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Alternate Construction Technologies for Mass Housing:

Challenges to Adoption in India

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Table of Contents

Acknowledgement ..... **i**

Abstract ..... **ii**

1. Introduction **1**

2. Construction Technologies – an Explanatory Note **4**

2.1 Conventional construction technology *4*

2.2 Some alternate construction technologies for affordable mass housing in India *5*

2.2.1 Alternate formwork systems *5*

2.2.2 Prefabricated sandwich panel system *6*

2.2.3 Steel structural systems *7*

2.2.4 Precast construction *8*

3. Research Approach **8**

4. Findings – Challenges in the Adoption of Alternate Construction Technologies for Mass Housing in India **10**

4.1 High initial investment *11*

4.2 Achieving optimal scale required for commercial viability *12*

4.3 Reorientation of planning and design *13*

4.4 Transportation of building components *20*

4.5 Lack of skilled professionals *21*

4.6 Consumer scepticism and questions on liveability *22*

5. Concluding Remarks and the Way Forward **23**

5.1 Improving financial viability *25*

5.2 Improving operational viability *26*

5.3 Improving uptake among home-buyers *27*

5.4 Comprehensive technology assessment through a participative approach *27*

Bibliography **29**

Appendix **38**

List of Diagrams

Diagram 1: Conventional construction 5

Diagram 2: Engineered formwork system made of aluminium 6

Diagram 3: Light gauge steel framed structure 7

Diagram 4: Precast wall panel 8

Diagram 5: Locations of Sectors 16, 30, and 34 15

List of Table

Table 1: Policy measures for increasing adoption of alternate construction technologies in mass housing 24

List of Boxes

Box 1: First timer challenges and role of project planning: Affordable Housing Project in Naya Raipur 14

Box 2: Backward integration supporting adoption of pre-cast/alternate technology: Dream Acres Project, Sobha Developers 18

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Abstract

Rapid urbanisation and economic growth will increase the demand for adequate housing in Indian cities. Mass housing projects can help cater to this need. However, building mass housing using conventional technology is slow, lacks quality and is detrimental for the environment. In contrast, more mechanised alternate construction technologies substantially reduce construction time, improve quality, produce less waste and consume less water. Recognising their potential, the Government of India has launched the Global Housing Technology Challenge programme under the Technology Sub-mission of the *Pradhan Mantri Awas Yojana – Urban* to mainstream the use of alternate construction technologies in mass housing projects. In this paper, we point out that attempts to increase the adoption of alternate construction technologies may not yield easy results. Based on semi-structured interviews with 40 experts and practitioners from the residential construction industry, government, academia, and civil society and a literature review, we find six major challenges to the adoption of alternate construction technologies for mass housing in India: (i) high initial investment, (ii) achieving optimal scale required for commercial viability, (iii) reorientation of planning and design, (iv) transportation of building components, (v) lack of skilled professionals, and (vi) consumer scepticism and questions on liveability. We conclude with an outlook on the adoption of these technologies and some ideas on improving their uptake.

Keywords: *Construction technology, affordable housing, mass housing, GHTC, PMAY U, Lighthouse Projects, offsite construction, modular construction*

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Alternate Construction Technologies for Mass Housing: Challenges to Adoption in India

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1. Introduction

Urban India suffers from a massive shortage of adequate housing. The number of households living in inadequate housing conditions was estimated to be 4.7 crore in 2018 in urban India (Roy & Meera, 2020).[4,5] The Government of India, under the *Pradhan Mantri Awas Yojana – Urban*, assessed an aggregate 'validated' demand of 1.12 crore houses (Lok Sabha, 2021).[6] The demand for affordable housing is expected to grow in the decades to come as India urbanises rapidly, with the urban population to total population ratio of 34.9 per cent in 2020 expected to rise to 52.8 per cent in 2050, and as incomes grow with economic growth (World Urbanization Prospects: The 2018 Revision, 2019). Massive reverse migration from Indian cities during the 'lockdowns' imposed in the first wave of the COVID-19 pandemic in 2020 reflects that the poor migrant labourers lacked safe and affordable shelter for their families in these cities. To supply adequate housing to the lower- and middle-income segments in Indian cities, mass housing projects i.e., large complexes containing about 500 or more apartments, situated in urban and suburban areas will gain importance (Roy et al. 2007).

