban and Rural

Particulars	Urban (million units)	Rural (million units)	Total (million units)
Current shortage	19	40	59
Additional	28	23	51
Vacant houses	9	10	19
Core demand	38	53	91

Source: Census 2011; Report of the technical group on urban housing shortage (2012-17), Ministry of Housing and Urban Poverty Alleviation; Working Group on Rural Housing for XII Five Year Plan, Ministry of Rural Development; KPMG in India analysis 2014

Table 2.3: India's housing need as estimated for 2022

Particulars	Urban (crore units)	Rural (crore units)	Total (crore units)
Current housing shortage	1.9	4.0	5.9
Required housing units by 2022	2.6-2.9	2.3-2.5	4.9-5.4
Total need	4.5-4.8	6.3-6.5	10.8-11.3

Source: Funding the vision — Housing for all by 2022, KPMG in India, 2014

- **Affordable housing – The order of the day**

  India's urban housing shortage is being primarily driven by the EWS and LIG categories. However, majority of the housing supply that has been built across urban India is beyond the affordability of the EWS and LIG segment. Real estate developers, private players in particular, have primarily targeted luxury, high-end and upper-mid housing segment owing to the higher returns that can be gained from such projects. Further, high land costs, archaic building bye laws, stringent licensing norms, delay in project approval and unfavourable banking policies made low - cost housing projects uneconomical for private developers. Hence, traditionally, low - cost housing has been the domain of the government. In the past three decades, government has adopted several policies assisting the delivery of affordable housing for the EWS, LIG and lower MIG.

2.3 Housing Schemes in India since Independence

Major housing schemes including major State schemes that have been implemented in India since independence are discussed hereunder:

2.3.1 Central Government Housing Schemes

- **Housing Programmes in the First and the Second Five-Year Plans (1951-1961)**

- ***Subsidized Housing Scheme for Industrial Workers and the Economically Weaker Sections -*** The first major housing programme launched in 1952, involved disbursements of loans to industrial employers or cooperative societies of industrial workers to cover a sizeable proportion (75 or 90 percent, respectively, with a 25 percent subsidy component) of the project costs of housing to be provided on a rental basis for a completed or open developed plot. The target beneficiaries were the industrial workers employed in mines and factories in the private sector with monthly incomes less than Rs. 500. Workers could obtain non-refundable loans from their provident funds to finance the remaining construction of houses.

- The ***Low-Income Housing Scheme of 1954*** had provided loans of upto 80 percent of the construction cost of a dwelling unit (subject to a cap of Rs.8,000) to individuals whose incomes did not exceed Rs.6,000 per annum. Loans under the scheme were also made accessible to non-profit organizations, educational institutions, and hospitals, to create rental or hire-purchase housing stock for their low-income employees.

- ***The Slum Clearance and Improvement Programme of 1956 -*** The programme was designed to rehabilitate slum dwellers at nominal rents into housing stock created by the Government. The recipients were provided either a bare minimal structure or an open developed plot around the size of 1000-1200 square feet with a toilet facility. The remaining construction was to be undertaken by prospective beneficiaries, with the use of limited building materials that were provided to them by the government on the basis of specific guidelines.

- ***Village Housing Project Scheme (1957) -*** The first housing programme for rural areas, namely, the village housing projects scheme was initiated by the central government. It was introduced as a part of the total rural reconstruction programmes. The scheme was aimed at rebuilding or substantially improving the 54 million houses in rural areas. The landless agriculture labour was given housing sites either free of cost or at a nominal price. The loans were also extended to construct houses through self-help process and expected to use locally available materials. Monetary assistance was given to the extent of 80 percent of the construction cost subject to a maximum of Rs.4000/- per house. Over 11 million workers were provided sites under this programme. The scheme was integrated with provision of amenities under rural development employment scheme. Unfortunately, the programme could not achieve the anticipated results.

- ***Land Acquisition and Development Scheme (1959)*** - The scheme was introduced to encourage the large-scale acquisition and distribution of plots to various income groups. This was primarily taken up by state housing boards and local development authorities and often the agencies themselves constructed houses on the acquired land.

These initial programmes did not result in significant benefits to the beneficiaries as envisaged. This was especially true of the Slum Clearance and Improvement scheme; whose locations were far from the City Centre and places of employment and livelihood of the beneficiaries. In many cases, the beneficiaries were not even in the position to pay the nominal rents.

- **Housing Programmes in the 1970s to 1990s**

- ***Schemes for Provision of Housing Sites to Landless Workers in Rural Areas (1971)*** - Allotment of housing sites cum construction assistance scheme was introduced in the central sector to provide housing sites to landless agriculture workers including SCs and STs free of cost. The objectives of the scheme were to provide free housing sites of 100 sq.yards to eligible agriculture landless workers in rural areas and assistance of Rs 250 per site, which was later increased to Rs 500 for development of sites per family and construction assistance of Rs 2000 per family.

- ***Minimum Needs Programme*** - Under this programme, highest priority was given to the rural housing sites and construction assistance to rural landless workers and artisans including scheduled castes, scheduled tribes. The scheme was earlier part of central sector scheme and was later transferred to state sector in 1974. The maximum size of housing site allotted was to be 100 sq. yards. The scheme also envisaged provisions of infrastructural facilities like access to roads, drinking water, and wells.

- ***One Lakh Housing Schemes (OLHS)*** - One of the most important efforts in serving the rural poor has been the one lakh housing schemes (OLHS), which was implemented during 1972-76. Developed housing plots were to be given free to eligible beneficiary through grants from the central govt. and, additionally, the state government decided to give a house practically free of cost. Each family had to pay only Rs 100 towards a house built at a cost of between Rs. 1250 to Rs 1500. Besides the governmental grants, efforts were made to mobilize the resources from public at large through donations. About 60,000 houses were completed over a period of about 5 years, averaging about 12,000 units per annum.

- ***Subsidies Aimed at Self Help Housing Schemes (SASH)*** - The scheme was based on the feedback on a few schemes implemented earlier leading to the introduction of a totally new and path breaking scheme known as SASH, towards the end of 1983. Most important innovation was involving over 1200 voluntary agencies in the process of beneficiary selection, resource mobilization, loan disbursements and supervision of house construction. This helped to inculcate user participation in the entire process, eliminating the sense of alienation which was quite common when Government provided houses. Low cost housing was also introduced through Nirmithi Kendras which not only manufactured low cost materials but also disseminated the knowledge by running training programme for artisans.

- ***Indira Awas Yojana (IAY)*** - Indira Awas Yojana was introduced for construction of low cost houses for the poorest of the poor belonging to the scheduled castes and scheduled tribes and indentured labourers in rural areas. The scheme was fully funded by the central government with the genesis on rural employment which began in the early 1980's where construction of houses was one of the major activities under the National Rural Employment Programme (NREP) launched in 1980 and Rural Landless Employment guarantee programme launched in 1983. The scheme operated as 100% subsidized centrally sponsored independent programme with the resources being shared on **80:20** basis by the central and state Governments. At the district level Indira Awas Yojana funds were operated by the district rural agencies, Zilla Parishads (ZPs). The Indira Awas Yojana was suitably modified later into two components for ease of implementation, (1) construction of new houses and (2) upgradation of kutcha houses. The State Government was allowed flexibility to utilize the funds either in upgradation or new construction depending upon the requirement.

- *Credit-cum-Subsidy Scheme (CCSS) for Rural Housing* - The Credit-Cum-Subsidy-Scheme for Rural Housing was launched in April, 1999. The Scheme targeted rural families having annual income up to Rs.32,000. While subsidy was restricted to Rs.10,000, the maximum loan amount that could be availed was Rs.40,000. The subsidy component was shared by the Centre and the State in 75:25 ratio. The loan component was to be disbursed by the commercial banks/Regional Rural Banks, Housing Finance Institutions etc. Since inception of the scheme, up to 2001-2002, against the central allocation of Rs.288.00 crore, about 86 thousand houses were constructed by incurring an expenditure of approximately Rs.78 crore. From the year 2002- 2003, the Central allocation under IAY and CCSS were combined.

- *The National Slum Development Programme (NSDP)* - To financially consolidate an integrated approach to tackle the multiple dimensions of poverty, the programme was launched in 1997 by combining the housing component of Nehru Rojgar Yojana and the Prime Minister's Integrated Urban Poverty Eradication Programme. The emphasis was on the provision of not only essential amenities involved in the upgradation of shelter but also social services such as skills enhancement.

- *Two Million Housing Programme* - In line with the National agenda for Governance identifying housing as a priority area, the government launched the 2 million Housing Programme in 1998. The programme envisaged provision of 20 lakh houses every year - 13 lakh houses in the rural areas and 7 lakh houses in the urban areas, with special emphasis on the low-income group and the economically weaker sections. HUDCO, a premier public sector techno-financing institution of the country, was assigned an annual target of facilitating 1 million units in rural areas. The cooperative sector and other housing finance institutions took up balance one million housing units in the rural and urban areas.

  HUDCO alone supported 4.11 million housing units against the assigned target during the period 1998-2002. This includes financial assistance to 1.76 million units in the urban areas and 2.35 million units in the rural areas. The Two million Housing programme was identified as one among the 100 best practices for the year 2002 by UN Habitat.

• **Housing Schemes in the 21st Century**

- **The Jawaharlal Nehru National**

Urban Renewal Mission (JNNURM) - Launched in December 2005, the JNNURM aims at a reform-driven, planned developmental transformation of India's urban areas. The Mission acknowledges the responsibility entrusted upon cities to act as the primary agent, engine and catalyst in the process of sustainable growth and development. Accordingly, it aspires to create *economically productive, efficient, equitable and responsive cities*.

The JNNURM had two sub-missions namely, ***Basic Services for the Urban Poor (BSUP)*** - the BSUP is designed for the upgrade and improvement of the conditions of slum settlements, assuring universal access to basic amenities such as water and sanitation, and social infrastructure such as health, education and social security. The BSUP covered 65 cities and towns (a) 7 cities having 4 million plus population as per the 2001 Census. (b) 28 cities having 1 million, but less than 4 million populations. (c) 30 selected cities of religious/historic and tourist importance.

- ***Integrated Housing and Slum Development Programme (IHSDP)*** - IHSDP sought to tackle the problem of housing for poor urban slum dwellers in cities and towns as per the 2001 Census, excluding those which were being targeted under BSUP.

- **Rajiv Awas Yojana (RAY)**. With the motto, "Slum Free India", the scheme was launched in June 2011. The motivation underlying the programme acknowledged the failure of the market and the government to secure the rights of the urban poor to a decent and dignified life. The RAY aimed to provide affordable housing with basic municipal services. Through the scheme, the government intended to circumvent the forces that are responsible for the failure of the market and the government in accommodating the housing and other basic needs of the urban poor. It is hoped that this preventive strategy will retard any further slum proliferation. The scheme also emphasizes the need to bring informal settlements within the coverage of the formal economy. The RAY strategy was two-pronged: the first component involved slum redevelopment, preferably in-situ redevelopment, of existing slums, while the second sought to make provisions that curb future creation of slums. The Affordable Housing in Partnership (AHP) was also introduced as the second component of the RAY to enable Public Private Partnerships in making provision for affordable housing stock - both on rental and ownership basis.

Both the JNNURM and RAY schemes have been criticized for the poor quality of the houses; in some instances, they have been worse than their habitation in the slums, even in size. Moreover, the housing projects have been located in areas lacking trunk infrastructure. Many beneficiaries face lack of electricity, water supply, sewerage and solid waste management. Often, open spaces around the newly constructed houses are reduced to serving as garbage dumps. Houses have structural defects as well (e.g., damp indoor walls, leaky ceilings). In some cases, houses have been constructed in areas distant from livelihood and income earning opportunities with inadequate provision of public transport. As a result, much of the housing stock created under the government schemes remains vacant.

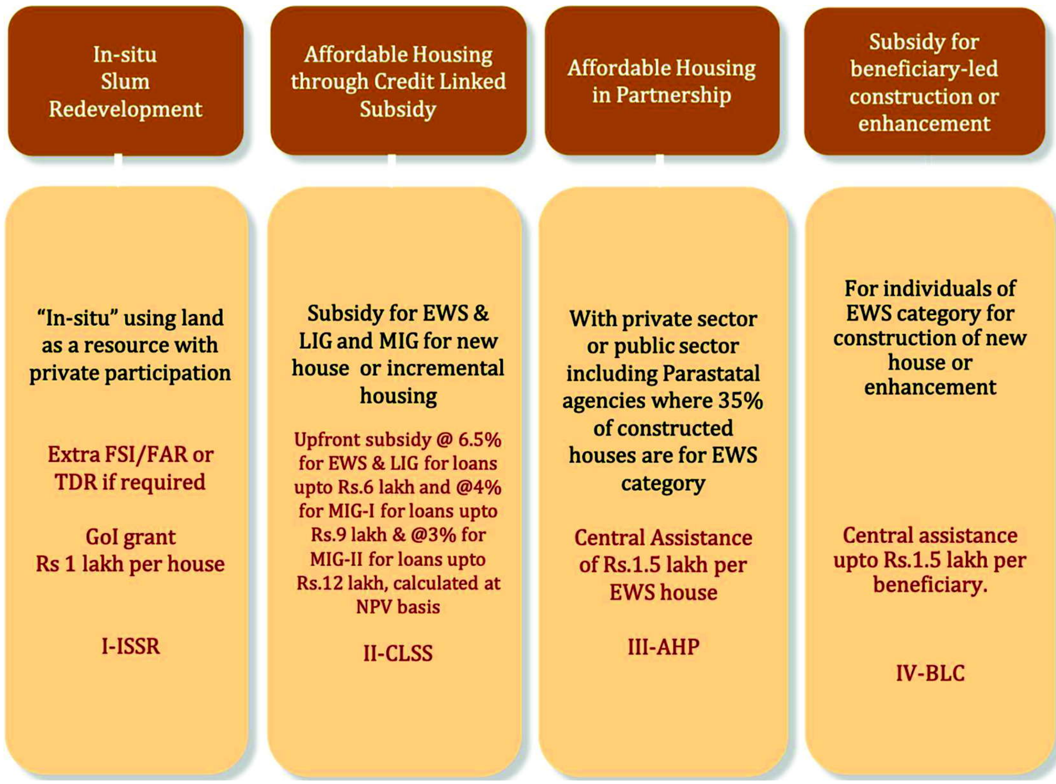
It may be argued that both JNNURM and RAY have enabled cities to respond to the housing shortage by creating affordable houses. However, creating new houses cannot come at the cost of lost employment or low quality of living, because these are the ends for which housing is the means. To be sure, it might also be noted that a larger proportion of the housing created under these schemes has been occupied. To that extent, these schemes may be regarded as successful. Before claiming success, however, it must be understood that these schemes have only housed existing slum dwellers, while having done nothing to combat the process of slum proliferation.

- **Pradhan Mantri Awas Yojana (PMAY)** – With the overall vision of Housing for All, PMAY (Urban) and PMAY (Gramin) were launched by the government in June 2015 and April 2016 respectively and are in operation as on date.

- ***Pradhan Mantri Awas Yojana – Urban (PMAY-U)***

PMAY (Urban) aspires to eliminate urban housing shortage in India by the year 2022. The mission supports construction of houses upto 30 square meter carpet area with basic civic infrastructure. States/UTs are given flexibility in terms of determining the size of house and other facilities at the state level in consultation. Slum redevelopment projects and Affordable Housing projects in partnership should have basic civic infrastructure like water, sanitation, sewerage, road, electricity etc. ULB should ensure that individual houses under credit linked interest subsidy and beneficiary led construction should also have provision for these basic civic services.

The Mission is being implemented through four verticals giving option to beneficiaries, ULBs and State Governments. These four verticals are as shown in **Figure 2.2.**



Source: PMAY(U) Guidelines, MoHUA

Figure 2.2: Implementation of PMAY(U)

Initially the demand set up by State Governments was of the tune of 20 million which was later modified to 11.2 million based on actual demand survey by respective State Governments/UTs. Till August 2022, 122.69 lakh houses have been sanctioned to State Governments out of which 103.52 lakhs houses are grounded and 62.43 lakhs houses are completed under EWS and LIG categories. It is pertinent to mention here that more than 15 lakh houses are being constructed using new emerging housing technologies. **Table 2.4** gives the summary of physical and financial progress under PMAY(U), while **Annexure 2.2** gives the state-wise details of physical and financial progress.

Table 2.3: Physical and Financial Progress under PMAY(U)

[as in August 2022]

Sr. No.	Particulars	Credit Linked Subsidy Scheme (CLSS)	(In-situ Slum Redevelopment (ISSR)	Affordable Housing in Partnership (AHP)	Beneficiary Led Construction (BLC)	Achievement under PMAY (U)
1	City/Town Covered	6,958	162	981	4,332	7,570
2	Project(s) Approved	-	327	2,284	24,746	27,357
3	Investment (Central, State & Beneficiary) (Rs in Cr)	3,51,497.82	16,786.08	1,87,466.65	2,69,031.37	8,24,781.92
4	Central Assistance Sanctioned (Rs in Cr)	55,095.00	6,520.82	31,212.15	1,08,516.69	2,01,344.66
5	Central Assistance Released (Rs in Cr)	48,095.00	2,591.99	11,873.86	57,931.80	1,20,492.65
6	Houses Sanctioned	23,96,864	4,33,334	20,63,162	72,36,792	1,21,30,152
7	Houses Grounded for Construction *	20,76,864	6,42,118	13,64,152	62,69,142	1,03,52,276
8	Constructions of Houses Completed / Delivered *	20,76,864	4,90,260	6,90,713	29,84,742	62,42,579

- ***Pradhan Mantri Awas Yojana - Gramin (PMAY-G)***

  PMAY-G aims to provide a pucca house with basic amenities to all houseless households and households living in kutcha and dilapidated house in rural areas by 2022. The objective is to cover households in rural areas, that are houseless or living in kutcha / dilapidated house and enable construction of quality houses by the beneficiaries using local materials, designs and trained masons. For houses to become homes, adoption of a habitat approach through convergence is proposed.

  The key feature of PMAY-G is:

- The minimum unit (house) size enhanced from 20 sq.m (under lAY) to 25 sq.m including a dedicated area for hygienic cooking.

- Enhancement of unit assistance from Rs. 70,000 to Rs. 1.20 lakh in plains and from Rs 75,000 to Rs.1.30 lakh in hilly states, difficult areas and lAP districts.

- The cost of unit (house) assistance is to be shared between Central and State Governments in the ratio 60:40 in plain areas and 90:10 for North Eastern and 3 Himalayan States (Jammu & Kashmir, Himachal Pradesh and Uttarakhand).
- Provision of assistance (Rs.12,000/-) for toilets through convergence with Swacch Bharat Mission - Gramin (SBM-G), MGNREGS or any other dedicated source of funding.
- Provision of 90/95 person days of un-skilled labour wage under MGNREGA for construction of house, over and above the unit assistance.
- Identification and selection of beneficiaries, based on the housing deficiency and other social deprivation parameters in SECC-2011 data, and verified by the Gram Sabhas.
- Setting up of National Technical Support Agency (NTSA) at national level to provide technical support in achieving the target set under the programme. The beneficiaries of PMAY-G, in addition to being provided financial assistance, shall also be offered technical assistance in the construction of the house.
- If the beneficiary so chooses, he/she will be facilitated to avail loan of upto Rs.70,000/- from Financial Institutions.
- Special Projects to be sanctioned by the Ministry of Rural Development after the approval of the Empowered Committee.
- Convergence with other Government schemes for provision of basic amenities viz., toilet, drinking water, electricity, clean & efficient cooking fuel, treatment of social and liquid waste etc.
- All payments to the beneficiary to be made electronically to their Bank/ Post office accounts that are linked to Adhaar with consent.
- Sensitization of the beneficiaries on PMAY-G.
- Focus on construction of quality houses by the beneficiaries using local materials, appropriate designs and trained masons.
- Adoption of saturation approach using Gram Panchayat, Block or District as unit, wherever possible.

The target number of houses to be constructed by the 2021-22 was 29.5 million as per PMAY-G Guidelines and the immediate objective was to provide 1 crore houses to the houseless and living in kutcha and dilapidated houses in 3 years, i.e. from 2016 to 2019. By the end of January 2019, nearly 1.25 crore houses were constructed under the scheme. In February 2019, the Cabinet has redefined target for PMAY-G to 1.95 crore houses under

PMAY-G Phase-II up to 2022. PMAY-G aims to provide pucca houses with basic amenities to houseless households and households living in kutcha and dilapidated houses in rural areas. As per the latest data, the target for PMAY-G is 262.34 lakhs. So far 173.84 lakhs houses have been completed. The state-wise break-up of targets and progress is shown in **Annexure 2.3**.

2.3.2 State Government Housing Schemes

Delhi Development Authority Housing Scheme, 2018

The Housing Scheme 2018 launched by the Delhi Development Authority (DDA) in December 2018 aimed at constructing 20,987 fresh units. Of these total units, 488 units were to be three-bedroom apartments for the high-income group (HIG); 579 units for the middle-income group; and 16,296 units for the low-income group (LIG) while 3,624 units were reserved for the economically-weaker section. These modern 1, 2 and 3 BHK houses, accompanied with amenities, were to be built across Vasant Kunj, Dwarka, Siraspur, Narela and Rohini area of Delhi. The scheme was linked to the CLSS component under PMAY(U).

Tamil Nadu Housing Board Scheme (TNHB)

The Tamil Nadu Housing Board (TNHB) developed into a full-fledged organisation in 1961 to fulfill the growing housing needs by providing shelter to people of various income groups. The board has launched three housing schemes at different locations - KK Nagar Division, Ambattur and MKB Nagar - for the sale of affordable housing units for lower income groups and middle-income groups.

Maharashtra Housing and Area Development Authority (MHADA), 2018

A lottery scheme by MHADA is launched every year wherein affordable homes are allotted for buyers from different income groups, based on lottery draw results. There are 1,000 units on offer, out of which 60 per cent are reserved for the poorer sections. These housing units will range in price between Rs 15.35 lakh and Rs 1.42 crore and will be available in various localities of Mumbai, namely, Borivli, Ghatkopar, Mulund, Mankhurd, Goregaon and Vikhroli.

NTR Urban Housing Scheme, 2017-18

The Andhra Pradesh government set a target of building 19 lakh houses. It had approved 1,02,977 houses under the NTR Urban Housing Scheme 2017-18. These houses were linked with the PMAY (Urban) scheme to secure subsidy from the centre for construction across 84 urban local bodies (ULBs) in Srikakulam, East Godavari, West Godavari, Krishna, Guntur, Prakasam, Nellore, Chittoor, Kadapa and Anantapur districts. Each house was to cost Rs 3.5 lakh with a central Governmental share of Rs 1.5 lakh and the state government share Rs 1 lakh. The beneficiaries would be given a loan worth Rs 75,000 and contribute only Rs 25,000. The objective of the state was to build 13,66,557 houses in rural areas and 5,39,286 houses in urban areas by investing a sum of Rs 56,000 crore.

2.4 Government Policies on Housing - Central and States

2.4.1 National Urban Housing and Habitat Policy 2007

Urban India is commonly characterized, besides housing shortages, by severe shortage of basic services like potable water, proper drainage system, sewerage network, sanitation facilities, electricity, roads and appropriate solid waste disposal. These shortages constitute the rationale for policy focus on housing and basic services in urban areas. This policy intends to promote sustainable development of habitat in the country to ensure equitable supply of land, shelter and services at affordable prices to all sections of society. Given the magnitude of the housing shortage and budgetary constraints of both the Central and State Governments, it is amply clear that Public Sector efforts will not suffice in fulfilling the housing demand. In view of this scenario, the National Urban Housing and Habitat Policy 2007, focuses the spotlight on multiple stake-holders namely, the Private Sector, the Cooperative Sector, the Industrial Sector for labour housing and the Services/ Institutional Sector for employee housing. Further, Policy seeks to promote various types of public-private partnerships for realizing the goal of Affordable Housing for All.

The National Urban Housing and Habitat Policy aimed at (a) *Urban Planning* - Encouraging State Governments, Urban Local Bodies, Development Authorities to periodically update their Master Plans and Zoning Plans which should, inter-alia adequately provide for housing and basic services for the urban poor; (b) *Increase Supply of Land* - Facilitating accessibility to serviced land and housing with focus on economically weaker sections and low income group categories; (c) *Special Provision for Women* - Involving women at all levels of decision making for ensuring their participation in formulation and implementation of housing policies and programmes; (d) *Employment Generation* - Up-gradation of construction skills and accelerated development of housing and infrastructure sectors for giving an impetus to employment generation; (e) *Management Information System* - Establishing a Management Information System (MIS) in the Housing Sector for strengthening monitoring of building activities in the country.