The conventional in-situ process of construction uses cement concrete and steel reinforcement to form reinforced cement concrete (RCC) used to build a framework of beams (horizontal members) and columns (vertical members). Subsequently, walls are constructed using brick masonry and floors are cast in-situ. This conventional process has limitations, particularly for large-scale mass housing projects (Building Materials & Technology Promotion Council, 2021). Assembling the timber-based formwork (i.e., moulds into which the concrete is poured) at the construction site is time-consuming, lacks repeatability, and is of poor quality and durability (Kazi & Parkar, 2015). Building the superstructure (i.e., the portion of the building above the ground level) in the open uncontrolled environment of a construction site exposes the project to weather disruptions and makes it difficult to monitor the quality of construction. This, in several cases, leads to inordinate delays, cost overruns, large quantities of construction waste, and suboptimal quality of the end product (Laubier et al. 2019).

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4 A household was considered to be living in inadequate housing if it was either homeless or living in an unserviceable *kutcha* house or in an obsolescent house or in congested condition in non-slum areas; or in slums

5 This includes 2.6 crore slum households and 2.1 crore inadequately housed non-slum households

6 An inadequately housed household may not necessarily be a part of the aggregate demand for new/improved housing. Only 1.12 crore households were assessed to actively want to upgrade their house or relocate to a better one as a part of the PMAY-U mission schemes

Alternate construction technologies offer an improvement over conventional in-situ construction by mechanising parts of the construction process. These alternate technologies can be classified under four broad categories – alternate formwork systems, prefabricated sandwich panel systems, steel structural systems, and precast concrete construction (Building Materials & Technology Promotion Council, 2021). There are several advantages of a shift to alternate construction methods from the conventional in-situ RCC process.

Most often, alternate construction technologies shift a part of the construction process to a factory location where the building components are manufactured at a rapid pace in a controlled environment. This reduces the construction time, often by as much as half the time estimated for conventional in-situ construction (N.Dineshkumar & P.Kathirvel, 2015) (Kaja & Jauswal, 2021) (Kazi & Parkar, 2015). The reduced construction time results in substantial cost savings by reducing the interest liability and providing quicker returns on investment (although the overall cost of deploying the technologies is likely to be higher due to high initial investment) (Macomber & Thapar, 2018) (Jaillon & Poon, 2008).

The quality of construction is superior since it is mechanised and produced in a controlled factory environment (Jaillon & Poon, 2008). Higher predictability that comes with the use of machines enables better planning and, therefore, optimal resource utilisation (Jiang et al. 2019) (Moradibistouni et al. 2019). Fewer unskilled labourers are required at the construction site reducing the human resource management burden for construction firms (Ginigaddara et al. 2019). The use of these alternate construction processes also reduces the risk of accidents at the construction site (Fard et al. 2015).

There are substantial environmental benefits from a shift to alternate construction processes as they reduce water consumption, optimise the use of resources, reduce the quantity of construction waste generated and are likely to have a lower overall carbon footprint. With global and national priorities aligned to limit climate change, this is another important driver for increasing the uptake of alternate construction technologies. It is important to point out, however, that the reduction in carbon footprint is also determined to a large extent by the design, the materials used and the transportation requirements other than the technology used (Pan et al. 2018) (Kong et al. 2020) (Moradibistouni et al. 2019) (Kawecki, 2010).

Considering the substantial advantages that the new technologies offer, the Government of India under the *Pradhan Mantri Awas Yojana – Urban* (2015) added a Technology Sub-mission to 'facilitate adoption of modern, innovative, and green technologies and building material for faster and quality construction of houses' (Ministry of Housing & Urban Poverty Alleviation, Government of India, 2015). The Technology Sub-mission is co-ordinating efforts to improve layout designs and building plans, mainstream innovative construction technologies, promote green buildings, and deploy disaster-resistant designs and technologies. The Global Housing Technology Challenge (GHTC) programme launched in 2019 under the sub-mission has taken several initiatives to showcase and create awareness about the benefits of innovative construction technologies.

A key initiative of the GHTC programme is the launch of six 'Lighthouse Projects' to build residential complexes of about 1,000 low-cost houses each using alternate construction technologies.[7] These projects are being built in six cities – Agartala, Chennai, Indore, Lucknow, Rajkot and Ranchi – by selected private contractors on land provided by the state government with the mandate that they had to be completed within one year (although all six projects have gone beyond their December 2021 deadline partly because of constraints posed by the COVID-19 pandemic) (Ministry of Housing and Urban Affairs, 2021). The projects are meant to demonstrate the speed, economy and better quality of housing that can be built using alternate technologies compared to conventional in-situ RCC construction. They are also meant to create awareness, encourage evaluation and documentation, and help mainstream the use of these technologies (Ministry of Housing and Urban Affairs, 2020).