2.4.2 Policies of State Governments

Madhya Pradesh Housing & Habitat Policy-2007

Provisions were made in the Madhya

Pradesh Housing and Habitat Policy - 2007 to seek participation of private and corporate sectors to meet the requirement of social housing in the State. In addition, provisions were to make available government land to construction agencies at concessional rates for development of low-rise and low-density habitations in a radius of 30 kilometers to reduce the pressure of population in big cities of the state. The state adopted a multi-dimensional approach by focusing on slum development, infrastructure, and land development. Additional FSI was made available for redevelopment in slum areas. Further, 30% plots/houses developed by Urban Development Authorities/Housing Board were for the poor. MP is the only state to regularize tenure of squatters on government land through a specific State Act - Patta Act (MP Nagariyon Kshetrake Bhumiheen Vyakti Adhiniyam, 1984)

Rajasthan Affordable Housing Policy-2009

The Rajasthan government launched the affordable housing policy-2009 which aimed to build 1.25 lakh houses for the low income and economically weaker sections of the state. Applicants under EWS and LIG categories were expected to get a house in Rs 2.40 lakh and Rs 3.75 lakh respectively. Private housing developers would also be included in the policy. The policy had the following objectives:

1. To reduce the housing shortage in the State, especially in EWS/LIG categories.
2. To take up large scale construction of Affordable Housing (with focus on EWS & LIG housing.
3. To bring down the cost of EWS & LIG categories of houses to affordable limits.
4. To promote investments in housing in Urban Sector on PPP Model.
5. To involve Private developers in the construction of EWS/LIG categories of houses by offering various attractive incentives.
6. To create Rental Housing as transit accommodation for migrants to urban areas,
7. To check creation of slums.

Kerala State Housing Policy- 2011

Taking stock of experiences from the housing programmes as well as focusing on the growth trends of the socio-economic fabric of the society, the Kerala State Housing Policy envisaged the promotion of sustainable development of the habitat with the objective to ensure adequate and affordable housing for all, ensuring supply of quality basic services with integrated livelihood mechanisms and special focus on the needs of the poor, marginalised and disadvantaged on a rights based framework for the accomplishment of "Adequate and Affordable Housing for All" in sustainable habitat mode, facilitating inclusive growth. The major salient features of the Policy were:

(i) Creation of adequate and affordable housing stock on ownership and rental basis on a right based framework.

(ii) Meeting the special needs of SC/ST/ disabled/fishermen/traditionally employed labourers / slum dwellers, elderly women, street vendors and other weaker and vulnerable sections of the society.

(iii) Facilitating accelerated supply of serviced land and housing with particular focus to EWS and LIG categories

(iv) Facilitating all dwelling units to have easy accessibility to basic services of sanitation, drinking water, power, waste disposal and social infrastructural facilities like education, health and transport.

(v) Skill upgradation programmes enabling the workers to move up the wage chain in employment.

Gujarat Mukhya Mantri Housing Scheme-2014

Mukhya Mantri Housing Scheme was announced to make urban area slum free for providing housing at reasonable price to poor, lower and middle income group urban families. The State aimed to involve both public institutions as well as private developers in such projects. The state government planned to construct 50 lakh houses in five years out of which 22 lakh houses were planned in urban area. As part of this scheme, beneficiaries who fell under EWS/LIG I and II and MIG I were to get well planned houses having basic civic amenities at affordable price.

Assam Urban Affordable Housing & Habitat Policy-2015

The policy envisaged creation of an enabling environment for providing "affordable housing for all" with special emphasis on EWS and LIG and other vulnerable sections of society such as Scheduled castes/Scheduled Tribes, Backward Classes, Minorities and senior citizens, physically challenged persons in the State and to ensure that no individual is left shelter less. The Policy further aimed to promote Public Private People Participation (PPPP) for addressing the shortage of adequate and affordable housing.

New Maharashtra State Housing Policy & Action Plan-2015

With the overall objective of "Housing for all", the policy had the following major features:

1. Continuous creation of land bank for affordable housing by using both Government lands as well as lands belonging to the private sector.

2. Increase in supply of affordable housing in the market leading to reduction in price to the consumer.

3. Optimum use of existing land resource by encouraging redevelopment.
4. Improving quality of life, overall living standards with due concern for environment.
5. Ease of doing business

The new housing policy, set a target to create 11 lakh homes in the Mumbai Metropolitan Region (MMR) and 8 lakh homes outside MMR by 2022.

Delhi Land Pooling Policy (Delhi LLP)

Delhi Land Pooling Policy (Delhi LPP) is a welcome step towards expediting the urban development and is a landmark policy. It has potential to create millions of square feet of development, across 5 zones and 95 villages, in residential/commercial/public/and semi-public categories by means of public private participation. In addition to encouraging PPP Model, Delhi LPP also includes promising features such as tradable FAR and single window clearance mechanism. Land Pooling Policy (LPP) is an assembly of small rural lands being converted into large parcels through readjustment. The infrastructure development is planned on this large land with around 60% of the land given back to the land owners which makes it a very fair proposition. In the new (and liberalized) land policy, DDA has enabled developer entities to directly acquire land from farmers or landowners through partnership in place of forceful acquisition. In a nutshell, a number of small holdings of land are pooled together. 40% of the pooled land is utilized for developing physical & social infrastructure, and the remaining 40% land is returned to the original owners with licences/development rights, post fulfillment of eligibility criteria.

2.5 Housing Sector Supply Initiatives

Housing being one of the catalyst for prosperity of the country, there are innumerable agencies both public as well as private, dedicated to deliver variety of houses including affordable houses. Historically, apart from central and state governments and their bodies, real estate sector and lending institutions are also contributing towards creation of variety of housing stock including affordable housing.

Apart from Central Government agencies, the State Governments through their PWDs, Public undertakings, Housing Boards and City Improvement Trusts, Urban Local Bodies are also involved in public housing. In the Central Sector, Central Construction Agencies such as CPWD, Central Public Undertakings, Military Engineering Services, Post and Telegraphs and Railways are involved. In addition to these, massive housing schemes are implemented through financial support by Housing and Urban Development Corporation (HUDCO), National Co-operative Housing Federation, and public institutions such as LIC, GIC and Banking sector which contribute through promotion of loans and advances to the employees and the promotion of the Co-operative Sector. The recent spurt in the construction of affordable housing is being triggered by the provisions of adequate finances by National Housing Bank, RBI, Commercial Banks in the private sector, corporations like HDFC and specialized institutions set up by Nationalized Banks. State Governments are also running specific programmes and policies in the public and private sectors.

As per estimate, the affordable housing projects by private developers have contributed to the extent of 25 percent decline in urban housing shortage in the last five years. Although, the urban housing shortage remains substantial, it is clear that active participation from private developers could help in tackling the urban housing shortage in India. However, affordable housing development continues to be a challenging proposition for developers and further policies need to be formulated by the Government to encourage greater participation from the private sector in the form of technological solutions, project financing and project delivery.

In order to provide affordable housing, various stakeholders, such as the Central Government, State Governments, real estate and infrastructure developers, financial institutions, urban planners and, most importantly, beneficiaries have to work together. In this context, while the role of financing and leveraging has caught enough attention from policy makers, the role of private sector is also to be encouraged. In an ideal PPP scenario, the public sector could look into aggregating land for projects, providing single-window and time-bound clearances, redrafting the local development bye-laws to suit the requirements of affordable housing projects and re-evaluating the taxes and levies from the perspective of reducing cost of home ownership for the target segment. Private sector entities can leverage core competencies such as planning & design, project development, technology best practices, project financing, human resources, sales and marketing.

2.5.1 Real Estate Industry–(Developers–RERA Act)

Real estate industry is often driven by the home owners who invest their life time savings to buy a property and thereby creating an asset. Real estate sector has also been a profitable proposition for investors, developers, corporate occupiers and consumers. These constitutes the major stakeholders for the real estate industry.

Investors

Investors generally invest directly in real estate. Investing directly in real estate involves purchasing residential or commercial property to use as an income-producing asset or for re-sale at a future time. Interest rates, demographics, general economic conditions and government policies influence real estate investors.

Developers

Developers play a key role in the real estate sector by bridging the gap between the construction facility and the consumer's need and offer value in terms of design, cost, functionality, and location. Real estate developers build for commercial and residential purposes. Recently affordable housing is also becoming prime focus of most developers, to fulfil the needs of the common man.

Corporate occupiers

Corporate occupiers in India continue to be focused on connectivity, accessibility, and overall infrastructure quality. A key challenge for developers is to build properties at competitive prices, in areas that are attractive to customers. In Indian real estate, foreign players are among the prominent corporate occupiers. As lifestyles in India changing rapidly, easy access to talent, low-cost real estate, a fast transition towards an organised space and a good location are what foreign corporate occupiers find the most appealing here.

Consumers

Like in all sectors of the economy, the customer is the king in real estate, too. He decides whether or not the venture of an investor or a developer will be successful. A buyer purchases a property when it meets his needs. To earn more profit, the developer needs to offer a better deal to the consumer.

The introduction of Real Estate Regulation Act (RERA) aims to protect the interests of buyers/consumers and bring in more transparency into the sector. It will make the operations of developers more transparent in an industry that was so far largely unregulated in India. The RERA also enables the consumer to approach the real estate regulator for a grievance redressal.

2.5.2 Post COVID-19 Initiatives

Post COVID-19, Government of India aims to promote economic activities aligned with the vision of "Atma Nirbhar Bharat". Moving forward, on 14th May, 2020, the Government of India announced development of Affordable Rental Housing Complexes (ARHCs) by Ministry of Housing and Urban Affairs. It will be run under Pradhan Mantri Awas Yojana – Urban (PMAY -U) for urban migrants/ poor. This initiative is being taken up for the first time in the country to improve their living conditions and obviate them from staying in slums, informal settlements or peri-urban areas.

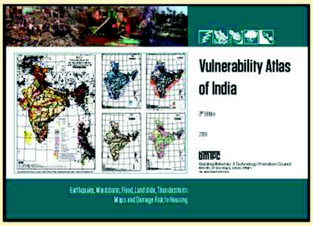
ARHCs aim at creating vibrant, sustainable and inclusive affordable rental housing avenues for urban migrants/ poor by 'aggregation of their demand at a given site'. These ARHCs will provide them dignified living with all civic amenities in proximity to their work place by:

1. Utilizing existing Government funded vacant houses in cities by converting them into ARHCs under Public Private Partnership (PPP) mode or by Public agencies as a Centrally Sponsored Scheme.

2. Construction, Operation and Maintenance of Affordable Rental Housing Complexes by Public/ Private Entities on their own vacant land as a Central Sector Scheme.

Also, in order to check the reverse migration which was realized in the wake of COVID-19, the Ministry of Housing and Urban Affairs is contemplating policy level interventions to provide onsite housing facilities for construction workers during construction which can later be converted to permanent housing for urban poor and maintenance/domestic workers and security persons in future projects.

CONCEPTS & TECHNOLOGIES FOR HOUSING



Vulnerability Atlas of India

3rd Edition, 2019

A Tool to natural disaster prevention, preparedness and mitigation for housing and related infrastructure

Vulnerability Atlas of India - Third Edition

The third edition of Vulnerability Atlas of India is collation of the existing hazard scenario for the entire country and presents the digitized State/UT-wise Hazard Maps with respect to Earthquakes, Winds & Floods for district-wise identification of vulnerable areas.

In addition, this version contains digitized maps for Thunderstorms, Cyclones and Landslides.

The Atlas also presents the district-wise Housing Vulnerability Tables based on wall types and roof types as per 2011 Census Housing data for earthquake, wind, flood hazards.

The Atlas is a useful tool not only for public but also for Urban Managers, State & National Authorities dealing with disaster mitigation and management.

Digital version Available on:

http://www.bmtpc.org

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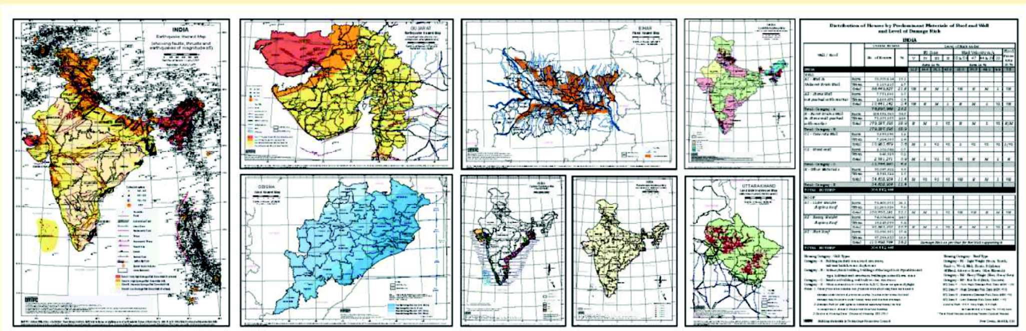


3. CONCEPTS & TECHNOLOGIES FOR HOUSING

3.1 Housing Typology and Categorization in India

India being a vast country having different geo-climatic regions, varying demography and multi-hazard zones, has different types of housing based on local materials and local skills. However, with the advancement in the area of building materials, the traditional housing types are being replaced slowly by masonry construction and RCC framed construction both in rural and urban areas. With the increasing demand of housing, especially in urban areas, emerging construction systems based on prefabrication and precast technologies are being preferred.

As per the Census of Housing 2011, the existing housing stock both in urban and rural areas are divided based on materials of construction for walls and roofs as follows:

a) Type of Roof:

i) Pitched or sloping roof using tiles, stone/slate; corrugated iron, zinc or other metal sheets, asbestos cement sheets, plastic polythene, thatch, grass, leaves, and bamboo, etc.

ii) Flat roof using brick, stone and lime, reinforced brick, and, concrete/reinforced cement concrete.

b) Type of Wall:

i) Mud, unburnt bricks, stone packed and not packed with mortar

ii) Burnt bricks laid in cement, lime or mud mortar

iii) Cement concrete

iv) Wood or Ekra

v) Corrugated iron, zinc or other metal sheets

vi) Grass, leaves, reeds or bamboo or thatch, plastic polythene and others

c) Type of Flooring:

Various types like, mud, stone, concrete, wood or bamboo, mosaic floor, tiles, etc.

Based on the wall and roof types, BMTPC in its Vulnerability Atlas of India 2019 appropriately categorised the housing in India as follows.

Based on Types of Wall

Category – A : Buildings in field-stone, rural structures, unburnt brick houses, clay houses

Category – B : Ordinary brick building; buildings of the large block and prefabricated type, half- timbered structures, building in natural hewn stone

Category – C : Reinforced building, well-built wooden structures

Category – X : Other materials not covered in A, B and C. These are generally light structures.

Based on Types of Roof

Category - R1 : Light Weight (Grass, Thatch, Bamboo, Wood, Mud, Plastic,

Polythene, GI Metal, Asbestos Sheets, Other Materials)

Category - R2 : Heavy Weight (Tiles, Stone/Slate)

Category - R3 : Flat Roof (Brick, Stone, Concrete)

The housing distribution with wall and roof composition as was recorded in Census of 2001 and 2011 is given in the **Table 3.1**, while the details with division into rural and urban housing stock are given in **Annexure 3.1**.

Table 3.1: Housing Distribution based on the Categories

Wall / Roof	2001 Census Houses		2011 Census Houses	
	No. of Houses	%	No. of Houses	%
WALL				
Category - A	7,37,99,162	30	7,68,90,969	25
Category - B	13,73,73,446	55	17,95,87,595	59
Category - C	97,37,330	4	1,37,64,950	5
Category - X	2,81,85,931	11	3,46,38,934	11
TOTAL BUILDING UNITS	**24,90,95,869**		**30,48,82,448**	
ROOF				
Category R1	8,66,92,658	34.8	10,07,00,181	33.1
Category R2	7,83,35,630	31.4	9,36,83,503	30.7
Category R3	8,40,67,581	33.7	11,04,98,764	36
TOTAL BUILDING UNITS	**24,90,95,869**		**30,48,82,448***	

3.2 Housing Design, Construction and Materials

3.2.1 Rural Housing

Rural housing is greatly influenced by the vernacular architecture, traditional practices, local building materials and local skills available, but is mostly non-engineered. In places where stone is available in abundance such as in Rajasthan, Gujarat and hilly areas like Himachal Pradesh, houses are constructed with stone walls and roof comprising of stone slab and slate etc. Bricks and tiles made out of local earth, are commonly seen in the rural houses of Uttar Pradesh, Madhya Pradesh, West Bengal, Bihar, Punjab, Karnataka, Tamil Nadu and Kerala. Timber and bamboo being available in plenty in the North Eastern States of Assam, Meghalaya, Tripura, Nagaland, Mizoram, Arunachal Pradesh and Manipur are liberally used for construction of houses in these states. The typical characteristics of rural housing in India are as follows:

- Houses in rural setup are designed to meet the essential and functional requirement of the households. Typically, two to three rooms with open space for kitchen and a courtyard in front are the characteristics of the layout for a rural house. Affluent people can afford a central courtyard also in addition to the front and back courtyard. A fair sized courtyard in front and more at the back is a common feature in rural homes where households carry out major production activities including daily activities like dairy, poultry and laying of kitchen gardens etc.
- Rural houses also have adequate provisions for storing agriculture produce, fodder, implements, fuel and other paraphernalia depending on the occupation and trade requirements, e.g., weaver, carpenter, blacksmith, etc.
- The floor is invariably made of stone in most of the homes. However, floors in huts are finished with rammed earth and earth cow dung plaster.
- Pucca houses have small windows and ventilators, while the others have small skylights or ventilators near roof. Natural light is made available mainly through doors and courtyard. The houses of poor families are generally dark, damp, and ill ventilated and use partially enclosed area within or outside to serve as bathroom.
- Protected drinking water facilities and closed drainage are still scarce in remote villages. Most of the villagers depend on personal or community wells or local lakes for drinking water.
- Houses of families, who can afford it financially, have sanitary latrines connected to septic tanks or leach pits. These are located away from

main house to prevent contamination of ground water source.

- Garbage generated by the family is disposed off into pits for ultimate use as manure in the fields. In the houses of farmers, cattle waste is also used in bio-gas plants to generate fuel and rich manure. Waste water from the kitchen and bathroom is diverted to the kitchen gardens.
- The houses are designed to provide for future expansion (in case of small rooms) as and when the need arises or availability of funds.
- However with the increase in education and economic status in villages, few of the houses are well planned to ensure privacy and good circulation and these have semblance to urban homes. These houses have provisions of toilet for proper sanitation to ensure hygiene.

3.2.2 Urban Housing

Urban housing is influenced by the size of its population, and industrial and commercial development. Urban areas have essential infrastructural facilities for healthy living such as protected water supply, electricity, and sewerage; and also the opportunities for education, employment and health. To meet the housing requirement of the ever-growing population, cities have been expanding both vertically and horizontally. With increasing industrialization, socio – economic changes are occurring on a large scale. Old patterns of society and family structure are undergoing great changes. The joint family system is breaking up and number of individual or nuclear families is on the increase. Thus, family units and households are increasing, which in turn demand more housing accommodation. Accordingly, cities are classified as class I, II and III based on the population, infra-structural growth and services. The typical urban housing has following characteristics:

- In any city or town, land-use pattern is controlled by municipality, town-planner or urban development departments, through statutory master plan or regional development plan with zoning regulations. Building byelaws and standards control the construction of buildings for various uses, to maintain an orderly development. The State Governments also make efforts to ensure better housing for economically weaker sections, low income groups and middle income groups of families through its group housing schemes.
- The type of housing in urban areas varies widely. There are row houses, bungalows and multi-storied apartments. Gated communities, Condominiums and suave housing societies are also in vogue with excellent amenities inside the premises.
- In urban areas the houses are mostly

strong and durable as these are constructed using sound engineering principles with RCC, bricks, cut stones, reinforced concrete depending on the life span of building.

- The older houses are big having more rooms, more open space around the house as compared to the modern houses which are more compact having living cum dining, kitchen cum storage, W.C. cum bath with little or no open space. The housing spaces also provide for the academic/professional pursuits and hobbies of the inmates.
- As per the socio-economic fabric, urban houses may have different rooms for different purposes like living, dining, bedrooms, bathrooms and kitchen having storage facilities by providing attics and built - in cupboards.
- In the cities, most of the houses or homes have water supply, drainage facilities, electricity and waste disposal management.
- Multi-storied apartments are common in cities due to scarcity of land and its high cost. These provide housing accommodation for low, middle and high-income categories. Most of the essential infrastructure services are provided to the public through public service departments.
- With the influx of migrating population, cities face the constraint of land scarcity and thus resulting in over-crowded settlements. The net result is a continual decline in the quality of life in urban areas.

3.3 Appropriate Technologies for Housing

The most commonly used building materials for construction are stone, stone aggregates, sand, cement, steel, aluminium, brick, timber, glass, plastics, ceramics, etc However, the lack of availability of these materials for the construction industry poses a problem for the housing sector. All these materials depend directly or indirectly, on a finite natural resource base which is fast depleting, and creating an imbalance in the demand and supply equation for materials.

The direct consequence of an increased demand would be the increasing price due to shortage of supply, leading to the increased cost of housing. The indirect consequence would be rapid and irrationally managed utilization of finite natural resources. Enhanced use of top fertile soil, use of timber for firing bricks, lime quarrying, surface working in stone belts etc. are some possible manifestations leading towards environmental degradation.

On the other hand, factory made materials such as cement, steel, aluminium etc. call for high energy inputs in an already power - starved economy. Greater demand would also be made on the transport networks for the purpose of transporting raw materials and finished products, thus enhancing the cost of a unit of output. Enhancing the supply of these conventional materials therefore would not always be feasible nor recommended under these circumstances.

Therefore, there is a need to adopt appropriate technologies either by upgradation of traditional technologies using local resources or applying modern construction materials and techniques with efficient inputs leading to economic solutions.

In the context of the large volume of housing to be constructed in both rural and urban areas, the consideration of limitations in the availability of resources such as building materials, besides skilled/experienced manpower and finance has become the most relevant aspect.

Market forces are consequently creating demand for cost-effective technologies. However, the alternate technologies and materials are not widely accepted in the construction sector and require enabling eco-system for their mainstreaming.

Cost-effective, energy-efficient, environment-friendly (EEEF) building materials and construction technologies developed by the various research and development bodies in the country, namely Central Building Research Institute (CBRI), Structural Engineering Research Centre (SERC), Centre for Application of Science and Technology to Rural Areas (CASTRA), Regional Research Laboratories (RRL), National Environmental Engineering Research Institute (NEERI), Building Materials & Technology Promotion Council (BMTPC) and many others are time-tested, proven and readily available. These technologies have proved to be appropriate and viable in the context of low-income housing delivery and being used in many regions of the country. Some of the appropriate technologies for walling material, roofing types, doors and windows and other elements are discussed below.

- **Walling Materials**

Walls being a major component of housing, can be constructed in variety of ways depending upon the designs for housing units, i.e. single to multi-storied, local situation, i.e. rural, urban and metropolitan, and the needs of the target groups. Mud walls to rammed earth, masonry construction to pre-finished dry wall construction, the walls have under gone phenomenal changes over the years. The major materials used for walling can be, Mud, Sun-dried bricks, Rammed earth, Stabilized soil blocks, Kiln-burnt brick. Laterite/stone, Timber/ bamboo, Stone block masonry, Concrete hollow blocks, Ferro-cement. Besides these, Precast/factory-made walling units made from light weight cellular concrete, EPS core panel, cement fibre boards, PPGI sheets, PUF, MGO boards, Aerated concrete panels, hollow core panels, etc., can also be used.

Some of the prevalent walling construction systems in different parts of the country for both urban and rural applications are listed below, and, are described in brief in **Annexure 3.2**. It may be noted that though these are in use for building houses, these are not meant for application in mass industrialised housing. Although many of these systems are well known and established for long, and, their details are available in relevant literature, these are covered here in brief for ready reference and for completeness.

i) Rat Trap Bond

ii) Staggered Masonry System

iii) Precast Stone Block Masonry System

iv) Hollow concrete Block Masonry System

v) Confined masonry system

vi) Ashlar Masonry System

vii) Random rubble masonry system

viii) Rammed earth system

ix) Compressed earth block masonry system

x) Fly Ash Bricks

xi) Other walling systems particularly relevant for Rural Housing are:

- ❖ Bamboo strip walling
- ❖ Kath-kuni Walling
- ❖ Dhajji-diwari walling system

- **Roofing materials**

Cast-in-situ reinforced cement concrete (RCC) roofing slabs are predominantly used in most of the housing projects across India and more so in the urban context. But the use of the many economic alternatives can play a major role in large housing projects. The various alternative systems that can be used are:

- ❖ Clay/micro-concrete tiled roofing with insulation over timber/ferro-cement rafters
- ❖ Stone roofing with distributors
- ❖ Terraces with insulation - Madras Terrace
- ❖ Corrugated sheet: asbestos, galvanized iron (GI) and asphaltic
- ❖ Prefabricated brick panel
- ❖ 'L' panel roofing
- ❖ Filler slab roofing with various filler material
- ❖ Clay tile - RCC batten roof
- ❖ Precast cellular concrete roofing unit
- ❖ RCC channel units
- ❖ Precast joist and hollow block construction
- ❖ Precast RCC solid planks/joists

- ❖ Funicular shells over edge beams
- ❖ Precast plate floors
- ❖ Ferro-cement roofing elements
- ❖ Precast hollow core floor slabs
- ❖ Composite deck slabs

Using prefabricated roofing elements, large-scale housing can be constructed economically. There are many successful applications of these systems in different parts of the country.

Some of the prevalent roofing materials in different parts of the country for both urban and rural applications are described in brief in **Annexure 3.3**. Although many of these systems are well known and established for long, and, their details are available in relevant literature, these are covered here in brief for ready reference and for completeness.

- **Doors and windows**

Timber has been used traditionally used for door and window frames and shutters. However, time has come to look for alternatives to timber. The use of shaped steel frames as well as precast concrete and magnesium oxy-chloride cement door and window frames are becoming increasingly popular. Precast concrete door/window frames are competitive in cost and function and do not need repetitive maintenance. These are widely accepted both by the public and private house builders. These of precast door and window frames as well as ferro-cement doors and shutters are also gaining considerable popularity in the housing scenario in the country. Use of alternatives like cement bonded particle boards or bamboo boards are becoming popular for door shutters in many regions.

- **Other Elements**

Just as in case of doors and windows, the alternate precast elements can be used appropriately for other areas of application in housing reducing the cost. Some of the various possibilities are as follows:

- Thin precast lintels
- Thin ferro-cement precast shelves
- Ferro-cement based sanitation units/cladding
- Ferro-cement water tanks
- Precast well rings for water wells
- Precast sanitation unit rings
- Precast septic tanks
- Ferro-cement bio-gas units
- Precast jalousies
- Precast poles for street lighting
- Precast posts for boundary walls

The use of ferro-cement water tanks has become very popular in some parts of the country. Similarly, the use of precast well rings for water well has also become popular because of the fact that these are manufactured by private sector outlets.

These CEEF technologies have been used successfully in the field but their use is not yet in the mainstream on account of various factors such as (a) absence of robust supply chain delivery mechanism,

(b) suitability for low rise individual housing, (c) restricted use in rural and peri-urban areas, (d) low level of mechanisation, (e) ignorance, (f) limited skilled workforce including artisans, (g) scalability, (h) acceptability, and (i) non-profitable proposition for entrepreneurs, etc. Further, with the fast pace of urbanisation and industrialisation and to fulfil the housing demand and aspirations, these technologies could not meet the expectations and a need was felt to bring paradigm shift in the construction sector through introduction of industrialised building systems.

3.4 Disaster Risks in Housing Sector

With 26 percent of land areas exposed to earthquake hazards in zone IV and V, 18% of land vulnerable to High Wind Velocity (55 & 50 m/s), 7% of land vulnerable to Floods, 12.6% of land vulnerable to landslides in hilly regions, and the coastal areas, especially eastern coast to Tsunami, the housing stock of the country are vulnerable to natural disasters in varying degrees.

India has a history of disasters leading to irretrievable losses to lives and properties on account of its geological settings and distinct demography. Natural hazards, which can be broadly classified into geophysical hazards (earthquakes, landslides and tsunamis), hydrological hazards (floods), meteorological hazards (cyclones, storm surges), and climatological hazards (thunderstorms), are common phenomenon in Indian subcontinent. These recurrent hazards leaving trail of destruction is a cause of worry. Realizing the need for mitigating destruction and losses on account of these, there have been concerted efforts made by Government of India to bring paradigm shift in its approach towards disaster risk reduction. The traditional 3 Rs. (Rescue, Relief and Restoration) are now replaced by 3 Ps (Prevention, Preparedness and Proofing). Some of the watershed moments in the annals of disaster management in India are enactment of Disaster Management Act, formulation of Disaster Management Policy and National Disaster Management Plan, which are in line with UN resolutions, Hyogo framework (2005-15), Sendai framework (2015-2030) on natural disaster reduction and sustainable development goals. As regards techno-legal regime towards disaster risk reduction, this will have to become part of the model town & country planning legislation, zonal regulations, development control, building regulation/byelaws for all natural hazard zones of India, model building byelaws and comprehensive Indian standards on disaster management.

BMTPC's Vulnerability Atlas of India 2019 is a useful tool for disaster risk reduction and can be used for hazard assessment up to district level and understanding the level of risk to the housing stock in each district of the country. 'A house saved is a house constructed'. Therefore, it is necessary to ascertain hazard and vulnerability of the area for selection of materials and technologies.

3.5 Emerging Construction Technologies

The world over, building construction has been shifted from site to the factory where building components are partially or fully manufactured and then transported to the site for their erection, assembly and finishing. We can take cue from metro construction or bridge construction where long span horizontal members (girders) are cast in casting yard and then assembled over piers in quick time. This is typically known as precast or prefabricated construction, where building components as a whole or in parts are cast in the factory. In addition, there are other options also such as replacing the wall by sandwich panels or creating a customized formwork for the building or manufacturing the entire three-dimensional building in the factory which can be pre-finished. Most of these techniques are time-tested and proven and it is high time that these global construction practices are considered for use by adapting them to suit Indian conditions. These are fast track construction systems with much improved structural and functional performance, better durability, low life-cycle cost, resource-efficient, with minimum wastages as well as air and land pollution as compared to the cast-in-situ RCC construction.

Building Materials and Technology Promotion Council (BMTPC) under the Ministry of Housing and Urban Affairs, has been engaged in identification and evaluation of such emerging technologies. BMTPC also operates Performance Appraisal Certification Scheme (PACS) (Gazette Notification No. I-16011/5/99 H-II in the Gazette of India No. 49 dated December 4, 1999). Several new and innovative construction technologies have been evaluated and certified. The provisions to use new construction technologies including those certified by BMTPC have now been introduced in the National Building Code (NBC), 2016 and CPWD's Schedule of Rates. The need of bringing emerging construction systems has also been well documented by vision documents by TIFAC, NITI Aayog and CSIR.

Within the ambit of the overarching PMAY (U), a Technology Sub-Mission (TSM) was set up, to facilitate the adoption of new, innovative, sustainable, green and disaster-resilient technologies and building materials for low-cost, speedier and quality construction of houses. Construction of houses at mass scale offers an opportunity for inviting new and alternative technologies from across the globe which may trigger a major transition through introduction of cutting-edge building materials, technologies and processes. MoHUA, therefore, conceptualized a Global

Housing Technology Challenge-India (GHTC- India) to enable this paradigm shift in the construction sector.

3.6 Prevailing Conventional Construction Systems

- ***Load Bearing Structure***

In this system, walls are constructed using bricks/ stone/block masonry, and, floor/roof slabs are of RCC/stone/ composite. It is a cast in - place system in which the load of structure is transferred to foundation and then to ground through load bearing walls.

- ***RCC Framed Structure***

In this cast in-situ system, the skeleton of a structure consists of RCC columns and beams with RCC slab. The infill walls can be of bricks / blocks / stone / panels. The load of the structure is transferred through beams and columns to the foundation.

The conventional construction systems are primarily cast in-situ slow pace construction systems and cannot meet the present requirement of housing shortage. Therefore, it is judicious to adopt new construction systems which are fast track and deliver quality construction without compromising functional and structural requirements.

The innovative systems are, precast concrete construction, hot and cold-formed steel construction, engineered formwork systems, sandwich panel construction, factory made prefabricated systems etc. These systems employ technologies which are environmentally responsible and resource-efficient through the life span of building, and, these are being deployed world over. Some of the developing countries have successfully met the huge housing demand using these systems.

3.7 Technologies from GHTC-India

Global Housing Technology Challenge – India (GHTC-India) is a platform with which a holistic eco-system can be facilitated so that appropriate technologies from around the world and relevant stakeholders can be catalysed towards effecting a technology transition in the housing and construction sectors of India. The challenge has three components: (i) Conduct of a biennial Construction Technology India, Expo-cum-Conference, to provide a platform for all stakeholders to exchange knowledge and business, (ii) Identifying Proven Demonstrable Technologies from across the world, and mainstreaming them through field level applications in Light House Projects (LHPs) across India, and (iii) Promoting Potential Future Technologies through the establishment of Affordable Sustainable Housing Accelerators-India (ASHA-India) for incubation and accelerator support.

Under GHTC-India, Construction Technology India – 2019 (CTI-2019) : Expo-cum-Conference was held at Vigyan Bhawan, New Delhi during 02-03 March, 2019 to bring together multiple stakeholders involved in innovative and alternative housing technologies, for exchange of knowledge and business opportunities and master classes.

The applications were invited online globally for participation in the challenge. 54 alternate technologies were shortlisted based on specified technical parameters and are being promoted as future technologies for the construction sector in India. A compendium of these 54 technologies has been published by Ministry of Housing and urban Affairs which provides concise information of these technologies, their application in real projects in India and abroad and also provides contact details of technology providers. The details of 54 innovative technologies included in the Compendium will provide synoptic view of these technologies which will be helpful to policy makers, public & private construction agencies and other concerned stakeholders for their adoption in future housing projects. The compendium is available on the website www.ghtc-india.gov.in. These 54 technologies have been further categorized into 6 broad categories which are given below along with brief explanation of the technology.

3.7.1 Precast Concrete Construction System – 3D Precast Volumetric

3D Modular casting using steel moulds and high-performance concrete enables to get form-finished walls cast along with the slab/roof or assembled together in the factory. The complete precast module is transported to site and erected one on another like Lego blocks.

3D construction provides faster construction, dust free environment at site, minimal wastage & disturbance at site, high quality, excellent finish, 90% work including finishing is complete in plant/casting yard, with minimum material storage at site. Being factory produced, the technique gives better quality, durability and performance. Life cycle cost is less as compared to conventional systems. This also ensures faster delivery of houses.

Maintenance cost is also comparable initially, but in case of repair and rehabilitation being required due to corrosion, such as in marine environment like in Chennai, this cost will be higher. Also being thin elements, thermal performance is lower than conventional brick masonry. Monolithic connection details need to be ensured particularly while working in seismic areas.

3.7.2 Precast Concrete Construction System – Precast Components Assembled at site

This system is based on mass manufactured structural components in a factory i.e. precast columns, beams, slabs for floors and roofs/semi-precast solid slab, staircase and customized elements. These elements are cast on site/off site and then assembled with cranes and other equipment. All the components and their jointing are accomplished through on-site concreting along with embedded reinforcement to ensure monolithic resilient, ductile and durable behaviour. The establishment of factory at or near the site provides an economical solution in terms of storage and transportation.

This type of construction provides high speed, elements are cast in a controlled factory condition resulting in better quality, durability and it is adoptable in all-weather working. This also ensures faster delivery of houses.

Life cycle cost is less as compared to conventional systems. Maintenance cost is comparable to conventional systems. In case, block/brick masonry is used in infill walls, insulation may also not be required.

Monolithic connection details need to be ensured particularly while working in seismic areas.

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

- ***Light Gauge Steel Framed Structure (LGSFS)*** consists of factory made galvanized light gauge cold formed steel structural components assembled as panels at site. Various walling and roofing system can be used with LGSF framing.

  LGSF structures save time in construction. The system has advantages of low wastage, resource efficiency, recyclability, clean & dust-free construction, having good thermal efficiency through insulating materials like rockwool, CLC etc. In another variant, the infill wall comprises of factory made precast panels filled with light weight concrete at site. Being lighter in weight, the system provides better seismic resistance and economy. The connectivity of the system with foundation/footing needs precautions.

  For high rise structures, the composite structural system comprising of LGSF and hot rolled steel needs to be provided.

  There are a variety of infill materials being used in LGSF and therefore, the fire rating, thermal conductance, moisture penetration needs to be ensured. In case of hollow infill walls, sometimes the safety, impact resistance and puncture resistance is to be checked for the acceptability.

- ***Pre-engineered Steel Structural System (PEB)*** is made of factory made hot rolled steel sections primarily used as columns and beams to form the building frame. Various walling and roofing options can be used based on the functional requirements like thermal efficiency, acoustics, fire rating, etc. This system is quick to install and provides quality construction as the components are factory made.

  Steel structures have good earthquake resistance, being light weight. However, the connections have to be properly designed to ensure adequate ductility. In aggressive environments, steel structures need to be properly protected from corrosion. Fire coating is also required in case of steel components.

3.7.4 Prefabricated Sandwich Panel System

Precast Sandwich Panel Systems presented under this category comprise of either, a) Expanded Polystyrene Core Panels which are finished on site by spraying concrete, or, b) Dry wall system, wherein the panels are made of inner & outer boards (fibre cement /MGO) with infill core of lightweight concrete with Fly ash & EPS beads / Poly Isocyanurate (PIR).

The panels are factory made components & thus quality of the panels can be better ensured because of controlled conditions. The walling panels replace conventional brick & mortar walling construction thus bringing about ibetter speed in construction.

The dry walls do not require plastering & thus manual work on site is reduced. EPS based panel, light weight concrete & Polyurethane brings thermal efficiency & thus brings in energy conservation/ sustainability. The technology reduces the use of natural resources to the extent of use of fly ash, EPS/ EPS beads etc.

Being monolithic construction and lighter in weight, it provides for reduced seismic loads but their resistance to lateral forces needs to be ensured during design.

The details as regards claimed fire rating and toxicity in case of such panels needs to be ensured.

For high rise structures, the composite structural system comprising of sandwich panel and RCC/steel frame needs to be provided.

3.7.5 Monolithic Concrete Construction

In this system, all walls, floors/slabs, together with door & window openings are cast in-situ monolithically in a single pour using specifically custom designed modular formwork made up of aluminium/plastics/steel/ composite, for the entire modular unit. Being modular predesigned formwork system, it acts as an assembly line production and enables rapid con-struction of multiple/mass scale units of repetitive type.

This form of construction offers high speed, as casting cycle of 2-5 days per floor can also be achieved based on type of resources. It provides a durable structure with smooth finish requiring no plastering and less maintenance. Being monolithic construction, it is excellent as regards earthquake resistance.

A lead time of about 3 months is required for initiation of work, as the formwork is custom designed, manufactured and prototype approved before manufacturing required number of sets of formwork.

In extreme hot climate, external insulation may be required, as the thermal conductivity of concrete is more than brick masonry wall. In case of repair and rehabilitation being required due to corrosion, the repair cost in multi-storeyed buildings is likely to be high.

3.7.6 Stay in Place Formwork System

The lost formwork systems are left in the structure and can either act as insulation or part of structural system. These formworks are made of Expanded Polystyrene (EPS) blocks/panels which are known as insulated concrete forms, steel cage filled with concrete/ lightweight concrete known as structural forms, Panels, PVC formworks etc.

Stay in place Formworks act as guide for fast construction of walling & slab as applicable. Being factory produced components, good quality of product is ensured. Formworks using EPS as outer core, and, alleviated concrete using EPS bead as in-fill walling, have good thermal & resource efficiency.

There are certain systems such as Factory made prefab Glass fibre reinforced panels which use phosphogypsum (a waste product from fertilizer industry) as major constituent & thus save natural resources/ bring sustainability.

Being monolithic construction, it has good seismic resistance.

In some of the stay-in-place formwork systems, functionality with respect to fire resistance, moisture penetration, jointing and maintenance need to be ensured.

Ministry of Housing & Urban Affairs, Government of India had organized Indian Housing Technology Mela (IHTM) as part of New Urban India Conference cum Expo during 5^{th}-7^{th} October 2021 in Lucknow, Uttar Pradesh. Indian Housing Technology Mela (IHTM) provided a platform for indigenous and innovative building materials, components, tools & equipment construction processes and technologies that are sustainable and suitable for construction of low rise (G + 3 storey) houses for demonstration, cross learning, enabling better adoption and market linkages, and achieving the desired scale. IHTM provided an interface for traditional technologies, new innovators & start-ups in the sector, technologists, to interact with Government and end consumers for knowledge exchange along with generating business opportunities under one roof. IHTM Expo-cum Conference showcased an exhibition of these indigenous and innovative building materials and technologies for all related stakeholders and general public for learning, pilots and adoption & mainstreaming in construction sector. 84 innovative technologies/systems/ products/materials were identified for use in low rise construction under PMAY-U. The details of the new construction technologies/ innovative building materials is available on the website www.ghtc-india.gov.in.

3.8 Demonstration of Emerging Technologies

3.8.1 Housing with New Technologies

Through Technology-Sub-Mission under PMAY(U), BMTPC has been advocating use of new technologies across India. Several handholding programmes, expo-cum-conferences are being organised in the States to disseminate the emerging systems on continual basis. Also, the technical support with regard to identification and selection of technologies including procurement are being extended under PMAY(U) through BMTPC to State Governments. Out of a total of 115.09 lakhs houses sanctioned till February 2022, 15 lakh houses are being constructed using new emerging housing technologies. This small proportion is because of the fact that, 70.71 lakhs houses are under Beneficiary Led Construction which have limited scope for new technologies. The breakup of State-wise use of emerging technologies is given in **Annexure 3.6**, while the technologies under implementation in the states are given in Table 3.2.

Table 3.2: Details of Various Emerging Technologies under Implementation

S. No.	Name of Technology	Number of Houses being Constructed
1.	EPS and other Sand witch Panel	2,328
2.	Monolithic RCC using Aluminum Formwork	10,51,672
3.	Monolithic RCC using Tunnel Formwork	43,196
4.	Precast RCC Technology	3,90,427
5.	Precast RCC (Waffle crete)	6,953
6.	SLIP form work	3,290
7.	Fly-Ash Hollow Blocks	864
8.	Precast3DVolumetricTechnology	2,528
9.	Prefabricated Steel Structure	249
10.	Structural Stay in Place Formwork System	52
11.	Light Gauge Steel Frame Structure (LGSF)	1,016
12.	Glass Fibre Reinforced Gypsum (GFRG)Pannel System	36
	Total	**15,02,611**

Note: The figures mentioned in the table are referring to the implementation in various stages

3.8.2 Light House Projects under GHTC-India

The companies, whose technologies were shortlisted under GHTC-India, were invited to plan and construct Light House Projects (LHPs) within the framework of PMAY(U) on pre-selected sites across six identified regions. These light house projects shall serve as open live laboratories for different aspects of transfer of technologies to field applications. The details of these Light House Projects are given in **Table 3.3.**

Table 3.3 : Details of Light House Project

S.No.	Location	DUs, Storeys	Technology
1.	Indore, MP	1024, S+8	Precast Sandwich Panel system (Precast RCC Columns & Beams, Hollow Core Slabs, EPS Cement Sandwich Panel walls)
2.	Rajkot, Gujarat	1144, S+13	Monolithic Concrete Construction (Tunnel Form)
3.	Chennai, Tamil Nadu	1152, G+5	Precast Concrete Construction – Precast components assembled at site
4.	Ranchi, Jharkhand	1008, G+8	Precast concrete construction – 3D Volumetric Construction
5.	Agartala, Tripura	1000, G+6	Light Gauge Steel Structural System & Pre-Engineered Steel Structural System
6.	Lucknow, UP	1040, G+13	Stay-in-Place Formwork System (Steel Structural System, composite decking floor & Stay-in-Place Formwork for walls)

3.8.3 Demonstration Housing Projects

Under the Pradhan Mantri Awas Yojana (Urban), BMTPC is implementing construction of Demonstration Housing Projects in different parts of India using emerging technologies with the objective of spreading awareness about new technologies and disseminate technical know-how in the States/UTs. These are being implemented in twelve locations as listed in **Table 3.4**. These efforts are bound to help in building up confidence and acceptability of proven and emerging technologies in public andprivate construction agencies, as well as amongst professionals.

Table 3.4: Demonstration Projects by BMTPC under PMAY (U)

S.No.	Location	No. of DUs	Emerging Technologies
1	Nellore, Andhra Pradesh	36 (G+1)	Glass Fibre Reinforced Gypsum (GFRG) Panel System
2	Bhubneshwar, Odisha	32 (G+3)	EPS Core Panel System
3	Gachibowli, Hyderabad, Telangana	32 (G+3)	Structural Stay in Place For mwork System (coffor) and Light Gauge Steel Frame structure (LGSF)
4	Lucknow, Uttar Pradesh	40 (G+1)	Stay in Place EPS based double walled panel System (Sismo)
5	Bihar Shariff, Bihar	36 (G+2)	Structural Stay in Place Formwork System (Coffor)
6	Agartala, Tripura		Destitute women hostel(G+1) Stay-in-place formwork system (Coffor)
7	Panchkula, Haryana		Working women hostel(G+3) Light Gauge Steel Framed Structure with Cement fibre board on both side & rock wool as infill
8	Hathijan, Gujarat	40 (G+3)	Integrated Hybrid Solution-using mortarless interlocking blocks with plank & joist system for flooring
9	Bhopal, MP	Sports Hostel (G+3)	Insulating Concrete Forms as walling and RCC slab for Roofing
10	Guwahati, Assam	40 (G+3)	Light Gauge Steel Frame Structure with V-infill concrete wall
11	Ayodhya, UP		Destitute widow Ashram& orphanage (G+2) Light Gauge Steel Frame Structure with Cement fibber board and mineral wool as infill
12	Tiruppur, Tamil Nadu		Working Women Hostel/Widow Home (G+3) RCC Precast Construction system

INDUSTRIALISED BUILDING SYSTEMS (IBS)

Light House Project at Indore

Technology- Prefabricated Sandwich Panel System with pre-engineered steel structural system

4. INDUSTRIALISED BUILDING SYSTEMS (IBS)

4.1 Basic Characteristics of IBS and Broad Types

4.1.1 Overview of IBS and Characteristics

The Industrialised Building System (IBS) involves the repetitive construction of standardised units, utilising standardised components, using automation and mass production concepts, with minimal wastage, maximum efficiency and best quality possible. This necessarily involves thorough prior planning, employing appropriate designs, prefabricating various standardised components under factory conditions, transporting them to the site and assembling them at the site using minimal, but efficient interventions. The systems for the joints and connections between the various components become especially important to ensure proper functional and structural quality. The system also implies an aspiration for the least cost possible, leveraging mass production principles, automation, and standardisation. A typical example is the popular Precast Concrete Construction. Apart from complete buildings, IBS may also be applied to parts of buildings, where efficient construction systems are adopted. Under the prevailing situation, this definition would need further modification to include 3D printed housing depending on how well their usage grows over time. The discussions in this Report for aspects related to IBS are meant for construction of buildings, and Housing, in particular.

4.1.2 Classifications of IBS

IBS applications can be generally classified into the following broad systems:

i) Precast concrete construction using linear framing, planar panels and slabs and three- dimensional box systems

ii) Cast in-situ concrete work using system formwork, frames and blockwork systems, tilt-up construction, lift slab construction, etc. Possibly also including 3D Printed Concrete.

iii) Structural steel systems- frameworks, expanded steel systems, with cover boards, etc.

iv) Prefabricated timber framing system.

4.1.3 Advantages of IBS

Major advantages of IBS are:

i) Lesser time and cost for construction based on maximised efficiency

ii) More inherent standardization

iii) Easier construction with lesser dependence on scarce skilled labour and possibility of using Just in Time (JIT) supply chain management

iv) Enhanced safety during construction

v) Lesser requirement for construction space and lesser susceptibility to inclement weather conditions

vi) Better quality along with concomitant better finishes and aesthetics

vii) Possibility of using recycled materials for better sustainability with more ease than for conventional construction, since factory-like production systems are to be used

viii) Possibility of using standardised designs for better utilisation of natural lighting and ventilation, and

ix) Better sustainability and easier maintenance to facilitate facilities management along with other conveniences which come along with the better planning required, etc.