The central government has also been organising biennial expositions to provide a platform to showcase and discuss innovative construction technologies under the GHTC programme. It also provides incubation and acceleration support to start-ups in the field of new construction technologies. Under the Affordable Rental Housing Complexes scheme of the central government, a substantial grant (of INR100,000 per double bedroom apartment and INR60,000 per single bedroom apartment) is to be provided for construction that uses innovative technologies. Thus, there has been a decisive effort by the central government to build the case for a technological shift in the residential construction industry over the last few years.

The central government's push to expedite the adoption of alternate construction technologies for mass housing is forward-looking but the transition from conventional to technology-intensive construction processes may not be smooth. As we point out in this paper, there are six major challenges that have prevented the diffusion of alternate construction technologies in the residential construction industry. The first is the high initial investment required before construction can begin. Second, a large number of housing units need to be built for the technologies to be commercially viable. Third, the transition from conventional to alternate construction processes involves a reorientation of planning and design. Fourth, for offsite technologies, there is an additional burden of transporting building components from the factory to the project site. Fifth, the shift in approach to planning and design requires a skill shift for construction professionals and vocational workers. Lastly, homebuyers are sceptical of purchasing houses built with new technologies, whose liveability data is as yet unclear.

There is another important implication of alternate construction technologies that we do not examine in great detail in this paper. The use of alternate construction technologies is expected to reduce overall requirement of construction labour (Jaillon & Poon, 2008). While this may benefit construction firms that routinely face delays due to seasonal availability of labour in conventional in-situ construction, the impact on the construction workers is likely to be mixed (Ram & Needham, 2016) (Roy et al. 2017). The shift to alternate construction processes will reduce unskilled jobs but will also produce more semi-skilled and skilled jobs in a

[7] In addition to the central assistance of INR150,000 per dwelling unit, a technology innovation grant (TIG) of INR400,000 for five LHPs and INR500,000 for Agartala LHP was also provided per dwelling unit, for each project.

manufacturing setting that would have a greater degree of social protection (Bertram, et al., 2019).

This paper is divided into five sections. In the following second section, we explain in greater detail how alternate construction technologies work and how the construction process differs from conventional construction. In the third section, we explain our research approach for semi-structured interviews with experts and practitioners and for the literature review. In the fourth section, we discuss in detail the six major challenges in the adoption of alternate construction technologies for mass housing in India based on interviews with experts. In the final, section we share the outlook for the adoption of these technologies and the way forward for improving their uptake.

2. Construction Technologies – an Explanatory Note

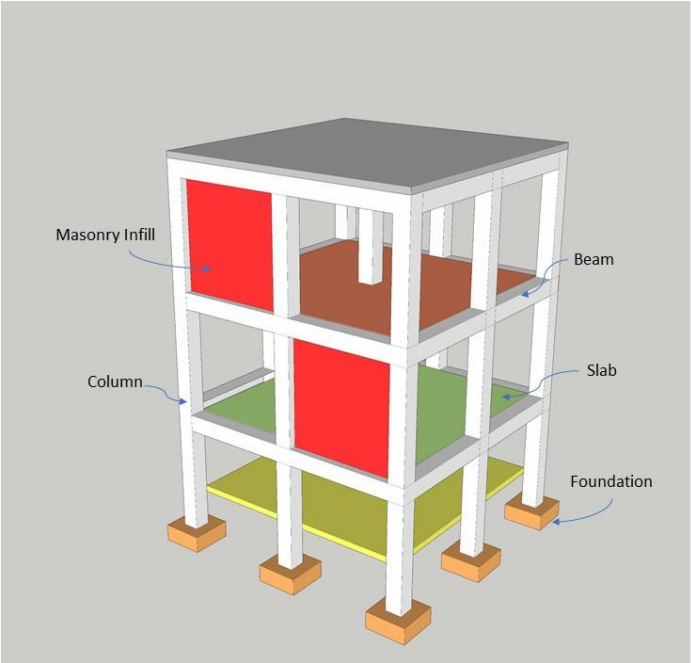
2.1 Conventional construction technology

The process of constructing a building involves clearing and levelling of land and laying the foundation of the building on which the frame or the superstructure of the building is built. The superstructure of the building comprises of vertical columns and horizontal beams that support the floor slabs and the weight of the building. (Diagram 1).[8] In conventional construction, the superstructure of the building is constructed on site. Once the floor level superstructure of the building is in place, the external walls which envelope the floor space of the building, and the internal walls are built. The internal walls divide the space into rooms. After this, finishing works such as electrical work, plumbing work, polishing the floors, and painting the walls takes place. Once the building is near completion, the external land is developed enabling clear access to the building, and the building is considered ready for occupation.