4.2 Enablers for IBS

To enable successful implementation of IBS a few facilitators as mentioned below would be advantageous:

i) Ensuring a steady demand to offset the fixed costs of the standing infrastructure involved in standardized mass production, for better financial viability

ii) Creating a demand for large projects where such standardised buildings can be used to recover the high initial investments

iii) Creating a large demand for large public sector-driven housing projects, with required, pre-approved land space being made available, to utilise the potential for large outputs

iv) Familiarizing the concerned agencies/ stakeholders such as Architects, Designers, Manufacturers as well as Construction agencies with the intricacies of IBS concepts and techniques so as to reap maximum benefits

v) Ensuring good planning and integration systems right from the beginning

vi) Ensuring the availability of the required equipment and automation systems and skilled labour

vii) Smoothening out potential transportation problems involved in delivery of large-size prefab components to the required sites

viii) Ensuring robust concepts and detailing for the joints and connections and possibly setting up testing procedures to ensure their proper performance

ix) Making available uniform standards and specifications covering functionalities, types, dimensions, tolerances, acceptance standards, testing and certification facilities, etc.

x) Encouraging Clients and Owners to adopt appropriate policies, by making available equitable contract documents and taxation policies, which are appropriate for IBS technologies and not just inappropriately adapted from conventional techniques, etc.

xi) Developing appropriate easy credit policies and flexible financial institutions to ensure required funding for IBS projects, as large initial investments are often required, with returns flowing back only at a much later stage, and

xii) Overall policy interventions to promote IBS as against conventional piece-meal construction with due changes in contracting formats, payment stages, etc.

In a nutshell, for IBS to be successful, an integrated approach has to be employed, comprising Conceptualising, Architectural planning, System design for the connections between any prefabricated components, Structural designs, Transportation to the site, Erection at the site and facilitating Facilities Management, apart from Quality Assurance aspects. Building Information Modelling (BIM) would also have to be an integral part of any modern IBS. Adoption of Lean Construction Management concepts and Digitalisation techniques enhance the value of IBS implementation significantly.

4.3 Problems Faced in Implementing IBS

4.3.1 Issues Faced in Other Countries

In order to meet rapidly rising demands for good quality housing and considering the several advantages of IBS, many countries around the world have taken steps to promote IBS. However, it is reported that while promoting IBS, some of these countries also faced issues, such as those mentioned below.

Even in developed countries, researchers had reported problems in using IBS. These are typically lack of stable demand for precast construction, lack of adequate standardisation, lack of widespread expertise in design and manufacturing, higher costs of transportation, limitation on the sizes of elements due to transportation difficulties, incompatibility between elements supplied by various manufacturers, inter-communication issues between the various agencies involved, and perception of bad performance of buildings, etc.

Researchers have reported that Malaysia had faced problems on account of difficulties in meeting the requirement for huge investments, higher initial costs, lack of involvement of small contractors, issues like moisture penetration and leakage in prefabricated structures, lack of expertise and adequate exposure to implementation of IBS, lack of expertise in design and execution of the complex projects, lack of flexibility in contractual payment terms, logistics issues, and negative perceptions of the performance.

Issues reported in Australia for Off-Site Manufacturing (OSM) include lack of expertise in design and higher design cost, transportation and carriage costs, lack of adequate skilled expertise, requirements for huge financing and stringent payment terms.

Issues experienced in Hong Kong include lack of in-house expertise, limited access to site and transportation problems, resistance to change from conventional methods.

4.3.2 Issues Faced in India

The issues highlighted in the previous section are required to be studied in the Indian context, so that steps to ameliorate these can be taken during the planning stage. Accordingly, the reported issues for India are, lack of large and steady demand for IBS projects, inadequate support from Government for sustaining IBS as a preferred solution for mass housing projects, despite the soaring demands of housing, lack of adequate standardisation and Handbook, lack of familiarity and required skills for both design and construction leading to high learning cycles, lack of involvement of smaller contractors, lack of adequate good quality transportation facilities, jointing problems/ quality issues, higher initial costs, unfavourable taxation and payment terms, etc.

4.4 Examples of IBS Practices and Incentives Available

4.4.1 Status in Other Countries

Many countries have realised the significant advantages of using IBS-related practices to accelerate mass housing construction schemes. Looking at the impediments coming in the way of implementing IBS, some countries have taken several measures for removing these obstacles. Some of the prevailing practices and corrective measures are reviewed below.

In USA 7.9% of total concrete construction is done using pre-casting. The major use of precasting is in parking structures contributing to 12.9% of the market. Structural precasting contributes to 90.1% of total precasting. 30% of all housing in US is using prefabrication technology. In the UK, 26% of the total concrete construction uses precasting. 45% of precast concrete is used in housing projects though conventional masonry still remains the main choice for housing (90%). Some incidences of failure led to modifications in BS codes for precast construction. Stable economic conditions in former Soviet Union helped in the rise of precasting industry, with market share of precasting being about 30%. Many European countries, particularly from Eastern Europe, have been using precasting systems as a preferred solution for housing. Precast concrete contributes to 10% of housing in Germany and Netherlands. 24% of housing was constructed using precast concrete in former East Germany. 70% of the total concrete construction uses precast construction in Finland. 74% of this contributes to structural precast concrete. Efforts by the Housing Development Board of Singapore have enabled the growth of precast construction and precast systems have been used in Singapore for high rise housing for the past 30 years. Fast-growing requirements for housing in Malaysia prompted the Ministry of Housing to adopt Industrialised Building Systems. To promote IBS, the official system there gives an IBS score for a construction project depending on the extent of prefabrication used and the levy on construction is reduced depending on how high a score is achieved. In 2019 about 39% of private sector development was with IBS and by 2020 about 50% was targeted. In China the average prefabrication level is about 10% of all construction processes.

4.4.2 Status of Various Systems used in India

- **Timber and Steel Systems**

Timber framed structures are not appropriate for mass housing because of insufficient availability of required quality of timber, except possibly in the North-East part of the country. Structural steel systems are well suited for prefabrication and fast assembly, but have been traditionally more expensive (initial cost). For conventional housing the steel framework will have to be masked by panelling which adds to the cost. The serviceability of steel frames and any panelling thereon under fire conditions is not good. Furthermore, frequent maintenance is required to minimise corrosion of steel. The skilled labour required for welding, riveting or bolting is also not available abundantly. This makes steel systems somewhat less acceptable, though this is undergoing change.

- **Lift slab and Tilt-up slab Systems**

Of the cast in-situ systems, Lift Slab technique has been very sparingly used in India and that too mainly for commercial buildings, for reasons of high requirements for skills and systems, with consequent higher costs. This implementation requires a high degree of pre-planning and coordination as well as the use of sophisticated techniques such as slip forming of the column members, use of strand jacks for lifting up the floor slabs, welding of the slabs to the columns under difficult conditions, etc. These factors make this system elitist and unsuitable for mass applications. Tilt-up slab systems are not generally suitable for multi-storeyed construction.

- **Frames and Blockwork Systems**

Conventionally the RCC framework is mostly cast in-situ along with the slabs which are generally post-tensioned for large spans. The walls are with blockwork construction either built up in-situ or erected using pre-formed panels. Though this system is quite prevalent as it is simple to use and does not require any sophisticated plant or systems, both the speed of construction and overall quality are seldom upto the mark.

- **Confined Masonry System**

This is a construction system where vertical RC elements are provided, interlocked with bricks at all wall junctions and door and window openings, and horizontal RC bands at plinth, sill and lintel levels. Masonry confined thus is more resistant to earthquakes (involving large lateral loads). Though this system may be useful for rural housing in highly seismic areas, it is not directly amenable to be an industrialised building system.

- **System Formwork Construction**

In-situ construction using pre-formed aluminium panels, tunnel formwork systems, use of automatic climbing form systems for the columns, table form systems, etc come under this category. The walls are generally of concrete. These systems are suitable for large volumes of construction with standardised modules. The quality of work is superior but the overall cost may not be very competitive, except under certain conditions of repetitiveness, using the company's own plant and systems with high degree of standardisation. While the time required for setting up and removing the shuttering may be reduced by systemisation, limitations of waiting for concrete hardening time, etc still remain as for conventional systems.

- **Precast Concrete Construction**

Of the main IBS concepts discussed above, Precast Concrete Construction (PCCon) has good possibilities in the present context in view of its undeniable higher speed of construction and lower costs with adequate volume of construction. PCCon has been very popular for the construction of bridges and industrial structures for quite some time and has also now made a successful entry into the housing sector. Various other IBS examples have also performed very creditably in certain given circumstances but as a general practice covering a broad spectrum of circumstances, PCCon appears to be a common technology appropriate in most circumstances. It is generally practiced in three broad forms: slab and wall panel system, framing elements and flooring systems. 3-D volumetric systems, with the slab and wall panel system possibly being more suitable for mass housing needs.

Best results can be obtained with effective architectural interventions to take care of functionalities, aesthetics, space utilisation, standardisation, etc. When large quantities of construction are involved with high degree of standardisation, with well-designed and executed precasting and erection systems, good skilled labour and availability of good lifting systems for erection, automated systems for precasting etc., this method would be the best suited for mass housing. Good quality, high speed, overall cost economy, better construction-time safety, etc are also possible.

Rural settings: PCCon can be implemented both in urban and rural contexts. However, for rural settings locally suitable appropriate technologies can be adopted for non-load bearing applications such as internal partition walls, toilet pods, etc. Clay bricks can be rapidly made with automated systems but they still need to be burnt in kilns, and walls built with conventional slow processes. With reasonably good approach roads, somewhat lighter elements precast centrally in a nodal precasting yard can be shifted to site and erected using low capacity cranes for moderate heights, say for G+3 buildings. With increasing population and growing pressure on available land, vertical construction to some extent may become inevitable even in rural areas and in such cases the above system would be of great use. In many cluster bridge projects, those were built using fully precast components based on standardised designs. Elements were precast in nodal locations and shifted to various sites by road for erection and assembly.

- **3D Printed Concrete**

Conventional concreting operations require a mould or formwork, whereas 3D Printing, or Additive Manufacturing as it is called, is a type of Digital Fabrication and involves depositing extruded micro concrete, layer by layer within strips of small widths progressively to build up the required shape. The concrete is cast or printed layer-by-layer through an automated process, using a "Printer" in which the Extruder can move along X, Y and Z axes to create the geometry required (using a gantry system). More details are given in **Annexure 4.1.**

4.5 Standards and Specifications for IBS

4.5.1 Available BIS Standards

Available Bureau of Indian Standards specifications and codes of practice are covered in another Chapter in this document. BIS standards also cover Glass Fibre Reinforced Gypsum (GFRG) wall construction developed jointly with IIT Madras. National Building Code of India (NBC) 2016 also covers some IBS topics.

4.5.2 Handbook for Precast Concrete Construction

Indian Concrete Institute had brought out the ICI Handbook on Precast Concrete for Buildings – Indian Concrete Institute publication: ICI Bulletin 2016. Although, this document has only a limited coverage of precast concrete construction, it was the first step towards a proper comprehensive Handbook. For a full-fledged precast construction industry to flourish, apart from a comprehensive set of standards and specifications, a detailed Handbook is also required, which sets up standardisation preferences for manufactured products, lays down detailed tolerances for various products for proper assembly at the site, indicates standard design procedures which would enable the construction industry to plan prefabricated structures systematically and choose available products for the best solution for a given problem. The PCI Design Handbook 8th Ed. (2017) (or any later edition) of the Precast/ Prestressed Concrete Institute of USA is an excellent example of such a document.

4.5.3 Contracting Systems for IBS

Conventionally public sector contracts have been item-rate contracts with systems based on pre-prepared standard designs and bill of quantities prepared by consultants. The shortcomings of this system are: Not encouraging the development of innovative designs or economic designs (as the emphasis is on "safe" designs without any Value Engineering or efficient/ modern construction methods), not giving scope for the efficient and economical deployment of the specific resources possessed by the various bidders, and not having an integrated system covering both Design and Construction methods/ equipment, etc. On the other hand, a Design & Construct or EPC (Engineering, Procurement and Construction) system has many advantages: giving full freedom for an appropriately integrated Design & Construction system which would be efficient and economical with good constructability, to encourage innovations in design and construction, enabling economical bids by giving opportunity to constructors to use their existing resources in the best possible manner, giving multiple choices to the Client to choose the best system, etc. The latter system is best suited for the modern IBS systems as many diverse technologies are available and it would be difficult for the Client to propose only one design system to suit all situations.

More efficient Relational Contracting systems are now coming up with the advent of Lean Construction Management, such as Integrated Project Delivery (IPD), Target Value Design (TVD), Alliance Contracting (AC), etc. which are quite efficient to deliver the projects in the best possible manner.

RECOMMENDED TECHNOLOGIES FOR IBS

Light House Projects

Location	Technology	Houses
Indore	Prefabricated Sandwich Panel System	1,024
Rajkot	Monolithic Concrete Construction System	1,144
Chennai	Precast Concrete Construction System-Precast Components Assembled at Site	1,152
Ranchi	Precast Concrete Construction System-3D Pre-Cast Volumetric	1,008
Agartala	Light Gauge Steel Structural System & Pre-Engineered Steel Structural System	1,000
Lucknow	Stay in-place Formwork System	1,040

GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

- GHTC-India was launched to identify and mainstream innovative proven construction technologies from across the globe which are Cost-effective, Climate & Disaster Resilient, Sustainable and Green.
- Shortlisted Technologies will showcase 6 Light House Projects (LHPs) in 6 States through challenge process as **Live Laboratories.**
- **3S** Mantra of Skill, Scale & Speed for superior quality of construction

5. RECOMMENDED TECHNOLOGIES FOR IBS

5.1 Review of Emerging Construction Systems

The housing problem of India is rather a complicated issue considering the huge variations in socio-economic characteristics of the heterogeneous population, the variations in climatic conditions across the country, the large variations in the prevalence of locally available materials and locally appropriate technologies, the rural versus urban dichotomies, and local preferences for particular types of housing, etc. In view of this, it is rather difficult to identify particular technologies for uniform adoption across the board and prescribe the same for adoption and implementation on the larger scales as required. However, looking at the huge scale of the demand, the urgency associated with the need to address this demand rapidly and the prior proven experiences in the country, some common technologies can still be identified to serve the needs of housing fairly judiciously.

The emerging construction systems available worldwide, which have been identified in the recent exercises by MoHUA and BMTPC, can be conveniently grouped into a few categories for better understanding and covering the various types of structural systems (See also Chapter 3). These categories are further discussed in this chapter for their universal suitability, particularly with reference to the experiences in the country so far.

5.1.1 Precast Concrete Construction System (PCConS) – 3D Precast Volumetric

This system envisages the assembly of the building using a number of precast three-dimensional modules. There are many advantages of PCConS; Construction is faster; most work being completed in the off-site plant/casting yard leading to a dust free environment; minimal disturbance and minimum material storage at site. The controlled factory environment brings resource optimization, reduced wastage, improved quality, and precision and better finish. The concrete can use industrial by-products such as Fly Ash, Ground granulated blast furnace slag (GGBFS), Micro silica etc. resulting in improved workability and durability, while also conserving natural resources. Use of plastering is eliminated and the other advantages are, optimum use of water through recycling, use of shuttering and scaffolding materials is minimal, and weather has only limited effect on the site construction. For the volumetric system the monolithic casting of walls and floor of a building module reduces the chances of leakage and improves the structural integrity.

On the negative side, the modules are generally quite large and potentially unstable in the temporary stage and the connections may not be very effective. Construction stage warping of improperly supported concrete projections, which are many, is a possible major problem. Structural continuity in vertical and horizontal directions is weaker and applicability in high seismic zones is to be proved. The thin elements are susceptible to corrosion and have poor thermal and acoustic insulation capabilities. This method is not suitable if a plant is not available nearby. It requires one or more large capacity cranes, along with access paths and skilled labour and supervision. The houses have to be completely designed and planned beforehand, along with all concealed services. It is said that a minimum of 1500 – 2000 dwelling units of 30 sq.mt. area each would be required in a project to make it viable.

5.1.2 Precast Concrete Construction System – Precast Components Assembled at Site

This system envisages the assembly of buildings using either precast columns and beams to create a framed structure or load-bearing precast wall and slab panels. In the former case, the flooring can be with the popular precast hollow core slabs with top screeding or precast slab panels and the walls are usually with precast blockwork. Precast half-slabs are also popular for floor slabs. In the latter system the slab is precast with about half the permanent thickness with a lattice system of shear connector rebars projecting above the precast slab. These bond with the upper half of concrete and re-bars placed in-situ. The various elements can be precast in a casting yard at the site or brought from a nearby plant since the elements are not too large. A large number of factories, about 50, are available in the country for the manufacture of these elements, and, there are many construction agencies which have experience in erecting such precast elements. Specific purpose small factories can also be installed in large project sites to cut down transportation.

This technology enjoys many of the advantages of precasting and factory production described in Sec. 5.1.1. The potential drawbacks are the connections, which if not executed properly, may lead to water seepage and other functionality problems. Tower cranes or large capacity mobile cranes are required for erection along with skilled labour and supervision. Since such cranes are in any case already becoming popular for all construction, this may not be a drawback factor. If wall panels are used, concealed services would have to be pre-planned.

For high seismic zones special detailing would be required and suitability for zones higher than Zone IV would have to be examined critically. In hot dry climate, the external walls may require additional insulation.

5.1.3 Light Gauge Steel Structural System (LGSS)

This system has a core of light gauge structural steel sections with walls and slabs being of different materials. Steel as a material has a high strength- to-weight ratio. This leads to lighter weight and significant reduction in design earthquake forces, lighter foundations, and easier transportability. Fully integrated computer based systems with Computerised Numerically Controlled (CNC) machines are primarily employed for manufacturing of LGSS sections and provide very high precision and accuracy.

Erection is easier and faster. There is also the advantage of re-use and recyclability. However, fire resistance, need for specialised labour to work with structural steel systems, questions of durability of wall coverings, need for separate roofing system possibly with reinforced concrete slabs, etc., are militating factors. Concealed services would pose problems for typical applications. LGSS buildings with different wall panels are recommended up to G+3 storeys. A minimum of 500 – 750 dwelling units of 30 sq.mt area is said to be the critical project size for this technology.

5.1.4 Pre-engineered Steel Structural System

This system envisages structural steel framing and light gauge covering, all made in a factory and assembled at site. This is an elegant system for long spans and tall internal spaces, which are typically required for industrial structures and amenable to fast erection and economy with scale. However, this system may not be suitable for conventional housing and for multistoried structures for the same.

5.1.5 Prefabricated Sandwich Panel System

This is a factory produced dry walling system, which brings speed in construction, water conservation and energy efficiency. Factory production leads to advantages described in preceding sections. The sandwich panels generally have a light weight material at the core. The lighter weight comes with attendant advantages. These also have good acoustics and thermal insulation. Application of this system has many limitations too and suitability for mass housing in India needs to be critically examined.

There are broadly two types of Prefabricated Sandwich Panel Systems, which are described below:

(a) *Sandwich panel system with outer walls of various types of boards with in-fill lightweight concrete and slabs*: Despite all its advantages and sophistication mentioned above, its applicability may be questionable in the context of industrialised mass housing in India.

(b) *Sandwich Panel system with reinforced Expanded Polystyrene Core Panel System (EPS):* Expanded Polystyrene (EPS) Core Panel System is based on factory made panels, consisting of self-extinguishing expanded polystyrene sheet with minimum density of 15 Kg/m^3, thickness not less than 60 mm, sandwiched between two engineered sheets of welded wire fabric mesh, made of high strength galvanised wire of 2.5 mm to 3 mm dia. The panels, if used as floors/ roofs, shall require screeding concrete of minimum 35 mm thickness with nominal reinforcement/ GI wire mesh for monolithic action to avoid leakage through panel joints. The technology has rather exacting requirements such as, the jointing between the panels requiring perfect bonding/ locking, cutting/chiselling of panels for openings such as doors, windows, service conduits etc. requiring trained skilled manpower.

Primarily, use of prefabricated sandwich panel systems is limited to non-load bearing non-structural applications. Nevertheless, the structural panels can be used upto G+3 storeys with careful planning. For higher rise, suitable structural framing system, either of RCC or steel, would be required. Thus, the system has limited scope for mass affordable housing.

5.1.6 Monolithic Concrete Construction using System Formwork

This system uses small-sized standard prefabricated formwork units which can be erected and dismantled quickly, to receive concrete poured monolithically for an entire floor comprising walls and roof slab. This system is very fast to use, structurally sound in view of less joints, gives excellent finish without the need for plastering and is suitable for multi-storied structures with good cost economy. In view of the simplicity of formwork the workforce need not be highly skilled. The system is economical only with large repetitions. Speed of construction may not be very high in view of the waiting time for concrete to be cured, unless accelerated curing is carried out. A lead time of about 3 months is required for initiation of work, as the formwork is custom designed. The system requires pre-planned architectural details and services for heat insulation and air ventilation etc. For the structural system consisting of thin shear walls, questions about its thermal performance, fire rating and user comforts need to be addressed.

This is the most widely used and accepted system in India at present, with a plethora of companies manufacturing customised formworks using high precision and robotics. The critical volume of project size for the technology is as low as 500 dwelling units.

5.1.7 Stay-In- Place Formwork System

Stay in place formwork systems are sacrificial formwork systems which are left in the structure to be either used as insulation or as structural reinforcement. GFRG (Glass Fibre Reinforced Gypsum) Board/ Rapidwall construction with in-fill concrete is an example of this system.

The system has some merits, but it is not amenable to affordable mass housing because of tedious installation, doubtful user acceptability, etc. GFRG raw material is also often in short supply and is supplied mainly by only one agency. In case of GFRG Panels, all openings and cut sections of full width of wall should be done at the factory itself and cutting of panels at site needs to be avoided. For curved wall and domes, these panels are not suitable. The electrical/ plumbing system should be such that most of the pipes go through cavities in order to facilitate minimum cutting of panels. The distance from the main factory also matters from an economic transportation point of view.

5.2 Requirements for Adopting Modern Technologies for Mass Housing

The technologies which can be recommended for mass housing should satisfy the following criteria: easy to adapt and adopt for wider use, ready availability of many producers and constructors of the technology, durability, suitability to a variety of climatic and seismic/ wind loading considerations across the country, cost economy, speed of realisation, reasonable extent of environment friendliness, suitability for urban and rural applications as well as for low-rise and high-rise structures, etc.

5.3 Recommended Technologies for Mass Housing

Considering the above factors, it will be advantageous and expeditious if preference is given for adoption in housing for mass applications at this stage, mainly to the two technologies described herein, viz. Precast Concrete Construction and Monolithic in-situ Construction, which are already being practised quite widely in the country by many agencies. Nevertheless, there are other technologies, with substantial merits, in different stages of development, and for which pilot projects have already been initiated to assess their suitability, or to determine how these can be made more acceptable for use in the mass housing programme of the country. However, before their acceptance for widespread usage, systematic studies need to be made of the trial installations to study the aspects of time, cost, quality, user friendliness, amenability for mass replication, etc and critically compared with the following two systems.

Precast Concrete Construction (PCCon)

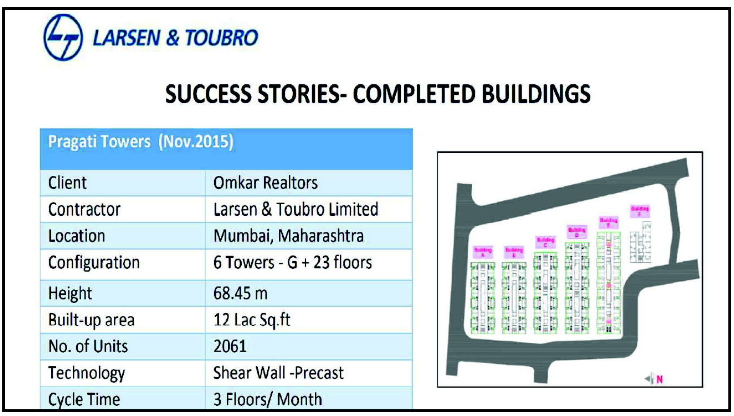
using either (i) framed structure components with in-fill precast blockwork walls/ precast wall panels and precast slab panels (including precast half-slabs) or precast Hollow Core Slab units with screeding on top; or (ii) precast wall and slab panels. There are many factories situated around the country which can supply the standard precast units, or for large scale applications for a particular site a dedicated factory can be set up at the site to produce the precast concrete units.