Building the superstructure in an open uncontrolled environment prevents precision in planning and makes it difficult to monitor the quality of construction. This in many instances results in inordinate delays, cost overruns, and suboptimal quality of the end product. The per unit cost of constructing repetitive elements of the building design is not brought down, i.e., economies of scale are not achieved adequately through standardisation and the use of technology in conventional on-site construction (Roy & Roy, 2016). A large amount of construction waste is also produced in the process, raising questions about the environmental sustainability of this approach (Jaillon & Poon, 2008).

[8] Before this method of construction became popular, masonry walls used to bear the weight of the building, instead of columns, beams and floor slabs. Such walls are referred to as load bearing walls. These buildings were usually one or two stories high.

Diagram 1: Conventional construction



Source: Author – drawn using Trimble Sketchup software and MS PowerPoint

2.2 Some alternate construction technologies for affordable mass housing in India

Various potential alternate construction technologies can be used for affordable mass scale housing in India. Twenty-four such technologies are at present being promoted by the Government of India (Building Materials and Technology Promotion Council, 2018).[9] These 24 alternate technologies can be broadly grouped into four categories following the classification followed in Building Materials and Technology Promotion Council (2021):[10]

- Alternate Formwork Systems
- Prefabricated Sandwich Panel Systems
- Steel Structural Systems
- Precast Concrete Construction

2.2.1 Alternate formwork systems

Formwork is the supporting frame made of timber or plywood or steel plates, which is assembled on site to form the mould for columns, beams and slabs into which concrete is poured. The assembled formwork is further propped up by supports made of steel or wood. Once the concrete has set and hardened, the formwork is dismantled. Usually, assembling and dismantling the formwork is time consuming and labour consuming, particularly for large-scale

[9] https://bmtpc.org/DataFiles/CMS/file/PDF_Files/BMTPC_Compendium_ET_Sept2018_3rdEdition.pdf, accessed on 21 August, 2021

[10] https://ghtc-india.gov.in/Content/pdf/Navaritih_Book.pdf, accessed on 5 November, 2021

mass housing projects. Instead, alternate formworks, using an entire unit – for example, one room or one floor – comprising columns, beams, slabs and walls can be cast in one pour of concrete, requiring less labour and time.

Such alternate formwork systems are of two types – engineered formwork systems and stay-in-place formwork systems. In engineered formwork systems, the formwork is dismantled once the concrete is set. Engineered formworks are made of aluminium, plastic or other composites (Diagram 2). They can be used for 300 to 500 repetitions and can be used for low-rise as well as high-rise structures (Building Materials and Technology Promotion Council, 2018). Stay-in-place formworks are suitable for low rise and mid-rise buildings. In a stay-in-place formwork system, the formwork is left within the concrete and thus becomes a part of the building. Engineered formwork and stay-in-place formwork is manufactured in factories by firms specialising in the manufacture of these alternate formwork systems and are made to order. In most cases, these alternate formworks are imported from outside India, where they are designed and manufactured exclusively for the project.

Diagram 2: Engineered formwork system made of aluminium

Source: Shutterstock

2.2.2 Prefabricated sandwich panel system

The prefabricated sandwich panel system includes floor slab panels, wall panels and stair panels. These panels are manufactured offsite in a factory, transported to the building site and then erected to form the superstructure of the building. A prefabricated sandwich panel has a core with outer layers of different material on either side. In many cases, these panels bear the load of the building, not requiring the use of columns and beams. Some of these panels have an inner core with metal meshes on both sides, on which concrete is sprayed. Other prefabricated sandwich panels do not require further coats of concrete and are usually referred

to as drywall panels. In some of these drywall panels, the inside core is made of insulating material like expandable polystyrene (EPS) and extruded polystyrene (XPS). These panels are also referred to as structural insulated panels (SIP). Usually, most prefabricated sandwich panel systems are suitable for low-rise to mid-rise buildings. Some panel systems, such as glass fibre reinforced panel systems (GFRG), can be used for high-rise structures as well. However, in that case, the columns, beams and slabs or the load bearing elements of the super structure are constructed using a different technology. Prefabricated sandwich panels are also manufactured in factories and transported to the construction site.

2.2.3 Steel structural systems

In steel structural systems, the conventional load bearing RCC columns and beams are replaced by a frame or skeleton of steel columns and beams. This steel frame supports the roof, floor and walls of the building. Recent innovations have enabled the use of light gauge steel framed structures (LGSF) for low-rise and mid-rise buildings. The walls and slabs (floor/roof) can be constructed using conventional or alternate methods. The lighthouse project in Agartala, Tripura, is being constructed using light gauge steel structural technology.