For industrial structures, Pre-Engineered Buildings in Light Gauge Steel are quite popular nowadays and have replaced the earlier concepts of precast concrete columns/ frames and long span precast concrete trusses with purlins and steel sheeting or precast concrete shells or folded plate roofing, though not popular for housing.

Monolithic in-situ construction, using standard pre-designed formwork plates in metal (mainly Aluminium) or plastic, which can be shifted up from floor to floor with easy erection and dismantling (popularly known as Aluminium formwork construction). In this system, as described earlier, concrete is poured in one go for the entire floor comprising the columns, wall and roof slab without any joints. The light-weight formwork panels can be easily shifted up to the higher floor on the next day using conventional labour, leaving props below the floor slab. Use of precast staircase elements can help in accelerating the floor cycle time. This is amenable for fast construction and economical with large repetitions of the formwork.

5.4 Typical Success Stories

Typical success stories for these two systems for construction are presented in **Figures 5.1** to **5.3**. Though instances from only a few manufacturers are presented in this section, there are many other examples. Some additional examples for various IBS projects are given in **Figures 5.4** & **5.5**.



Pragati Towers (Nov.2015)	
Client	Omkar Realtors
Contractor	Larsen & Toubro Limited
Location	Mumbai, Maharashtra
Configuration	6 Towers - G + 23 floors
Height	68.45 m
Built-up area	12 Lac Sq.ft
No. of Units	2061
Technology	Shear Wall -Precast
Cycle Time	3 Floors/ Month

Figure 5.1: Example of Successful Application of Precast Concrete Construction

Provident Sunworth (Mar.2018)	
Client	Provident Housing Ltd.
Contractor	Larsen & Toubro Limited
Location	Bangalore, Karnataka
Configuration	29 Towers – B+S+12F
Height	41.9 m
Built-up area	31.8 Lac Sq.ft
No. of Units	2784
Technology	Shear Wall -Precast
Cycle Time	4 Floors/ Month

Figure 5.2: Example of Successful Application of Monolithic Construction

No. of Units	1245	1928
Cycle Time	2.5 Floors/ Month	2.5 Floors/ Month
Technology	Shear Wall -Aluminium Formwork	

Olympia Grande, Chennai (Sep.2016)	
Client	KSM Nirman
Contractor	Larsen & Toubro Limited
Location	Chennai, Tamil Nadu
Configuration	17 Towers – B+G+11F
Height	36 m
Built-up area	11.5 Lac Sq.ft
No. of Units	770
Technology	Shear Wall -Aluminium Formwork
Cycle Time	3 Floors/ Month

Figure 5.3: Example of Successful Application of Shear Wall-Aluminium Formwork

Figure 5.4: Example of Pre-Fabricated Steel Construction in Mohali, Punjab

Typical Lage Panel

Day 42

Day 71. External Finishing Completed

Day 91- All Floor Lobbies and Elevators Ready

Figure 5.5: Mission 96 - 96 flats in 96 days

Mission 96 showcases the true potential of the Precast Large Concrete Panel (PLCP) system. L&T took on 'Mission 96' challenge in late March 2022 to complete one Stilt+12 storey tower superstructure with 96 flats in 96 days that were to be handed over to City and Industrial Development Corporation (CIDCO), Maharashtra, with all architectural and MEP finishing, under the PMAY. The mission tower comprised of production and installation of 1985 precast elements of the superstructure along with Architectural Finishes and MEP works of the approximately 6,400 sqm built-up area. Each floor is of about 450 sqm with 8 flats of about 30 sqm carpet area.

The PLCP system focuses on construction of the building using Precast Walls and Slabs that is similar to the popular Cast-In-Place Aluminium Formwork Load Bearing Wall System. The system avoids use of time consuming second stage site activities such as blockwork and plastering to improve productivity as well as quality of the construction work.

The meticulous mission planning, carried out in merely 15 days, included deployment of two dedicated heavy-duty cranes in tight footprint of 450 sqm with state-of-the-art Anti-Collision Device. Strategic installation sequence for precast elements was devised for minimal interference. A Mobile Crane of 100MT capacity was exclusively deployed to decouple element unloading from Tower Cranes.

Continuous supply of elements for two floors was ensured throughout the project duration from L&T's massive 11000 sqm production facility at Ulwe. Along with Mechanization, the Mission also highlighted adoption of modern digital ways such as Concrete Maturity Method for real time concrete strength monitoring as well as tower progress monitoring using the Digital Twin approach with the BIM model developed for the project. The herculean task of completing end to end finishing works in just 86 days was managed per planned schedule to accomplish the Mission 96 on July 9, 2022 with utmost attention to safety and quality.

Successful completion of the Mission 96 has once again highlighted L&T's PLCP system capability to build tall residential buildings at an astonishing speed. This has opened a new avenue for ultra-rapid construction of tall residential buildings that will offer a fitting solution for India's Mass Housing needs through the next decade.

5.5 Future of IBS in India

Various types of Industrialised Building Construction have been practised in India over time and there has been a steady metamorphosis in technologies with the infusion of more and more automation and prefab technologies. There have been many innovative developments in materials, equipment, processes, construction methods, IT applications and project management paradigms over time. With the growing trends of urbanisation and as available space in urban areas keeps shrinking, the need for tall structures will be on the rise. The existing old structures may have to give way to the new, and the demolition wastes will need to be recycled to conserve the environment. This will again place an emphasis on more centralised working for the recycling of C&D (Construction & Demolition) wastes and utilising the materials in factories producing new construction elements. Of the current two technologies identified in Section 5.3 above, Precast Concrete Construction (PCCon) has a higher potential in view of the complete possibility of avoiding/ minimising site-based working and better environment friendliness. A number of growing factors such as limitations on space at construction sites, environmental restrictions on avoiding dust and debris, non-availability of good construction labour, need for fast realisation of projects, need to recycle old C&D wastes, etc will also be positive factors for the growth of PCCon. Measures to facilitate the growth of this system are enumerated elsewhere in this report. 3D Printing is still only a nascent technology and has to be developed to a much greater degree before it can become a significant factor in affordable mass housing.

ENABLERS FOR IMPLEMENTATION OF EMERGING TECHNOLOGIES

Demonstration Housing Project, Hyderabad

Technology- Structural Stay in Place formwork System and Light Gauge Steel framed structure

6. ENABLERS FOR IMPLEMENTATION OF EMERGING TECHNOLOGIES

6.1 General

In order to provide affordable housing, the various stakeholders involved such as the Central Government, State Governments, real estate and infrastructure developers, financial institutions, urban planners, and most importantly, the beneficiaries have to work together. In this context, both the public as well as the private sectors have to play their part. In an ideal PPP (Public-Private Partnership) scenario, the public sector could look into aggregating land for projects, providing single-window and time-bound clearances, redrafting the local development bye-laws to suit the requirements of affordable housing projects and re-evaluating/ optimising the taxes and levies from the perspective of reducing cost of home ownership for the target segment. Private sector entities can leverage core competencies such as planning and design, project development, best technology practices, project financing, human resources, sales, marketing and management of facilities. All in all, it is imperative to have a coordinated and integrated involvement of all the concerned stakeholders to play their respective parts in the most synergistic manner. This would necessitate the identification and active involvement of a single Nodal Agency to do such coordination, which is a very vital step as would be seen later in this Chapter.

Furthermore, it is imperative to understand the differences between established conventional methods and the modern ones in order to chalk out the approach needed to implement emerging technologies and even those in their nascent stage. It is also necessary to understand how these can be brought into the main stream of construction options. This applies substantially even to PCCon, which is comparatively better established and already in practice to an extent.

6.2 Basic Differences between Conventional and Modern Methods

Many modern technologies have come to light in the process of the Global Housing Technologies Challenge (GHTC). Some of the major differences between traditional and modern methods, which necessitate a totally different outlook while formulating the project and contractual aspects are given below.

S.No	Traditional Methods	Modern Methods
1	Initial site mobilisation and subsequent flow of progressive work taking place at site	Based on substantial simultaneous work on a number of parallel fronts, most of the off-site activities (e.g. Planning, Engineering, Mobilisation, Manufacturing, etc) converge at the site at a much later time after commencement. While progress of these activities can be measured against stipulated milestones, they are not readily apparent at the construction site.
2	Work takes place only in the available land and in sequential manner. Design and subsequent activities start only after award of work.	Since the upfront engineering is based on the layout and configuration of a particular project to be appropriate, the land availability and all the clearances of the project must be fully ensured before the bidding process starts. All project preparation activities (land acquisition, re-settlement of any Project-Affected People, environmental and other clearances, various local approvals, approach roads, availability of water and power, etc) have to be taken care of before bidding starts so that the fast-track execution does not suffer.
3	Sub-contractors are all normally present at the site.	Several agencies are at work, but working in off-site factories and other theatres of operation.
4	Labour-intensive and slower to unfold.	More automation-oriented and unfolds rapidly at the site, as most preliminary works are done earlier off-site.
5	Progress and quality of work can be measured at the site itself.	Progress and quality need to be measured in many other locations also (e,g. precasting factory, etc).
6	Is a stabilised process with long histories, but with slower progress, etc.	Keeps changing frequently with new (often disruptive) developments in technology, and often it is not possible to show previous implementations, which have been in existence for many years for prequalification purposes.

7	For a particular project, work is based on one single implementation at the site and can be costed on that basis.	Work hinges on deployment of prefabrication systems a priori, and acquisition of a large number of costly equipment, etc, all of which require considerable upfront expenditure, and this money has to be amortised over large volumes of work, to be economically viable. While this system can be more cost effective and have better functionality and quality as compared to the traditional, the realisation of these benefits depends on the assured availability of a large volume of work for a particular project.
8	Engineering can be progressive and unfolding along with construction.	Requires the availability of complete engineering practically up front in view of the prefabrication and the embedment of services in the various components. Many of the modern technologies are still evolving in the Indian context and working out good cost estimates is difficult and calls for good expertise.
9	Based on widely used technologies for which cost estimates can be quickly worked out based on previous experiences and standard "Schedule of Rates".	Particularly, items such as Planning, Coordination, Tooling, etc are difficult to cost using any of the earlier techniques.
10	The cash flow can be measured out progressively after the constructor mobilises at the site.	Cash flow has to start immediately after the award of work to facilitate engineering, BIM modelling, tooling, and simultaneous manufacture of various components, etc.
11	Work in progress is confined mainly to the site.	If the client wants to stop the work at any intermediate stage, cognizance has to be taken of partial completion in a number of different fronts as well as planning in progress and mobilisation of enabling activities including equipment, factory, skilled labour, etc., for the purposes of cost compensation.

6.3 Mainstreaming Emerging Technologies–Issues and Possible Solutions

The various issues, which the construction industry experiences while implementing mass housing projects using modern technologies, have been compiled in this section.

6.3.1 Preparedness Issues

Despite various circulars about the usage of emerging construction systems by erstwhile Ministry of Urban Development, Govt. of India, CPWD, and BMTPC as well as inclusion of technologies in BIS documents, the technical professional fraternity is still not prepared to adopt these systems with open arms. The various reasons for the same and suggested remedial actions are given below:

i) Misconceptions about new systems
Apprehensions regarding performance of joints, earthquake resistance, functional performance, etc.
Action: Develop a comprehensive knowledge base and BIS Standards on the new technologies

ii) Risk avoidance by policy makers and technocrats
Policy makers and technologists generally feel comfortable only with the current system as they don't have to take any 'out of the way' decisions which might need deviating from the standard technical and financial norms.
Action: Policy level interventions through a committee of experts representing technical and financial departments.

iii) Apathy at implementation level
Any innovative use requires a concerted initial push with a well-defined plan of action.
Action: Incentivize innovation in construction through the suggested Nodal Development Body.

iv) User acceptability
Users and many industry stakeholders (such as architects, designers, supply chain, etc) are so accustomed to 'brick and mortar' construction that they are generally not receptive to new construction methods, even if these technologies are superior.
Action: Awareness creation and construction of some public buildings are likely to build confidence in the public.

v) Inadequate capacities at professional levels
Action: Create a pool of specialists and training establishments, through the Nodal Development Body.

vi) Skill development
Action: Capacity building and skill development using various agencies, such as CIDC, BMTPC, etc. to be taken up.

vii) Need for IEC activities
Information, Education & Communication (IEC) are required for generating awareness.
Action: Initiate IEC through the Nodal Development Body.

6.3.2 Skilled Back-up & Cost Issues

There are certain agencies claiming to have innovative technologies which are fast, economical and sustainable, but their claims are not yet verified in the Indian context and most of them do not have prior experience of construction with emerging construction systems. BMTPC and State governments have come out with 'technology neutral' tendering systems, design & build contracting system, QCBS systems in tendering, etc, but despite all these efforts, certain issues still remain, as discussed below.

i) Paucity of Contractors/ Implementing Agencies

Technology providers who bring technology may not be contractors, and therefore, they are unable to participate in the tenders. This calls for creating a pool of contractors who are willing to join with technology providers. In India at present there are only very few contractors participating in Government tenders, who have technology know-how by themselves.

Action: Build a platform for technology providers & contractors.

ii) High Initial Cost & Economies of Scale

All new systems require a manufacturing set up, and therefore, initial costs would be higher. To ensure financial viability there should be a reasonably large volume of work over which the high initial costs can be recovered.

Action: Configure large-size work packages and stipulate emerging technologies for mass housing.

6.3.3 Procurement Issues

There has been a general agreement that in order to bring a paradigm shift in construction practices in housing industry, there is a need to bring radical changes in procurement policy. However, there is the conventional school of thought too, which would prefer to persist in the use of existing systems and procedures while giving only a lip service to emerging construction systems. Some of the important issues, which require a national level consensus, are listed below:

i) To do away with item rate contract and adopt EPC contract system

Normally contracts are given on the basis of tenders, which are prepared on item-rate basis, which requires prior design and quantity calculation as per the conventional system, and follows a specified Schedule of Rates. In order to provide a common platform for diverse emerging technologies, the EPC approach needs to be adopted. Engineering, Procurement and Construction (EPC) or Turnkey System or Design & Build system are the contracting arrangements, where the contractor does all the activities covering conceptualization, design and construction, and commissioning. As an alternative, the rate per sq.m may be fixed along with user specifications and the tenderer may be allowed to innovate, design and build. In addition to EPC contract, quality-cum-cost based selection (QCBS) may also be adopted in which separate weightage can be given to technical parameters (like quality, speed, life cycle cost, etc.) and financial cost. In order to bring in new technologies, the lowest bid (L1) system needs to be replaced by the above-mentioned innovative systems.

Action: Bring in a new Procurement Policy

ii) Conventional pre-qualification criteria

Presently, as per Government norms, the bidder must have done a certain minimum volume of 'similar work' to get qualified. It is to be understood that being new technologies, specified volume of 'similar work' experience may not be available presently with the bidders prevalent in India. Therefore, till these technologies are well established, there is a need to relook and amend the pre-qualification criteria to create a conducive environment for adoption of these technologies keeping in mind the various CVC circulars.

Action: Revisit existing pre-qualification criteria in tender documents.

iii) Lack of modular/standardized planning & design

Whenever industrialization or mechanization of construction is talked about, it is of utmost importance that the sizes of rooms, windows, doors, services, fittings, etc. are modularized and standardized, possibly on the basis of regions, if not on pan-India basis.

Action: Prepare modular plans and concepts for different geo-climatic regions of India.

iv) Absence of demonstration at grass-root level

There is a need to construct demonstration buildings in different parts of India with such new systems so as to showcase and educate the masses about the technologies, as well as to benchmark construction time period, constraints, costs, etc. Unless successful case studies are created, it is difficult to build user-acceptance and general confidence.

Action: Demonstration projects to be created with new technologies. Assess the learnings from the new Light House Projects and circulate.

6.4 Issues in Implementation of Emerging Technologies

While many different technologies were presented in GHTC, a critical analysis of the effectiveness and appropriateness of the various technologies in the context of the Indian environment has yet to be done, as shown elsewhere in this report. A few suggestions for ameliorating the hindrances are highlighted here for adoption of suitable technologies for mass housing projects and for the implementation of schemes for housing.

6.4.1 Affordable Housing Schemes

- Under the Affordable Housing in Partnership (AHP) module of PMAY, the Centre and State Governments provide a Capital Grant for each dwelling. The gap between the price of the dwelling and the Capital Grant, if any, is to be financed by the beneficiary. Though the Government has tied up with Financial Agencies like HUDCO to provide this finance, most beneficiaries do not have sufficient credentials for receiving a loan. To overcome this, there is an effort by Government Agencies to minimize/ eliminate the beneficiary component. Due to their strained financial conditions, many State Governments have tried to artificially limit the price of the dwelling unit such that the State Capital Grant amount can be minimized, while also minimizing/ eliminating the beneficiary component. This has resulted in States approving bare minimum/ sometimes non-liveable specifications, which may not be acceptable to the end users.
- In order to overcome this problem there is a need to quickly set up a central common agency which can work out realistic cost estimates for the various technologies suitable for various locations, while meeting the end user requirements and configurations of the projects.

6.4.2 Identifying New Technologies

- Modern technologies are capital intensive and require a large volume of work for feasibility and viability. Hence each call for bids should be based upon a minimum volume of work appropriate for the envisaged method of construction, to be decided in consultation with an identified expert nodal agency.
- As far as possible the prequalification criteria should conform to the earlier-mandated and well-established CVC

guidelines, duly modified to suit the environment of infusion of new technologies, and may not propose new guidelines, which vary from project to project.

- The Government has not mandated the adoption of a specific construction technology for Affordable Housing. Hence most developers continue to use the conventional framed structure design, which is suited only for small project volumes and leads to increased cycle time, increased material wastage and large quantities of second stage works like masonry and plastering, all leading to more construction time. In order to ensure that the returns on the investment made by the Government are realised quickly and that the end-users are able to get their dwellings at an early date, (both of which have an indirect cost aspect), the construction time period must be fixed on the aggressive side, suitable for the modern methods.
- The Government of India scheme has not standardized the finishing specifications required for Affordable Housing, due to which a large variability exists in the specifications offered to end users. For maximum facility/ functional utilisation for the end-users, the Government must do a considerable extent of planning for each housing project a priori. This planning should cover the list of amenities including common amenities for a cluster of dwellings, typical layouts and floor plans and functional specifications and finishes for each unit, optimum orientation of the buildings for maximum natural lighting and ventilation, etc. using expert agencies such as CBRI, NID, etc before bidding out. As far as possible, the structure must include auto-finishes and built-in services, which are integral with the precast elements and not requiring additional downstream work for plastering, etc.

6.4.3 Other Issues

- The quality of land (location, accessibility, topography, proximity to utilities, etc) generally allotted for mass housing schemes tends to be sub-par (brownfields, water bodies, remote locations and/or hilly terrain, etc), which tends to increase construction costs and/or could adversely affect the liveability aspects of completed tenements.
- The lead time required for obtaining statutory approvals for developing these projects, despite steps taken by governments to streamline, remains a deterrent for many players in entering the domain of mass housing.
- To alleviate these problems special priority should be given to Affordable Housing projects. The project preparation aspects including

developing the lands for the housing projects, should be got done by other agencies beforehand so that the main project can proceed in a fast-track mode to realise the benefits at an early date.

6.5 Specified Contractual Issues in Identifies Public Sector Schemes

6.5.1 Prequalification System

- A significant percentage of Government housing projects are item rate contracts based on conventional technology. However, some Government agencies have awarded technology-specific/ technology-neutral Design-cum-Build lump sum contracts. The latter are more favourable as they promote efficiency and innovation, facilitate adoption of the best appropriate technology, and enable each agency to leverage its speciality systems and equipment in a holistic manner to limit the cost, etc.
- The Pre-Qualification (PQ) Criteria should be careful about specifying restrictions on minimum height of structures that have been previously constructed by the bidder, lest it inadvertently rules out certain new technologies.
- PQ criteria for technology-neutral tenders should follow certain common guidelines to ensure that approved rapid construction technologies are only followed, and at the same time making sure that a certain minimum volume of work is made available to ensure the financial viability of such a technology.
- It is strongly recommended that since this is a new requirement for modern technologies, the PQ criteria are uniformly fixed by the Central Government for all projects, including the State Govt. projects.

6.5.2 Contractual Formats & Clauses

- Most Government contracts follow the CPWD or State PWD form of contract, while a small percentage follows the FIDIC form of contract. Even for some FIDIC contracts, while the GCC (General Conditions of Contract) is FIDIC, the SCC (Special Conditions of Contract) clauses tend to dilute the essence of the FIDIC contract. It is recommended that the FIDIC system be followed with minimal SCC clauses in a standardised format.
- Some clauses in the CPWD/ PWD form of contract are not suitable for fast-track high value projects. For example, some contracts do not provide for arbitration such that any dispute not deemed settled by the EIC's decision must go to court. Similarly, some contracts provide timelines within which a submitted bill would be certified, but no timelines within which a submitted bill would be paid. Most Government

contracts do not provide for a financial claim by the contractor even for delays not attributable to him. Relief is limited only to extension of time. These clauses should be made more equitable.

6.5.3 Architectural & Structural Design

Architectural planning (space planning, thermal, acoustic and fire resistance parameters) and structural design issues are paramount. Different technologies have different structural design considerations due to system and other requirements, including wall thickness, which impact the carpet area. It is better to specify the overall carpet area requirement for each dwelling and built-up area to carpet area ratios, with some leeway, instead of specifying minor parameters.

6.6 Some Additional Issues

6.6.1 Cost Estimate

Government cost estimates are typically prepared using Government-issued Schedules of Rates (SoRs). While the CPWD's Delhi Schedule of Rates has incorporated items related to multiple new rapid construction technologies, other State level SoRs are yet to do the same, and thus are based on conventional construction (framed structures). As a result, even for technology-neutral tenders, the Government estimate may not be amenable to adoption of new technologies as the cost impact of the same is not factored in. Additionally, cost impacts specific to high rise construction (like Tower Cranes, Passenger Hoists, Safety Screens, etc) and to new technologies (like Gantry Cranes for Precast Works) are not factored in for most SoRs. This also leads to large variation between Government estimates and received bids unless special allowances are made in the estimates.

It is recommended that an expert central agency be identified which will prepare cost estimates duly appropriate for modern technologies on a common basis for all projects, while factoring in local conditions wherever required.

6.6.2 Handing Over and Commencement

As handing over of completed assets to the end-users is a complicated process for residential buildings, some Government contracts tend to include handing over of the units to end-users within the scope of the contractor. This has a significant adverse impact on cash flow of the contractor, as stage payments and final bill payment get delayed. Further, return of Bank Guarantee etc also gets delayed for factors over which the contractor may have no control, as responsibility for many items of work are not within the competence of typical construction contractors.

Several projects run into delays because of disputes related to land acquisition which become apparent only after the contractor takes over the project site. Typical Government contract clauses may not provide for financial respite to the contractor in such cases. As mentioned earlier, all project preparation activities should be got completed before bidding out the projects aiming to use modern technologies.

6.6.3 Technology Issues

Most modern rapid construction technologies are based on modularity principles. However, some recent PMAY scheme projects have seen tenders issued with conventional floor plans that are in practice based on the traditional construction methodologies. While each technology has its own specific requirements for the architectural floor plans and elevations, a single ideal solution may not be feasible, and therefore, the architectural layouts should be planned such that they offer constructability and feasibility options to adopt the new technologies. Such floor plans should be schematic and focused on linear geometric layouts without excessive in and out corners, projections, and considerable variation between different building floors. The room dimensions could be standardized not only to make the technology adoption easy but also cost effective in terms of wastage of finishes and improved productivity.

6.6.4 Taxation Issues

Though housing is a key focus area of the Government, high GST rates of raw materials tend to increase construction costs. Major raw materials like cement (28%), reinforcement (18%), concrete admixture (18%), pipes (18%), roofing sheets (18%) and bathroom fittings (28%) are placed in the higher tax brackets. Output GST for construction works has also been mandated to be 18% for general works and 12% for specified government projects. This aspect needs to be looked into, to make the housing truly affordable.

6.6.5 Continuity of broad policies

Immunity from being affected by the changes in the political and governance system/structure for ongoing construction is necessary for the constructors, in order that they are not forced into providing for extra cover (through bid cost) in the contracts, and thus bring about a reduction in the cost of the project.

6.6.6 Non-uniformity in Administrative Processes for Approvals

PMAY schemes should be enforced with a unified criterion for eligibility and approvals except for the functional and design requirements based on the geographical locations. This will significantly help reduce tender turnaround times and control overall costs. PMAY committee could even maintain a database of eligible contractors and continually update the same for added experience with time for overall uniformity and fairness.

6.6.7 Impact of Contractual Issues

Contract formats and conditions have a considerable impact on time and cost of completion, functionality and even the very feasibility of schemes with modern technology. These have to be properly administered centrally to ensure uniformity and equity to all concerned agencies, to ensure rapid realisation with efficiency and economy.

6.7 Specific Requirements for Promoting PCCon (Precast Concrete Construction) System

PCCon is one of the IBS technologies available and already in vogue for many years, without large scale adoption yet, in the housing industry. For effective implementation of PCCon systems in large volumes, it deserves certain measures to be taken in the near future by various stakeholders: Government, Architects & Engineers, Academia & Researchers, Development Agencies and the Manufacturers & Erectors of Precast Concrete Products. Much of what has been mentioned in Secs. 6.3 and 6.4 is generally applicable to PCCon also. However, the requirements vis-à-vis PCCon have been brought into more specific focus in this Section.

For the promotion of PCCon a Nodal Agency is required to coordinate as follows:

(a) Coordinating with the various stakeholders to deliver technologies, standards and practices for fast- track construction of housing using PCCon with best standards of performance, functionality, quality and economy.

(b) Conducting periodic technology related events to disseminate information on PCCon to various stakeholders (e.g., architects, designers, planners, clients) as well as to promote dialogue within the industry for developing better technologies, standards and practices.

(c) Developing standards for PCCon, such as a detailed Precast Concrete Construction Handbook similar to the PCI Handbook; developing standard Technical Specifications and Contracting Practices appropriate for PCCon and not merely based on conventional technology. These will require the mobilisation and coordination of various agencies such as BIS, CPWD, ICI, IITs and CSIR Labs engaged with PCCon knowledge base as well as the PCCon industry itself.

(d) Developing Testing and Certification practices for Systems, Elements, Connections and Functionalities; identifying authorised and capable Agencies for the same, similar to NPCA (National Precast Concrete Association) of USA or Construction Research Institute of Malaysia (CREAM).

(e) Setting up and running Skills Training Institutes for training the skilled labour required by the industry.

(f) Encouraging Academia and R&D Agencies to develop new technologies for materials (such as alternative raw materials for concrete to reduce carbon content for better sustainability, lightweight concrete, joint sealants for better durability, etc); better Joint systems, better Design & Detailing systems to suit all seismic zones; better construction systems and practices; better Quality and Safety standards and Practices; better project management practices such as Lean Construction Management; development of Building Information Modelling (BIM) and other Integrated Digitalization practices for enabling better Speed and Quality of materials management and construction (BIM, ERP, SCM, AR, VR, Lean,...); developing teaching materials for Engineering College students to learn more about PCCon before graduating, etc.

(g) Conducting specific familiarisation sessions for Architects, Designers and potential Customers on the advantages of PCCon and how to take advantage of this superior technology. It may be noted that one of the current impediments for development of PCCon is the reluctance of Architects and Engineers to use PCCon as no common general information is available for systems, dimensions and tolerances, joint systems, load bearing capacities, etc, and also due to an unfounded fear that precast systems are monotonous/ non-aesthetic, etc.

(h) Facilitating the development and nurturing of a common Precasting Industry Forum.

(i) Developing a Rating System for PCCon buildings based on Design, Construction methodology, Innovations and Quality, and administering the same.

(j) Conducting independent Audits of PCCon buildings to consolidate learnings from previous applications and improve the standards of the industry for future applications.

STANDARDIZATION IN HOUSING

PMAY(U) Project East Godavari-Andhra Pradesh

Technology - Monolithic Concrete Construction System

7. STANDARDIZATION IN HOUSING

7.1 Introduction

In all infrastructure development, including housing, it is necessary to prescribe appropriate quality benchmarks so that the huge investments made for the purpose result in assets which are truly functional, safe, durable and sustainable. In the field of housing, this would involve specifying standards for planning aspects and space norms, building materials and components, and for design and construction. As per entry no. 35 of Schedule VII of the Constitution of India, land development and building construction is a state subject. Further, as per the 18 entries of Schedule XII of the Constitution introduced through *74th Constitutional Amendment Act, 1992*, the concerned activities are to be regulated by the urban local bodies. The Town and Country Planning Act/Development Act, Municipal Corporation/ Municipality Act and Local Building Bylaws/Regulations are some of the instruments which are used by the states/urban local bodies for regulating the building construction activities within their jurisdiction.

The Bureau of Indian Standards (BIS) is the National Standards Body (NSB) of the country responsible for formulation of National Standards (called Indian Standards) under the provision of the *Bureau of Indian Standards Act, 2016*. As per the Act, the Indian Standards are voluntary in nature, but may become mandatory through a contract between parties, or through reference in a legislation or through a special order of the Government. For the sake of uniformity in concepts, understanding and implementation, it is necessary to have standardization across the various activities and the BIS Standards serve this purpose.

For housing and other building occupancy types, the BIS has formulated a series of standards on building materials and components, test methods for evaluating the same, basic loading codes, design and construction codes of the good practices for various material streams, construction project management guidelines and standards for various building and plumbing services. These have also been duly interwoven for ease of understanding and implementation in the National Building Code of India (NBC). In addition, NBC gives administrative provisions for regulating the building construction, apart from focusing on ensuring accessibility for persons with disabilities and the elderly, and also for sustainability and management of built asset/facility.

7.2 Indian Standards for Building Materials and Components

Building materials and components form essential ingredients to be utilized through various methodologies for building construction, as per the design requirements and practices prevailing in various parts of the country. These provide a wide choice for selection depending upon local availability of materials and skills, vulnerability of the location/site, design requirements, and aesthetic requirements of the owner. Various Standards are available covering a wide variety of such materials..

The complete set of Indian Standards for product standards and methods of their testing, and other standards can be accessed from BIS website www.bis.gov.in.

7.3 Indian Standards for Design and Construction

Buildings have to be designed to be safe against various loads, forces and effects covering dead loads; imposed loads; wind loads; snow loads; loads due to temperature, vibration, vehicles striking the buildings/stilts, fire tender movement, etc; or seismic forces. Therefore, BIS has brought out loading codes as well as formulated design codes for safe design of buildings to withstand these loadings, using various material streams/technologies. Also, the good practices for construction have been standardized to ensure actual execution as per the design and quality requirements.

As per the dynamic process of standardization, all standards are reviewed periodically and amended or revised from time to time, as may be required. As a continuous process to suit the needs of innovation and development, new standards for various items are formulated from time to time and existing standards are regularly updated.

7.4 National Building Code of India

In order to unify the building construction practices in the country and make them more rational, at the instance of the Planning Commission, the then Indian Standards Institution (now Bureau of Indian Standards) brought out the first building code of the country in 1970, as the National Building Code of India 1970 (NBC 1970). The various provisions of Indian Standards and additional information were carefully interwoven for a cogent reading and facilitating easy implementation. It became quite popular instantly and became the basis for development of building bye-laws by various state/local authorities, besides its copious references and use in architecture and engineering education, and for professional practice. The Code was subsequently revised in 1983, 2005 and 2016, with intermittent amendments as and when required. The

National Building Code of India 2016 (NBC 2016) is the current version covering detailed administrative and technical provisions in its 13 Parts (Part 0, and Part 1 to Part 12), some of which are further divided into Sections/ Subsections making a total of 33 chapters under the Code.

The contents of Part 2 'Administration' and Part 3 'Development and Control Rules and General Building Requirements' together are utilized to frame the main contents of the local building byelaws/regulations. Other Parts/Sections of the Code are cross-referred in the byelaws for compliance, with brief information additionally given in some cases to emphasize upon certain critical aspects. However, with the revision in the latest NBC 2016, the state/ local building regulatory instruments need to be quickly revisited, and revised and revamped, wherever still not done. The same should be then scrupulously implemented to ensure orderly, safe, accessible and sustainable land development and building construction. The Code needs to be made a part and parcel of the architecture and engineering education to help develop future building professionals to be well conversant with Indian Standards and the National Building Code of India.

7.5 Standards for Housing Technologies and Industrialized Building Systems

As already brought out in this report the focus is on speedier and large volume construction through the use of industrialized building construction.

For some of the technologies used as IBS, new Standards have been already developed, such as the following:

a) For Glass Fibre Reinforced Gypsum Panel based building construction:
   i) IS 17400:2021 Glass fibre reinforced gypsum panel-Specification
   ii) IS 17401:2021 Design and construction of buildings using glass fibre reinforced gypsum panels - Code of practice.
b) For pre-engineered buildings using mainly steel:
   i) IS 800:2007 General building construction steel - Code of practice (*third revision*)
   ii) IS 801:1975 Code of practice for use of cold-formed light gauge steel structural members in general building construction (*first revision*)
   iii) IS 15917:2020 Building design and erection using mixed/ composite construction (*first revision*)
c) Over the years, precast/ prefabricated concrete component has evolved as a viable alternative to conventional construction. BIS has formulated the Indian Standard, IS 15916:2020 'Building design and erection using prefabricated concrete - Code of practice (*first revision*)' which covers detailed provisions on

each of the following aspects:

i) Materials, plans and specifications
ii) Modular coordination, architectural treatment and finishes
iii) Components
iv) Prefabrication systems and structural schemes
v) Design considerations and requirements
vi) Joints (covering feasibility, practicability, serviceability, fire rating, appearance and water tightness of joints)
vii) Tests for components/structures
viii) Manufacture, storage, transport and erection of precast elements
ix) Equipment
x) Prefabricated structural units
xi) Common defects and remedies
xii) Common precast joint connections

Various other partial prefab component specifications and their design and construction standards find a reference in IS 15916:2020. The standard has been recently revised and updated.

d) A series of Indian Standards on planning, modular co-ordination and housing; partial prefab components including walling and flooring units and other precast concrete products, serve as complimentary standards to support the industrialized building construction. Also deployment of proper techniques of construction project management is important for success of prefab concrete construction (PCCon) projects by avoiding time and cost over-runs, and mitigating potential problems relating to quality, health and safety, risk to the project, etc. A series of standards have therefore also been formulated to address the above aspects, as IS 15883(parts 1 to 12).

7.6 Handbook for Precast Concrete Construction (PCCon)

In order to support the cause of promoting PCCon-based industrialized building systems, it would be required to develop IS 15916 as a further detailed elaborate standard or publish a separate detailed Design and Construction Handbook.

7.6.1 Background

The main impediments to widespread use of PCCon are the lack of awareness amongst architects and designers of the possibilities; lack of ready availability of details of various precast concrete components, the jointing systems, properties, etc coming from various manufacturers or different systems of precasting; lack of standard connection systems for various precast concrete elements across the entire range of manufacturing; lack of rigorous and uniform system of tolerances of precast components. To improve this situation it is necessary that all manufacturers of precast concrete components should (a) conform to the same set of standards, (b) make freely available all details of their manufactured components, (c) come to some understanding of standard connection systems which will be applicable across all the manufacturers, with an uniform set of tolerances. The above can be made possible by developing a common Handbook of Precast Concrete Design and Construction. The PCI Handbook of Precast and Prestressed Concrete developed by the Precast Concrete Institute of USA (PCI) (in ninth edition now) is an excellent example of such a Handbook. The Indian Concrete Institute (ICI) had indeed brought out a Handbook in 2015 but that was only the beginning and much more data has to be added to that to make it comprehensively useful to the construction industry. Particularly, the publication needs to prescribe compliable provisions which could become part of any successful contract, apart from certain guiding/informatory contents.

7.6.2 Contents of Handbook

In order to build up awareness among architects, engineers and potential home owners about the possibilities for PCCon and to minimize unnecessary duplication and wastage in manufactured components, it is suggested that the Handbook should contain, at minimum, the following data:

- List of standard precast concrete elements with preferred standard dimensions
- A collection of possible usages for assembling various types of structures using these elements
- A set of preferred standard connection systems applicable to the standard elements
- Standard loading systems applicable for these elements
- Standard designs for these elements for the standard loading systems, design procedures, nomograms and charts, standard details including rebar and prestressing cable layouts for these elements
- Standard erection procedures for these elements
- Standard procedures for testing and certifying these elements and connections
- Possible variations in these standard elements to create various architectural possibilities covering variations in colour, finishes, etc
- Use of advanced integrating technologies such as Building Information Modelling (BIM)
- Other standard data applicable for the various elements
- Standard technical specifications for design, manufacture and erection of these elements
- Standard contract conditions which can be applicable for PCCon. This is very essential as currently for PCCon contract conditions adapted poorly from similar conditions for *in-situ*

construction work are only being used and this poses enormous problems for PCCon construction. Typically, in PCCon, considerable work has to be done much before site erection can start, as works will go on simultaneously at many off-site areas, and as requirement considerable monetary investments have to be normally made for manufacturing of the precast elements well before start of construction at the site, etc.

7.6.3 Methodology for Compilation

To compile such a standard Handbook efficiently and speedily, it is necessary to bring together a multidisciplinary team well-versed in PCCon technology. The various experts should cover inter alia space planning, ergonometrics, architectural designs, structural designs, advanced concrete- related materials, manufacturing techniques, transportation possibilities, industrialized erection techniques, etc. Typically the efforts can be coordinated by an industry professional/ neutral body such as ICI (Indian Concrete Institute) in conjunction with INAE, BIS, PSSI (Pre-engineered Structures Society of India-the body of precast concrete manufacturers) and comprise experts from various fields such as architects, structural designers, material specialists, construction engineers, academic/ research bodies, etc. An expert from BIS, well conversant with the National Building Code of India (NBC), should also be involved to ensure that the Handbook is in line with the overall philosophy of the Building Code and is implementable. INAE participation will ensure that the Handbook will have good outreach among engineers and professionals and will also enable to bring on board eminent professional experts in the associated fields. A very competent Chairman is essential to head this body to properly coordinate the various agencies and persons and complete the work in a time bound manner. After the initial deliberations to define the common grounds, work has to go on in many parallel fronts for quick convergence. Possibly, about 9 to 12 months may be adequate to compile the Handbook with the above process.

7.6.4 Methodology for Widespread Use

The Handbook should be discussed in various public forums on a periodic basis during its development to elicit comments from the various connected groups - user clients, architects, designers, constructors, standardization experts, etc - so that such comments can be suitably incorporated in the Handbook even during evolution. After compilation, a series of workshops should be held to release the Handbook and popularize it among the various user groups.

THE RECOMMENDED WAY FORWARD

PMAY(U) Project Naya Raipur- Chattisgarh

Technology- Precast Concrete Technology

8. THE RECOMMENDED WAY FORWARD

8.1 Introduction

This Chapter contains *the recommended way forward* based on the study described in the preceding seven chapters, for consideration by the policy–makers, engineering & technology establishments, the industry, financial institutions, and, various stakeholders generally, all of whom face the challenge of providing adequate good quality housing for the entire population of India.

The suggested strategies to overcome the constraints for adequate supply of affordable housing given below are grouped into five categories, namely, *Financial, Efficient Land Use, Appropriate Technologies for Construction, Mainstreaming of Technologies by Policy, and, Developmental Studies.*

8.2 Financial Issues

There is an obvious need for creating a robust institutional framework for a financial mechanism to ensure access by the needy for getting the loans, and earmarking funds for affordable housing through Government resources as well as extra budgetary resources. Also, reducing regulatory complexities and introducing single window clearance are essential for bringing in new financial models such as 'rental-cum ownership housing'.

Further, in order to reduce the overall cost, *life cycle cost* approach should be adopted instead of the *initial cost* basis alone, and utilization of waste based recycled materials and products need to be promoted. The latter is also an environmental need to ease out the waste disposal issues and improve sustainability.

8.3 Efficient Land Use

A data bank should be created for the appropriate land lying idle within the public sector domain of the central/ state governments, to encourage some of its possible utilization for housing. In addition, there is a need to introduce urban governance reforms, such as, removing the need to obtain permission for non-agricultural use in the case of land that has been earmarked for residential purposes in master plans. Also, all relevant permits and approvals should be secured a priori.

8.4 Appropriate Technologies for Construction

In keeping with the need of industrialised mass housing, it is required to introduce state-of-the-art technologies for safer and disaster resilient housing, which are affordable and sustainable ensuring faster delivery. These will also improve the quality of construction in a cost effective and environment friendly manner across states/regions and achieve economies of scale in urban areas.

Besides this, there is a need to continually work upon and bring about innovation in the conventional technologies deployed in rural housing, such that the housing thus created meets the challenge of the rising aspirations of the rural population while satisfying the requirements of changing environment in a better manner.

8.5 Mainstreaming of Modern Technologies

8.5.1 New Technologies

As brought out in the report, there is considerable ongoing effort for developing or adopting new technologies suited to speedier and good quality construction of housing. However, in order to achieve due success, the following specific suggestions may be noted:

1. Adoption of EPC contract system for which Procurement Policy needs to be encouraged. Adoption of appropriate contract conditions such as, povisions of additional mobilization advance (for example, 20% in place of existing 10%) to the contractors to facilitate setting up of the manufacturing plant/ production of components, etc is also important.
2. Policy level interventions are also important for adoption of new technologies through a high-level committee of experts representing technical and financial departments to best mitigate and manage the risks perceived by policy makers and technocrats. Creation of a capable Nodal Agency to steer the various initiatives through the various stakeholders is very important.
3. Revisit pre-qualification criteria, especially the requirement of 'quantum of similar works' in tender documents to facilitate adoption of new technologies.
4. Demonstration of construction with new technologies at grass-root level required to showcase and educate all the stakeholders about the technologies. Awareness creation and construction of some public buildings to build confidence in public and increase user acceptability would be useful.
5. Capacity Building & Skill Development. There is a need to create a pool of specialists since at present there are inadequate capacities at professional level. As there is paucity of contractors working with new technologies, there is a need to build a platform/ panel of technology providers & contractors. Also, motivate existing

developers/builders to make use of emerging construction systems and utilize their plants & equipment, including capacities for "housing for all" mission.

6. Incentivizing innovation in construction through suitable reward or rebate could be a booster to new technologies.

7. Modular/standardized plans & design for different geo-climatic conditions to achieve appropriateness, speed and economy.

8.5.2 Industrialized Building Systems (IBS)

IBS concepts have been developed to meet the needs for rapid and quality construction of buildings on large scales with good economy of cost. IBS concepts have many advantages, such as: speed, cost economy, high quality, standardization, high construction safety, less need for construction space at site and better managed facilities. However, certain logical prerequisites have to be met, such as,

1. Ensuring large and sustained demand to meet the higher initial capital costs, standardisation, equipment and labour with better capabilities and specific designs.

2. Promotion by giving incentives, such as: higher ranking for qualification, taxation benefits, preference in bidding, etc.

3. Adoption of appropriate systems, such as, the slab and wall panel system for Precast Concrete Construction (PCCon) in urban applications, and locally suitable technologies for rural applications, with effective architectural interventions to take care of functionalities, aesthetics, space utilisation, and standardisation.

4. Particularly, for PCCon systems, familiarising the Architects and Designers in PCCon concepts, developing standardisation for uniformity across the entire PCCon industry, developing guidelines and comprehensive handbook material for a shared approach between clients, designers and producers, setting up testing and certification institutions.

8.6 Developmental Studies

In the aforesaid section, under the four heads, certain recommendations have been made in order to face, in a more effective manner, the challenge of providing good quality housing for all in the country. The implementation of these recommendations by and large will need to be addressed by technological establishments besides a very committed substantial push by the policy makers. In addition, it is felt by the authors of this report that scientists, engineers and architects in academic and R&D establishments have a definite role to play in taking this laudable and challenging task forward. Areas that should be taken up as part of this endeavour (these are indicative and not inclusive) are given below:

1. Innovative development related to Designs and Technologies for Rural Applications, with effective architectural interventions to take care of functionalities, aesthetics, space utilisation, and standardisation.

2. Assessment of Material and Skilled Manpower Resources for meeting projected demand for development of housing over the next two decades, to bridge the gap between demand and availability (keeping in view also the competing demands from other sectors of civil infrastructure), and to identify measures to overcome deficiencies.

3. Structural Health Monitoring Measures to be developed to enable the existing as well as upcoming housing stock to be utilised to the 'last mile', in order to economise on the use of financial resources.

ANNEXURES

Annexure 2.1

SUMMARY OF OBJECTIVES IN SDG 11

Goal 11: Sustainable cities and communities

More than half of us live in cities. By 2050, two-thirds of all humanity - 6.5 billion people - will be urban. Sustainable development cannot be achieved without significantly transforming the way we build and manage our urban spaces.

The rapid growth of cities - a result of rising populations and increasing migration - has led to a boom in mega-cities, especially in the developing world, and slums are becoming a more significant feature of urban life.

Making cities sustainable means creating career and business opportunities, safe and affordable housing, and building resilient societies and economies. It involves investment in public transport, creating green public spaces, and improving urban planning and management in participatory and inclusive ways.

Facts and Figures

4.2 billion In 2018, 4.2 billion people, 55 percent of the world's population, lived in cities. By 2050, the urban population is expected to reach 6.5 billion.	**3%** Cities occupy just 3 percent of the Earth's land but account for 60 to 80 percent of energy consumption and at least 70 percent of carbon emissions.	**828 million** 828 million people are estimated to live in slums, and the number is rising.
33 In 1990, there were 10 cities with 10 million people or more; by 2014, the number of mega-cities rose to 28, and was expected to reach 33 by 2018. In the future, 9 out of 10 mega-cities will be in the developing world.	**90%** In the coming decades, 90 percent of urban expansion will be in the developing world.	**80%** The economic role of cities is significant. They generate about 80 percent of the global GDP.

Source: https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-11-sustainable-cities-and-communities.html

Annexure 2.2

Pradhan Mantri Awas Yojana (Urban) - Housing for All (HFA) States/UTs wise Progress

Sr. No.		Name of the State /UT	Project Pro-posal Consid-ered	Physical Progress of Houses (Nos)			Financial Progress (in Crore)		
				Sanctioned	Grounded*	Completed/ Delivered*	Investment	Central Assistance	
								Sanctioned	Released
1		Andhra Pradesh	1,203	20,71,776	19,21,824	5,83,125	88,685.56	31,555.35	14,340.20
2		Bihar	520	3,26,546	3,07,783	96,098	18,329.26	5,165.61	2,544.76
3		Chhattisgarh	1,796	3,01,781	2,54,123	1,48,380	13,313.86	4,755.72	2,899.23
4		Goa	10	3,097	2,867	2,865	657.98	72.21	67.72
5		Gujarat	1,717	10,54,790	8,74,865	7,38,065	1,06,172.84	21,060.84	15,327.60
6		Haryana	457	1,65,427	88,221	53,416	15,510.32	2,944.68	1,349.18
7		Himachal Pradesh	308	13,053	12,625	7,876	863.33	235.81	172.41
8		Jharkhand	453	2,34,114	2,10,416	1,12,869	11,541.54	3,682.33	2,520.23
9		Karnataka	2,760	7,00,578	5,91,418	2,74,609	51,193.35	11,493.56	5,407.70
10	States	Kerala	699	1,57,430	1,28,878	1,02,396	8,270.76	2,611.60	1,832.43
11		Madhya Pradesh	1,853	9,58,100	8,58,671	5,20,939	52,506.62	15,709.71	11,671.14
12		Maharashtra	1,556	16,34,553	8,78,339	6,39,182	1,90,648.19	28,620.19	13,916.70
13		Odisha	976	2,12,950	1,61,777	1,08,869	9,727.56	3,350.97	1,885.86
14		Punjab	871	1,11,896	1,00,443	55,057	7,977.06	1,986.21	1,294.36
15		Rajasthan	422	2,66,692	1,70,187	1,37,516	21,857.38	5,039.92	3,313.22
16		Tamil Nadu	4,708	6,91,236	6,30,336	4,63,092	48,598.21	11,257.92	8,591.22
17		Telangana	303	2,47,079	2,35,413	2,10,079	30,099.27	4,396.03	3,044.09
18		Uttar Pradesh	4,536	17,14,013	15,29,132	11,40,483	83,785.89	26,978.71	19,355.84
19		Uttarakhand	243	66,473	39,775	24,991	5,289.01	1,209.46	636.35
20		West Bengal	656	6,93,436	4,90,692	2,84,631	37,500.52	11,070.19	5,654.40
Sub- total (States):-			26,047	1,16,25,020	94,87,785	57,04,538	8,02,528.52	1,93,197.02	1,15,824.65
21		Arunachal Pradesh	61	8,999	8,269	3,366	510.70	189.84	146.13
22		Assam	441	1,61,309	1,55,578	55,538	4,884.85	2,441.23	1,155.92
23		Manipur	45	56,029	45,569	6,555	1,445.21	841.11	342.78
24	North East States	Meghalaya	36	4,752	3,661	902	185.29	72.08	24.95
25		Mizoram	52	40,452	35,810	5,332	917.31	618.81	204.60
26		Nagaland	75	32,335	32,023	8,106	1,050.01	511.02	306.97
27		Sikkim	11	701	562	179	34.26	11.88	6.41
28		Tripura	122	94,289	80,689	60,117	2,948.44	1,512.97	1,091.21
Sub- total (N.E. States) :-			843	3,98,866	3,62,161	1,40,095	11,976.07	6,198.92	3,278.98
29		A&N Island (UT)	2	378	377	45	95.74	5.87	1.97
30		Chandigarh (UT)	-	1,194	1,129	1,129	253.29	27.13	25.56
31		UT of DNH & DD	9	10,011	8,789	6,370	848.33	210.26	164.95
32		Delhi (NCR)	-	28,449	27,288	27,288	5,444.16	653.44	624.76
33	UT	J&K (UT)	403	48,832	46,670	14,520	2,666.48	750.03	363.50

34		Ladakh (UT)	8	1,363	1,071	596	67.73	31.05	22.15
35		Lakshadweep (UT)	-	-	-	-	-	-	-
36		Puducherry (UT)	45	16,039	15,632	6,854	901.61	252.43	167.64
Sub- total (UT) :-			467	1,06,266	1,00,956	56,802	10,277.33	1,930.22	1,370.53
Grand Total* :-			**27,357**	**121.30 Lakh!**	**103.52 Lakh***	**62.43 Lakh***	**8.25 Lakh Cr.**	**2.01 Lakh Cr.**	**1.20 Lakh Cr.**

* *Includes completed (3.41 lakh)/ grounded (4.01 lakh) houses of JnNURM during mission period.*

! Out of 122.69 lakh houses sanctioned as on 31.3.2022, 1.4 lakh non-starter houses have been curtailed by some States against which States to put up new proposals by August 2022.

Source: Website of Ministry of Housing & Urban Affairs - https://pmay-urban.gov.in/

Annexure 2.3

STATE-WISE TARGETS AND PROGRESS (PMAY-Gramin)

S.No	State Name	MoRD Target	Completed	Percentage of Completion against MoRD Target
	Total	**27056624**	**19872931**	**73.45**
1	ARUNACHAL PRADESH	41596	5901	14.19
2	ASSAM	2084070	651767	31.27
3	BIHAR	3883611	3096048	79.72
4	CHHATTISGARH	1097150	826008	75.29
5	GOA	1707	138	8.08
6	GUJARAT	320306	388699	121.35
7	HARYANA	30789	21126	68.62
8	HIMACHAL PRADESH	15483	10605	68.49
9	JAMMU AND KASHMIR	201633	97226	48.22
10	JHARKHAND	1603268	1285457	80.18
11	KERALA	42212	21281	50.41
12	MADHYA PRADESH	3789400	2759941	72.83
13	MAHARASHTRA	1505983	851770	56.56
14	MANIPUR	46166	16200	35.09
15	MEGHALAYA	81677	31529	38.6
16	MIZORAM	13538	5987	44.22
17	NAGALAND	24775	5202	21
18	ODISHA	2695837	1700558	63.08
19	PUNJAB	41117	23312	56.7
20	RAJASTHAN	1733959	1365529	78.75
21	SIKKIM	1079	1073	99.44
22	TAMIL NADU	817439	411952	50.4
23	TRIPURA	282238	165605	58.68
24	UTTAR PRADESH	2615951	2577554	98.53
25	UTTARAKHAND	29052	25816	88.86
26	WEST BENGAL	3482359	3373260	96.87
27	ANDAMAN AND NICOBAR	1337	1117	83.55
28	DADRA AND NAGAR HAVELI	6763	2391	35.35
29	DAMAN AND DIU	68	13	19.12
30	LAKSHADWEEP	53	44	83.02
31	PUDUCHERRY	0	0	0
32	ANDHRA PRADESH	256270	46719	18.23
33	KARNATAKA	307746	101675	33.04
34	TELANGANA	0	0	0
35	LADAKH	1992	1428	71.69
	Total	**27056624**	**19872931**	**73.45**

Source: Website of Ministry of Rural Development - https://pmayg.nic.in/netiay/home.aspx

Annexure 3.1

DETAILS OF RURAL AND URBAN HOUSING STOCK AS PER CENSUS 2001 & 2011

Wall / Roof		2001 Census Houses		2011 Census Houses	
		No. of Houses	%	No. of Houses	%
WALL					
A - Mud / Unburnt Bricks	Rural	6,58,07,212	26.4	6,60,82,280	21.7
Unburnt Brick Wall with mortar	Urban	79,91,950	3.2	1,08,08,689	3.5
Total - Category - A		**7,37,99,162**	**30**	**7,68,90,969**	**25**
B - Burnt Bricks + Stone packed	Rural	8,30,63,818	33.3	10,45,52,560.0	34.3
With mortar	Urban	5,43,09,628	21.8	7,50,35,035.0	24.6
Total - Category - B		**13,73,73,446**	**55**	**17,95,87,595**	**59**
C1 - Wood + Concrete	Rural	46,17,179	1.9	58,31,438.0	1.9
	Urban	51,20,151	2.1	79,33,512.0	2.6
Total - Category - C		**97,37,330**	**4**	**1,37,64,950**	**5**
X - Other Materials	Rural	2,40,49,304	9.7	3,00,97,412.0	9.9
	Urban	41,36,627	1.7	45,41,522.0	1.5
Total - Category - X		**2,81,85,931**	**11**	**3,46,38,934**	**11**
TOTAL BUILDING UNITS		**24,90,95,869**		**30,48,82,448**	
ROOF					
R1 - Light Weight	Rural	6,93,42,567	27.8	7,94,30,355	26.1
Sloping Roof	Urban	1,73,50,091	7.0	2,12,69,826	7.0
Total		**8,66,92,658**	**34.8**	**10,07,00,181**	**33.1**
R2 - Heavy Weight	Rural	6,52,99,492	26.2	7,40,34,404	24.3
Sloping Roof	Urban	1,30,36,138	5.2	1,96,49,099	6.4
Total		**7,83,35,630**	**31.4**	**9,36,83,503**	**30.7**
R3 - Flat Roof	Rural	4,28,95,454	17.2	5,30,98,931	17.4
	Urban	4,11,72,127	16.5	5,73,99,833	18.8
Total		**8,40,67,581**	**33.7**	**11,04,98,764**	**36**
TOTAL BUILDING UNITS		**24,90,95,869**		**30,48,82,448***	

* Total No. of Houses excluding Vacant/Locked Houses

Source of Census of Housing, GoI, 2001 and 2011

Annexure 3.2

PREVALENT WALLING CONSTRUCTION SYSTEMS

i) **Rat Trap Bond:** Rat trap bond (RTB) is a type of modular masonry in which the bricks are placed in a vertical position such that a cavity is formed in the center of the wall while the thickness is maintained the same as that of the conventional brick wall masonry. The reduction in the center does not reduce strength but reduces the quantity of bricks by about 25%. The air cavity also provides good thermal comfort inside the building. RTB masonry walls are load bearing wall which are more sustainable and eco-friendly than solid masonry walls.

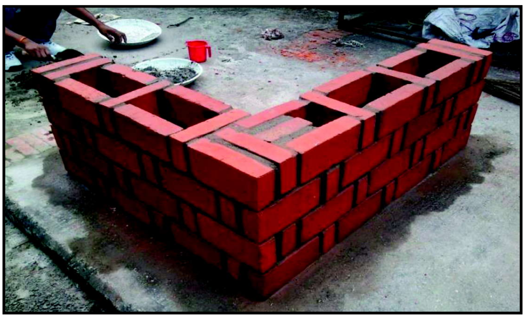


Figure A3.1: Rat Trap Bond

ii) **Staggered Masonry System:** Staggered masonry is a special type of masonry technique for construction of load bearing half brick/single wall (115 mm thick) suitable for a single/double storey building. Bricks required for this masonry technique should be of high quality and strength. To make the walls able to take lateral loads, a brick column of 230x230 mm is placed at intervals or 1200/1800 mm. The brick walls are laid such that each alternating wall is placed at alternating faces of the brick column laid in between. This gives the wall a zigzag or staggered look. Although it is a labour intensive technique, it saves almost 50% of the bricks as compared to conventional brick masonry.

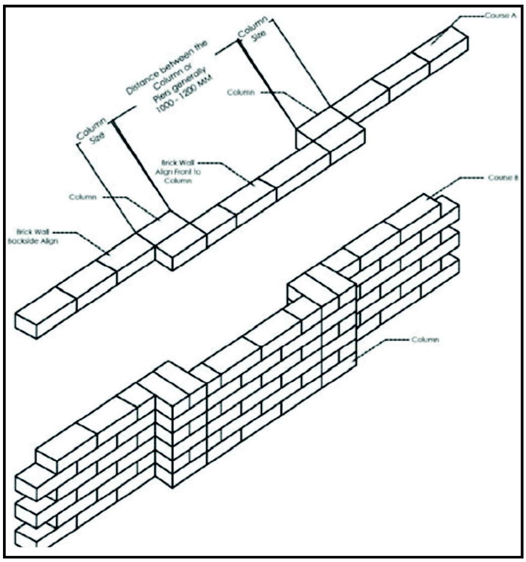


Figure A3.2. Staggered Masonry System

iii) **Precast Stone Block Masonry System:** In locations around the country where stone is readily available and is the major construction material, precast stone block masonry provides a viable option for walls. These walls constructed are thinner as compared to random rubble masonry. In precast stone block masonry technique, moulds are used for casting of uniform sized blocks. Stone spalls are places in these moulds and covered with concrete mix. Plate vibrators are used to compact the concrete. The walls constructed by this method are load bearing walls which can be used for construction of houses upto 3 storeys. Precast stone block masonry is faster, cheaper and more sustainable/resource efficient.

Figure A3.3. Precast Stone Block Masonry

iv) **Hollow Concrete Block Masonry System:** In hollow concrete block masonry system, concrete blocks of fixed sizes are used in masonry. These blocks have solid materials upto 50 to 75% of the total volume, with a hollow in the centre. The hollow portions in the center of the blocks can be used to conceal electrical conduits or water pipes. Due to the void the blocks are much lighter in weight than solid concrete blocks and possess high thermal and sound insulation. Various locally available materials like fly ash, cinder, river shingle, hydraulic lime etc. can also be used in the production of these blocks. The hollow parts of the blocks can also be reinforced with steel reinforcements for safety against earthquakes and cyclones.

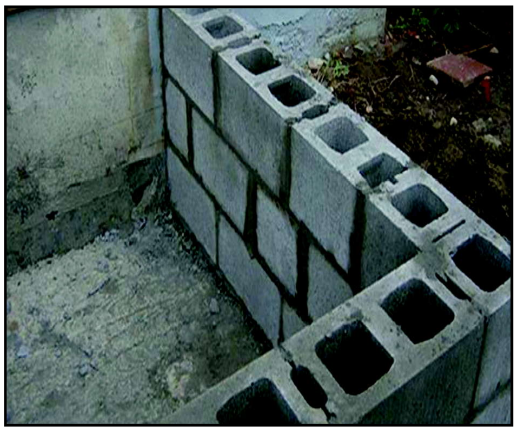


Figure A3.4. Hollow concrete block masonry

v) **Confined masonry system:**Confined masonry system uses the same materials for construction as the RCC frame construction with infill walls but in different sequence. Confined masonry building technology is applicable for construction of low-to-medium rise building. This technology has excellent seismic resistance, cost-effective and makes use of locally available construction materials and skills. In this system walls carry the seismic load and the concrete is used to confine the walls. In confined masonry system after the layout at site nominal reinforcements are erected first at the corner of the room and at intersections. After that masonry walls are erected upto the height of 1000mm by providing 25 – 40 mm toothing arrangement in masonry at interface of column and wall. The columns are 230x230 mm in size with light reinforcement and are called tie columns. Bond beams are placed at plinth and lintel level. The tie column and bond beams are used to bind the masonry walls in place.

Figure A3.5. Building with Confined Masonry

vi) Ashlar Masonry System: Ashlar masonry is a type of stone masonry which is formed using dressed stones of same size, shape, and texture laid together in cement or lime mortar with equal size joints at right angles to each other and in level courses. Since the basic construction material used is stone, the construction is very strong and weather resistant and possesses long life. For ashlar masonry work, it is specified that the length should not exceed three times its height. The breadth should not be greater than three-fourths of the thickness of the wall or less than 150 mm. The height can be up to 300 mm. It is considered best suitable for load bearing walls. Types of stone commonly used in this kind of building construction are granite, trap, basalt, quartzite, limestone, and sandstone.

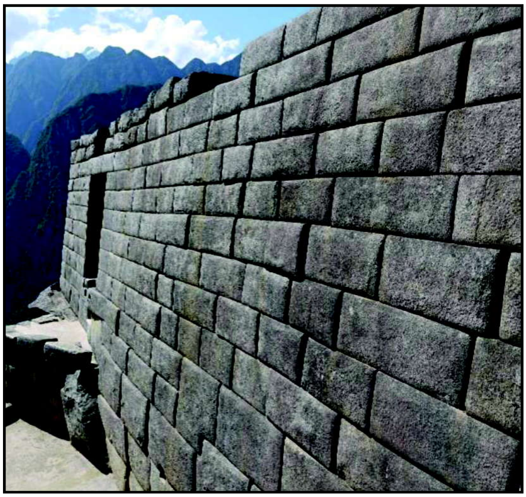


Figure A3.6. Ashlar Masonry System

vii) Random Rubble Masonry System: In random rubble masonry, irregular sized stones are used for erection of the walls and so no dressing of stones is required. This makes it the most economical solution available for construction amongst all the construction techniques in stone construction. These walls work with static compression loads only and are used with RCC beams and columns for resistance to earthquakes and wind load. The construction is durable and weather resistant. Types of stone commonly used in building construction are granite, trap, basalt, quartzite, limestone, and sandstone etc. Sometimes locally available softer varieties of stone like Laterite is also used in low rise houses.

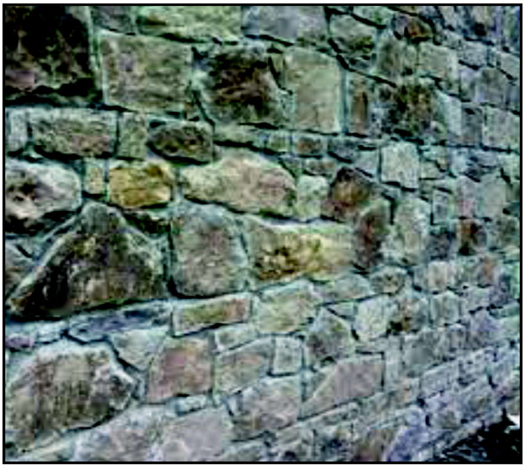


Figure A3.7. Random rubble masonry Image

Source: Clviconcepts.com

viii) Rammed Earth System: Rammed earth walls as the name suggests uses raw materials such as earth, chalk, lime or gravel. The process of constructing walls in rammed earth system involves formwork/ mould placed beforehand and filling it with suitable proportions of sand, gravel, clay, and stabilizer and compacting it inside the formwork. The proper compaction is done in layers to achieve upto 50% of its original volume. Since the major component is basically earth the walls are highly susceptible to moisture and needed high maintenance. Therefore, the construction technique cannot be used in high flood prone regions or areas with high rainfall. Apart from that if the walls are protected from moisture the walls are highly weather resistant and have a very low carbon footprint in comparison to other masonry systems.

Figure A3.8. Rammed Earth System Image

Source: research gate.net

ix) Compressed Earth Block Masonry System: A compressed earth block (CEB), is a building material made primarily from damp soil compressed at high pressure in a mechanical press to form blocks. If the blocks are stabilized with a chemical binder such as Portland cement they are called compressed stabilized earth block (CSEB) or stabilized earth block (SEB). These are cost effective for the construction of single or double storey houses duly strengthened by RBC/ RCC corners, junctions and bands. These blocks can be produced locally, with local resources by semi-skilled labour, hence economical and generates local employment.

Figure A3.9. Compressed earth block masonry system Image
Source: Wikipedia.org

x) **Fly Ash Bricks**: A fly ash brick is made up of min. 50% fly ash, the rest being Cement/lime and sand. Water is added to prepare the mix and to perform curing of bricks. It is a masonry unit, and is a 100% replacement/alternative to conventional bricks / red bricks. Government has provided guidelines to all the construction agencies working in the radius of 100km from any coal/lignite based thermal power plant, making it a must for them to use only fly ash based products/components. Fly ash being an industrial waste, is cheaply available in abundance. It is also hazardous to health and environment when loosely dumped in open areas. Thus, utilisation of the same in construction materials, saves the environment and health of people living in surrounding areas. These bricks can be manufactured right at the construction site using mobile unit or setting up of small manufacturing unit depending upon the quantity of bricks required.

Figure A3.10. Fly Ash Bricks Image
Source: Indiamart

xi) **Other Walling Systems Particularly Relevant For Rural Housing:** Apart from the construction techniques mentioned above there are certain walling systems which can be employed to take advantage of local materials, and which can be economic and eco-friendly considering the region of application. Some of these walling systems are described in brief in the following section:

xii) **Bamboo Strip Walling:** Bamboo is a prevailing construction material used in hilly regions. Bamboo construction can be predominantly seen in the north-eastern region of India. In areas where bamboo is a readily available material and is available at cheaper cost compared to conventional construction materials, bamboo strip walling systems can be a viable alternative. In this system stripped long pieces of bamboo are used to make a sheet structure by weaving the strips of bamboo together. These sheets can in themselves be used to create temporary partitions. In case of walls of residential rooms, these walls are additionally treated to be more resilient to environmental factors and various other horizontal forces protecting the habitants. These woven sheets are tied to the frame and then reinforced by fixing chicken meshes on top and covering with a 1:5 mix of cement mortar to provide additional stability. These walls can be upto 30mm thick after completion but cannot work as load bearing member.

Figure A3.11. Bamboo strip walling

xiii) **Kath-kuni Walling:** Kath-Kuni is an indigenous construction technique prevalent in the isolated hills of northern India, especially in the region of Himachal Pradesh. Kath kuni walling system employs the two most abundantly available resources in the mountains which are wood and stone as the name depicts, kath-

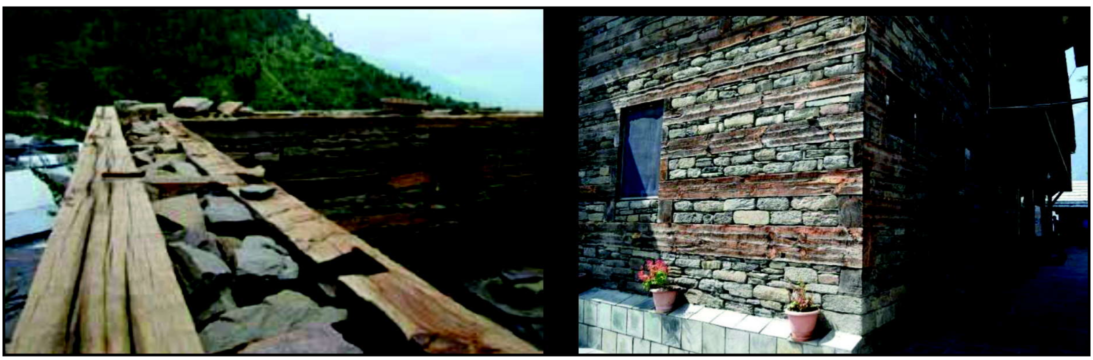


Figure A3.12. Kath-kuni Walling Image
Source: architecturaldigest.in

kuni literally means wood-corner. The Kath-kuni system is made by layering alternate courses of wood and stone to reach the height of ceiling in two layers with void in between. This void is then filled with smaller stones. They also act as insulation fillers between the outer layers. This makes the wall thicker - the thickness of such walls is around 600mm. Cost effective technology for the hilly regions where stone is freely available and local timber is cheap. Low maintenance with good seismic performance.

Dhajji-diwari walling system

Dhajji-diwari is a timber frame with stone and earth infill, typically used in the mountain regions of India. The spaces left between the bracing and/or frames is filled with a thin wall of stone or brick masonry traditionally laid into mud mortar, so as to create a patchwork of small size masonry panels. It is quite prevalent in the earthquake prone areas of Jammu and Kashmir. Significant earthquake resistance, cost effectiveness, use of indigenously available resources and skill, swiftness in construction process makes it a selective choice for earthquake disaster re-inhabitation.

Figure A3.13. Dhajji-diwari walling System Image
Source: www.iik.ac.in

Annexure 3.3

PREVALENT ROOFING MATERIALS/ SYSTEMS

(i) **Clay/micro-concrete Tiled Roofing with Insulation over Timber/Ferro-cement rafters:** Micro Concrete Roofing (MCR) tiles are made of concrete (mixture of cement, sand and cement) as an alternative to traditional roofing materials such as thatch, iron sheeting, or asbestos. MCR roofs can be used for a variety of applications in low-cost housing, institutional buildings, factories, parking areas, etc. These tiles are securely tied to the under structure with wires and therefore can also meet performance requirements of roofing in regions of high velocity winds like the coastal belt. MCR is used as a roofing material and can be made on frames made with timber construction or Ferro-cement rafters.

Figure A3.14. Micro-concrete tiled roofing

(ii) **Terraces with Insulation - Madras Terrace:** This is a traditional roofing technique particularly practiced in south India. It involves the use of wood and "aachikal "(a locally termed material which is a small brick, 25x75x150mm made from high density and high strength clay) and lime plaster, and is commonly used for small spans. Wooden beams laid at regular intervals from each other are used to cover the span. The gaps are filled with bricks on edge with lime plaster. Upon this surface, "aachikal brick" on edge is laid across in diagonal fashion plastered with lime.

Figure A3.15. Madras Terrace

(iii) **Various Roof Coverings:** The selection of roof covering material depends upon various factors such as availability of material, cost, appearance, durability, climatic zone etc. Mangalore tiles, or corrugated tiles, are the oldest and the most popular tiles since ages. The conventional size of Mangalore tiles is 420mm x 250mm but these are available in different sizes to suit different requirements. The tiles can be single or double grooved at the edges and are interlocked while laying. Country tiles, or curved pan/half round tiles, are attached with nails to the wooden sheathing or the common rafters of the pitched roof, spaced 300mm apart. The tiles are 330mmto 380mm long and 230mm to 280mm wide and are laid with sufficient overlap over each other. Concrete tiles are made of mixture of sand, cement and water, moulded under heat and high pressure. The exposed surface of a tile may be finished with a paint like material. They have additional water locks, or interlocking ribs on the edges that prevent water infiltration. These are resistant to hail, wind, and fire, making them a very safe roofing material when properly installed. Corrugated Galvanised Iron (CGI) sheets are a light weight roofing material made of thin sheets, stiffened by corrugations. These sheets should be properly anchored to each purlin/batten that supports them. Corrugations, such as waves, considerably increase the strength and stiffness of the lightweight material.

(iv) **Prefabricated Brick Panel System:** Prefabricated brick panel system is a durable and economical roofing/flooring system for low-cost houses. It provides strong and economical roof/floor consisting of partially precast RCC joists supporting the prefabricated brick panels covered with 35 mm thick cement concrete having suitable reinforcement. It is 30-35% cheaper compared to RCC slab; savings in cement, steel and brick are 20-25%, 32-40% and 30-35% respectively.

Figure A3.16. Prefabricated Brick Panel

(v) **'L' panel Roofing (Precast L-Panel Roofing):** Prefabricated L-Panel roofing mainly consists of full span R.C.C. L-shaped components. Sheets and purlins/battens, normally used in conventional sloping roof, are monolithically cast into single precast panel section as ‘L’ in this system.

Its smaller leg functions as rib of an L-beam and the wider leg (flange) as sheeting. The precast L-panels can be supported over sloping masonry gable walls, trusses, portal frames or sloping beams.

Figure A3.17. 'L' panel (above) & Filler slab roofing

(vi) Filler Slab Roofing with Various Filler Materials: Filler slab technology is a simple and cost effective technology in which concrete is partially replaced with light weight and low cost filler material. The filler materials are so placed that the structural strength, stability and durability is not compromised, resulting in replacing ineffective and non-functional tension concrete. This results in economy in consumption of high energy intensive material, cost savings and decreased dead load of the slab. An internal cavity can be provided between the filler material which adds an extra advantage of improved thermal comfort for the interiors. Light weight, inert and inexpensive materials such as low grade Mangalore tiles, Thermopolis Burnt Clay Bricks, Hollow Concrete blocks, Stabilized Mud blocks/ Hollow Mud blocks, Clay pots, Coconut shells, AAC blocks etc. and so can be used as filler materials.

(vii) RCC Channel Units (Precast Channel Unit): This system is used for faster and economical construction of floors and roofs in single and multi-storey buildings. It consists of a full span trough shaped precast RCC unit which can be used for roofs supported on suitable structures like brick/stone walls and RCC beams. The outer sides of the unit are corrugated and are grooved at the ends to provide shear key action between adjacent units. The length of the unit may be adjusted to suit the span to be covered, but the maximum length is restricted to 4200 mm for stiffness considerations.

Horizontal corrugations are provided on the two longitudinal faces of the units so that the structural roof acts monolithic after the concrete, grouted in the joints between the units, attains strength.

Figure A3.18. RCC channel units

(viii) Ferro-Cement Roofing Elements (Ferro-Cement Roofing Channels): The roofing system uses pre-cast Ferro-cement roofing channels of a segmental arch profile which are placed adjacent to each other, spanning over two supports. After partly filling the valley between channels with concrete, the channels form an idealized T-beam and are able to carry the load of a roof/floor. Ferro-cement usually comprises a uniform distribution of reinforcement by use of chicken wire mesh and welded mesh encapsulated in rich cement mortar, thereby achieving significant reduction in both steel reinforcement and dead weight of roof. This composition provides a more uniform distribution of strength as compared to RCC.

Figure A3.19. Ferro-Cement Roofing

Annexure 3.4

IMPLEMENTATION OF EMERGING TECHNOLOGIES IN VARIOUS STATES

S.No.	State/UT	EPS and other Sandwich Panel	Monolithic RCC using Aluminium Formwork	Monolithic RCC using Tunnel Formwork	Precast RCC Technology	Precast RCC (Waffle-crete)	SLIP form work	Fly-Ash Hollow Blocks	Precast 3 D Volumetric Technology	Prefabricated Steel Structure	Structural Stay in Place Formwork System	Light Gauge Steel Frame Structure (LGSF)	Glass Fibre Reinforced Gypsum (GFRG) Panel Sys tem	Overall houses Sanctioned
1	Andhra Pradesh	192	7,01,481	-	2,336	-	-	-	-	-	-	-	36	7,04,045
2	Chhattisgarh	-	6,882	-	11,111	-	-	-	-	-	-	-	-	17,993
3	Delhi	-	17,412	-	73,496	-	-	-	-	-	-	-	-	90,908
4	Gujarat	-	47,606	1,144	-	6,953	-	-	-	-	-	-	-	55,703
5	Haryana	-	14,700	-	10,750	-	-	-	-	-	-	-	-	25,450
6	Himachal Pradesh	-	-	-	-	-	-	-	-	249	-	-	-	249
7	Jharkhand	-	-	750	40,665	-	-	-	1,008	-	-	-	-	42,423
8	Karnataka	-	29,074	-	12,555	-	133	-	1,520	-	-	-	-	43,282
9	Madhya Pradesh	1,024	-	-	-	-	-	-	-	-	-	-	-	1,024
10	Maharashtra	-	1,72,277	32,031	1,66,306	-	3,099	864	-	-	-	-	-	3,74,577
11	Odisha	32	-	-	7,762	-	-	-	-	-	-	-	-	7,794

S.No.	State/UT	EPS and other Sandwich Panel	Monolithic RCC using Aluminium Formwork	Monolithic RCC using Tunnel Formwork	Precast RCC Technology	Precast RCC (Waffle-crete)	SLIP form work	Fly-Ash Hollow Blocks	Precast 3 D Volumetric Technology	Prefabricated Steel Structure	Structural Stay in Place Formwork System	Light Gauge Steel Frame Structure (LGSF)	Glass Fibre Reinforced Gypsum (GFRG) Panel Sys tem	Overall houses Sanctioned
12	Puducherry	-	1,136	-	-	-	-	-	-	-	-	-	-	1,136
13	Tamil Nadu	-	21,428	532	3,664	-	-	-	-	-	-	-	-	25,624
14	Telangana	-	12,316	8,739	-	-	-	-	-	-	16	16	-	21,087
15	Tripura	-	-	-	-	-	-	-	-	-	-	1,000	-	1,000
16	Uttar Pradesh	1,080	12,572	-	61,782	-	-	-	-	-	-	-	-	75,434
17	Uttarakhand	-	2,187	-	-	-	-	-	-	-	-	-	-	2,187
18	West Bengal	-	12,601	-	-	-	58	-	-	-	-	-	-	12,659
		2,328	**10,51,672**	**43,196**	**3,90,427**	**6,953**	**3,290**	**864**	**2,528**	**249**	**16**	**1,016**	**36**	**15,02,575**

Note: The figures mentioned in the table are referring to the implementation in various stages

Annexure 4.1

DETAILS OF 3D CONCRETE PRINTING

(i) What is 3D Printed Concrete?

Conventional concreting operations require a mould or formwork, within which the concrete in a fluid consistency is placed and vibrated to attain the same shape as the mould after deshuttering and after curing to attain required strength. Whereas 3D Printing, or Additive Manufacturing as it is called, is a type of Digital Fabrication and involves depositing extruded micro concrete, layer by layer within strips of small widths progressively to build up the required shape. The concrete is cast or printed layer-by-layer through an automated process, using a "Printer" in which the Extruder can move along X, Y and Z axes to create the geometry required (gantry system). Alternatively, a robotic arm system is also possible to have more flexibility. A Digital Construction Modelling Platform is required to form the concepts of the structure, translate the structure's information into the machine language for the Printer to form the structure. Buildings, Furniture or even Bridges can be 3D printed. Typical Printers are shown in Figs. A4.1 and A4.2. Some of the variants used in projects are Autonomous Robotic Construction System (ARCS), Large scale Additive Manufacturing (LSAM), Freeform construction (FC), DCP or c3DP (3D construction printing), LSAM (Large Scale Additive Manufacturing), Contour Crafting (CC), etc.

(ii) Advantages of 3D Printed Concrete

The elimination of formwork and staging, requirement for less labour force, increased productivity with the automated process, minimisation of waste and the flexibility in the design and geometry are some of its advantages. The machine-made production ensures high quality. It is easy to form complicated and elegant shapes without having to design, fabricate and use intricate moulds to cast these shapes. The process is much faster than conventional concreting. The compact equipment is light enough to be erected at any location without much difficulty. Overall, it can be considerably more economical than conventional construction, as seen from examples so far, if properly deployed. This technology could be useful for low cost mass housing, which are typically low-rise structures, without too many frills.

(iii) Examples so far

After initial trials with small-sized elements about 20 years ago, the technology has now sufficiently developed to form small buildings. Some of the examples are shown in Figs. A4.3, A4.4, A4.6, A4.7. US Army has demonstrated this technology to form barracks (Fig. A4.4). It is estimated that the growth of 3D printed concrete is about 15% per annum, on an exponential growth pattern. The first Indian 3D printed full-scale structure (Fig. A4.3) is a demo structure of size 1.8 × 0.8 × 2 m and was fabricated by assembling 3D printed modules, within the campus of Indian Institute of Technology Madras. IIT Madras is in the forefront in India, for developing this nascent, high-potential technology. A larger building in their campus was completed recently and inaugurated by the Vice President of India.

(iv) The Process

The prevalent basic processes of digital printing are extrusion-based printing, binder jetting, mesh mould approach (cutting and welding), smart dynamic casting, etc. Among the processes, the most widely used method is the extrusion-based printing. Extrusion, which depends on rheological properties of the material and geometrical configurations of the extruder, is classified as full-width printing (extrudate is equal to the breadth of target layer) and filament printing (breadth of the extrudate is much smaller than that of target layer), based on layering technique. The basic idea is that the additive material is capable of being pumped easily, extruded easily and upon extrusion is stable enough to stand without collapsing under its own weight and the weight of the subsequent superimposed layers. The material should not get clogged in the pipeline or the extruder but at the same time have enough yield strength to retain its shape with integrity and also bond with the new layers. In extrusion-based printing, one of the major challenges is the formation of the bond between the layers.

Since extrusion is so important for further performance that real-time quality monitoring may be desirable. One method is using a vision-based technique, in which 2D images are analysed in the system, and the reliability of the system assessed by comparing the images with material variations. This system is to develop a feedback-controlled closed-loop extrusion system which can be a precursor for automated quality monitoring of 3D concrete printing. The goal is to have layers which harden quickly but remain fluid enough to successfully bond with new layers.

Often it may not be possible to extrude the entire structure as one assembly. Some of the parts may have to be extruded separately and attached to the base by bond or dowels. It Is necessary to have a digital model of the whole structure and identify the portions which have to be extruded as separate units. The geometrical information is sent to the extruder in a machine language for extrusion along desired lines. The coordination between the nozzle travel speed and the material flow rate is crucial to the outcome of the printed filament. It is necessary to have a good integrated conceptual approach covering the geometry of the structure, the available equipment and the material characteristics and plan the work accordingly.

(v) Equipment required

Figs. A4.1 and A4.2 show typical Printers, in which the head (Fig. A4.5) can move along rails along x-axis, on rails transversely along y-axis and move up and down along z-axis. A robotic arm which has more degrees of freedom is also possible. The material can be fed into the pump through a hose from a typical mixer and the pump moves the material to the extruder. Typically, the print head can be a rectangular nozzle of 30 × 20 mm size. The head is controlled by a program to develop the required geometry. The unit is portable, facilitating its installation at various locations in the site.

(vi) Materials required

The quality of work depends on the properties of concrete such as pumpability, extrudability, buildability, and open time. Pumpability is the ease of transport of materials through the system, i.e. from the mixer to nozzle. Extrudability is the ease of extruding concrete through the nozzle at a given rate. Buildability is the ability of the printed concrete to retain the imposed loads of subsequent layers without deformation. The open time provides us with information about the change of workability over time: it refers to the time during which concrete retains its necessary fresh properties.

Some of the components of the materials are Portland-limestone cement with special additives, superplasticiser, etc. Polypropylene fibres are also used. The mixes that are designed for 3D printing need to be extruded through a nozzle to attain the required shape. The yield stress is an important rheological parameter for 3D printable concrete. An important factor, particularly for industrial applications, is that the mix must be robust with less variability.

(vii) Other aspects

The technologies of materials, process and equipment are still evolving. The process is highly sensitive to the material properties. Hence, there is a strong need for research & development covering all the areas to bring 3D printing to a stage where it can be used freely by many agencies. As mentioned earlier, in order to get the best utilisation out of this technology, it is necessary to have a totally integrated approach right from the architectural conception to site work, covering all the intermediate stages of mix design, process development, machine selection and operation, etc.

(viii) Further Work

The lack of established models for mechanical parameters for 3D printed structures, robust material properties for various types of equipment and forms and the absence of structural design codes and testing procedures require more research and attention. Building permission agencies also need to evolve approval parameters and procedures. Architects and structural designers have to evolve forms and procedures for designing suitable structures. Equipment manufacturers have to evolve universal designs to suit a variety of applications. Construction agencies have to come forward to adopt this technology freely in their projects. Academic institutions should conduct training programmes for the various stakeholders in using this technology universally. If the above are all done then 3D Concrete Printing has a very bright future for India, particularly for mass housing for economically weaker sections in both urban and rural areas.

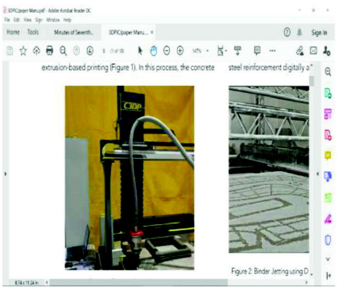


Fig. A4.1: A Frame Axis Printer

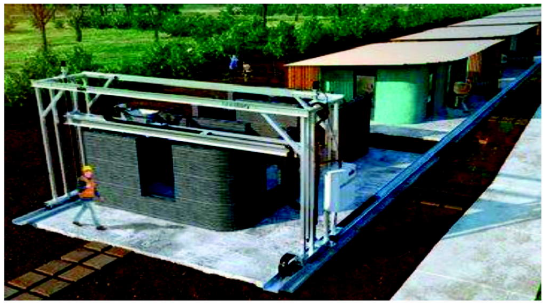


Fig. A4.2: A Portable Printer

Fig. A4.3: India's first 3D Printed Building

Fig. A4.4: US Army 3D Printed Barrack

Fig. A4.5: A Printer Head & Nozzle

Fig. A4.6: 3D Printed House

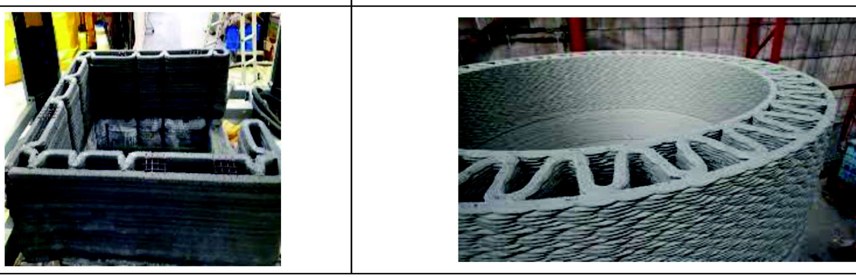


Fig. A4.7: 3D Printed Examples

Generally all edges of manufactured elements may be mildly chamfered or rounded to avoid damages during handling.

APPENDICES

Appendix A

List of domain experts/organizations with whom Extended Summary was shared and invited for discussion

Sr. No.	Name
1.	Sh. Durga Shanker Mishra, Secretary, Ministry of Housing Urban Affairs (MoHUA)
2.	Sh. R. K. Gautam, Director (HFA-V)Ministry of Housing and Urban Affairs Nirman Bhawan, New Delhi
3.	Dr. N. Gopalakrishnan, Director, CBRI – Central Building Research Institute Roorkee – 247 667, Uttrakhand,
4.	Shri P. K. Gupta, CMD, NBCC (India) Limited
5.	Shri Rajeev Mehrotra, CMD, RITES Limited,
6.	Director General, CPWD,
7.	Sh. Rakesh Desai, Director Managing Urbanisation NITI Aayog,
8.	Shri O. P. Agarwal, CEO, World Resources Institute (WRI) India
9.	Shri Sanjay Seth, Senior Director, Sustainable Habitat, TERI,
10.	CMD, National Housing Bank
11.	Deputy Director General, Rural Housing (RH), Ministry of Rural Development New Delhi,
12.	Smt. Rasika Chaube, Additional Secretary, Ministry of Steel, New Delhi,
13.	Shri Hitesh Vaidya, Director,National institute of Urban Affairs (NIUA)
14.	CMD, HUDCO
15.	Shri Rajeev Talwar, ChairmanNational Real Estate Development Council (NARDCO),
16.	Shri Satish Magar, Chairman, Confederation of Real Estate Developers' Associations of India (CREDAI)
17.	Shri Chandrajit Banerjee, Director General, Confederation of Indian Industry (CII)
18.	Shri V Suresh, Chairman Indian Green Building Council & Former CMD, HUDCO
19.	Shri Arindam Guha, Partner, Government & Public Services Leader, Deloitte India

20.	Sh. Sarvagya Kumar Srivastava Chairman, State Environment Impact Assessment Authority (Constituted by Ministry of Environment, Govt of India)
21.	Joint Secretary & Director General (NRIDA)Ministry of Rural Development, New Delhi

List of Academic/Industry experts

Sr. No.	Name
1.	Dr. A. Meher Prasad, Professor, Department of Civil EngineeringIndian Institute of Technology Madras, Chennai – 600036 Tamilnadu
2.	Prof. K. N. Satyanarayana, Director, IIT Tirupati
3.	Dr. B. Bhattacharjee Professor Department of Civil EngineeringIIT, Delhi
4.	Director School of Planning & Architecture, New Delhi

Industry experts	
1.	Shri Vijay B. Shirke, Chairman & Managing Director, B. G. Shirke Construction Technology Pvt. Ltd.
2.	Mr. Pranesh BabuTeemage India
3.	Shri Ramesh Joshi, Sr Vice President and Head Business Development, UltraTech Cement Ltd
4.	Mr. Satyanarayana CherukuriInventa Industries Pvt. Limited Flat No. 3200, Block 2A, Lodha Bellezza KPHB Colony, Kukatpally Hyderabad- 500072
5.	Everest industries limitedEverest Technopolis, D-206, Sector 63, Noida-201301
6.	Sh. Hitesh Jaju MGI Infra Private Limited, D-66, 60 Feet Road, First Floor, Chattarpur, New Delhi- 110074
7.	Col. M. AnandRCC Infra Ventures Ltd.14 GF, Vipul Agora, MG Road, Gurugram- 122002
8.	Sh. Rajib GhoshHIL Ltd.7th Floor, SLN Terminus, Survey No. 133, Gachibowli, Hyderabad- 500032
9.	Sh. R P GuptaRising Japan Infra Private LimitedI-203, SomVihar, R. K. Puram, New Delhi- 110022
10.	Smt. Saumya AnandCovestro (India) Private LimitedSB-801, 8th Floor, Cloud Campus, Empire Tower, Thane-Belapur Road, Airoli, Navi Mumbai-400708

11.	Sh. Jignasu Mehta Outinord Formworks Pvt. Ltd. Gat No. 628, 629, Tal Khed, Kuruli Chakan, Pune- 410501
12.	Sh. Rohit Sharma MFS Formwork Systems Pvt. Ltd. A1/268 1st Floor Indusand Bank Neelam Bata Road, NIT Faridabad Faridabad- 121001
13.	Sh. Sudhir Kumar Novel Assembler Private Limited 1418 B-Wing, Dalamal Tower, F.P. Journal Marg, Nariman Point, Mumbai City- 400021
14.	Shri M V Satish, Whole time Director & Senior Executive Vice President (Buildings) Larsen & Toubro Limited
15.	Shri S J. Vijay, Chairman Salmon Leap and Director hoM Mission India

List of INAE Fellows

1.	Prof. Indranil Manna, President INAE Vice Chancellor, Birla Institute of Technology (BIT), Mesra, Ranchi, Jharkhand
2.	Dr Sanak Mishra, Immediate Past President INAE341 Green Heavens, SAIL-CGHS,Plot 35, Sector 4, Dwarka, New Delhi-110078
3.	Dr. Purnendu Ghosh, Executive Director, Birla Institute of Scientific Research, Statue Circle, Jaipur – 302001
4.	Prof. AB Pandit, J.C. Bose National Fellow, UGC Research Scientist, Professor and Vice Chancellor, Institute of Chemical Technology, Nathalal Parekh Marg, Matunga, Mumbai-400 019
5.	Prof. Sivaji Chakravorti, Professor, Electrical Engineering Department, Jadavpur University, Kolkata-700032
6.	Mr. VN Heggade CEO, STUP Consultants Pvt. Ltd., 1004&5 Raheja Chambers, Nariman Point, Mumbai-4000021
7.	Dr. S Arunachalam Director, Jaypee Wind Engineering Application Centre, Jaypee University of Engineering and Technology, A.B. Road, Raghogarh, Guna, Madhya Pradesh-473 226
8.	Prof. R Gettu Dean, Industrial Consultancy & Sponsored Research, and Prof. VS Raju Chair Professor, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai - 600 036
9.	Prof. Ligy PhilipProfessor,Environmental & Water Resources Engineering, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai-600036
10.	Prof Subrata Chakraborty Professor and Head of Civil Engineering, Department of Civil Engineering, Indian Institute of Engineering Science and Technology Shibpur (Formerly Bengal Engineering and Science

	University Shibpur), Howrah-711 103 (West Bengal)
11.	Dr. SK Kamra Emeritus Scientist, Division of Irrigation & Drainage Engineering, Central Soil Salinity Research Institute, Karnal-132 001
12.	Dr. VN Sharda, Flat No.202, Tower No.3A,Suncity Parkrama Housing Complex, Sector 20, Panchkula-134 116 (Haryana
13.	Prof. MC DeoDepartment of Civil Engineering, Indian Institute of Technology Bombay, PowaiMumbai-400076
14.	Mr. MM Madan H.No- 704, Shiva Apartment,Sector- 21D,Faridabad-121001, Haryana
15.	Prof. Mahesh C Tandon, Managing Director,Tandon Consultants Pvt. Ltd.,17, Link Road, Jangpura Extension,2nd Floor, New Delhi -110 014
16.	Prof. Subhasish Dey Professor, Department of Civil Engineering,Indian Institute of Technology, Kharagpur-721 302 (WB)
17.	Prof. PP Mujumdar Chairman, ICWaR; Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore-560 012
18.	Dr. RK Bhandari, Distinguished Visiting Professor IIT, Roorkee
19.	Mr. VK Agarwal Formerly Chairman, Railway Board & Ex-officio Principal Secretary, Govt. of India
20.	Prof. PC Basu Former Distinguished Scientist & Director, Civil & Structural Engineering Division, Atomic Energy Regulatory Board, Mumbai
21.	Prof. SS Chakraborty, Formerly Chairman-cum-Managing Director, CES (India) Pvt. Ltd., New Delhi;
22.	Ms. Alpa Sheth, Managing Director,VMS Consultants Pvt Ltd, 83, Sakhar Bhavan, 230 Nariman Point,Mumbai-400021
23.	Prof. DN Singh, Department of Civil Engineering, Indian Institute of Technology Bombay,Powai, Mumbai - 400076
24.	Prof. SK ThakkarFormerly Professor, Railway chair & Professor of Earthquake Engineering, IIT Roorkee

Appendix B

INAE Forum on Infrastructure (HOUSING) Discussion Meeting Online

09 December, 2021. 12noon – 13.30 hrs

PROGRAMME

Welcome	Lt. Col. (Retd.) Shobhit Rai Deputy Executive Director INAE
About the Study on Housing	Professor Prem Krishna Chairman, INAE Forum on Civil Infrastructure
The Housing Scenario in India	Professor P K Sikdar, FNAE
Emerging Technologies for Mass Housing	Dr. S K Agarwal Executive Director, BMTPC (Buildings Materials and Technology Promotion Council)
Impediments & Way Forward	Prof. N. Raghavan, FNAE
Invited Address	Shri Durga Shankar Mishra, Secretary MH&UA
Presidential Remarks	Professor Indranil Manna, President, INAE
Discussion	*Moderators:* Prof. S. K Bhattachharyya, FNAE Dr. Mangu Singh, FNAE
Conclusion of Proceedings	Professor Mahesh Tandon, FNAE

The Indian National Academy of Engineering (INAE), established on April 20, 1987 as a Society under the Societies Registration Act, is an autonomous professional body. INAE was formally inaugurated on 11th April 1988 at New Delhi by the Hon'ble Prime Minister of India. It is supported partly through grant-in-aid by the Department of Science & Technology, Government of India since 1995. INAE comprises India's most distinguished engineers, engineer-scientists and technologists covering the entire spectrum of engineering disciplines. It was established with the mission of providing vital inputs to the planning for the country's development, particularly related to engineering and technological content and depth. The Academy provides a forum for futuristic planning for country's development requiring engineering and technological inputs and brings together specialists from such fields as may be necessary for comprehensive solutions to the needs of the country.

INAE honours Indian and Foreign nationals who are elected by “peer” committees in recognition of their personal achievements in “Engineering” which are of exceptional merit and have demonstrated distinctive eminence in the new and developing fields of technology. In the year 2022, INAE has 890 Fellows from India and 94 Foreign Fellows on its rolls identified in ten Engineering Sections. As the only engineering Academy of the country, INAE represents India at the International Council of Academies of Engineering and Technological Sciences (CAETS); a premier non-governmental international organization contributing to the advancement of science & technology and sustainable economic growth.

INAE has a three-tier interaction with the engineering and technological community, through eminent engineers and technologists who are elected as Fellows, Young Associates and Student Members. The Academy undertakes a large number of meaningful technical activities each year, which have enhanced its visibility in the national engineering domain. The activities of the Academy are carried out through the Fellowship and Young Associates supported by a lean team of professionals at INAE Headquarters