Diagram 3: Light gauge steel framed structure

Source: Photograph taken by the Project Architect, Mr. Shrutiniwas Sharma, on October 28, 2018, in NOIDA, Uttar Pradesh

2.2.4 Precast construction

Precast technologies involve the manufacture of various components of the superstructure of the building in an offsite plant and assembling these components on site. Columns, beams, slabs, walls, stairs, and even entire rooms are manufactured in an offsite plant, transported to the site and assembled to form the superstructure (Diagram 4). The precast components are assembled with the help of cranes and other machinery, and joined together using joinery elements like splices, billets, bolts and inserts of different shapes and sizes depending on structural design requirements. The kind of cranes and other machinery required on site depends on the volume, the size of the precast components and the height of the building. Once assembled and joined together, the building only requires finishing work in terms of electrical work, plumbing work, flooring, painting and other internal and external finishes. Precast technologies involve moving a significant proportion of the construction process offsite to a factory-controlled environment.

Diagram 4: Precast wall panel

Source: Shutterstock

3. Research Approach

The study involves a review of literature and media articles accompanied with semi-structured interviews with various experts and practitioners associated with the affordable housing sector, particularly those involved in the adoption of alternate construction technologies. The adoption and diffusion of alternate technologies for construction of affordable housing in India will involve co-ordinated efforts of a network of policy actors. The decision to use alternate technologies for an individual project will involve the developer, financiers, contractors,

structural engineers,[11] architects and quantity surveyors. The mainstreaming of alternate technologies in the residential construction industry will involve the support of various industry bodies, government and its agencies, construction firms, manufacturers, architects, academics and civil society organisations. The aim of this study was to understand the varying perspectives of policy actors involved in the adoption of alternate construction technologies to build mass housing. To this end, a group of experts and practitioners with several years of experience in alternate construction technologies were chosen for interviews from the range of policy actors highlighted above. Appendix 1 gives details of the profiles of experts and practitioners interviewed for this study.

Since the purpose of this study was to understand the challenges in the adoption of alternate construction technologies for mass housing, a sizeable chunk of the interviews was conducted with developers and general contractors who are decision-makers and have day-to-day experience with the use of these technologies. Their insights were useful in developing the authors' understanding of the challenges faced on the ground and nuancing the insights from the literature review. A diverse set of practitioners were interviewed, from middle management (site managers, engineers) to upper-management (director, senior executives), with experience in different kinds of alternate construction technologies.

Government officials interviewed ranged from site engineers to administrators who were involved closely with the adoption of alternate construction technologies. Their insights brought forth the measures that the government was taking to further the adoption of these technologies across several levels – from policies to site level execution. The academic experts interviewed had vast research and teaching experience in the use of these technologies. Their insights were helpful in corroborating insights from other experts and bringing about a deeper understanding of the challenges faced. Experts among architects were selected based on their experience in designing affordable housing projects involving alternate construction technologies. Discussions with them brought forth the pros and cons of using these technologies while focussing on the challenges associated with the designing and planning of such projects.

Experts from civil society organisations and think tanks engaged with affordable housing were interviewed for their views, along with an experienced journalist working in the domain of real estate and construction. Their views were important in developing the authors' understanding of the middle-income homebuyers' and low-income homebuyers' response to these new technologies.

An interview guide (Appendix 2) was developed for the interviews, after consultation with two experts – (i) an academician and researcher of construction techniques, and (ii) an architect and structural engineer involved in an offsite housing project with a prominent affordable housing developer. Based on the interviewee's area of work, emphasis was laid on certain sections of the interview guide. For example, architects were asked more questions about design aspects;

[11] A structural engineer designs the load bearing structures of a building – columns, beams and floor slabs – keeping in mind the safety and longevity of the building

the discussion with developers and contractors was built around investment, scale and logistics, while civil society professionals were asked more questions about acceptability among homebuyers. Interviews were conducted through video-calls, voice-calls and in-person meetings in 2021.

In total, 40 interviews were conducted. In the first set of 14 interviews, an outline of the major challenges highlighted in this paper became evident. In the next set of interviews, a nuanced understanding of each challenge was developed. By the end of 31 interviews, the authors noted significant repetition of key insights that were substantiated by different kinds of examples. At this point, all interviews were analysed and a second round of literature review was conducted. Thereafter, 9 more interviews were conducted to corroborate the authors' understanding of the challenges and draw conclusions from the evidence.

A semi-systematic literature review was conducted for this study in two phases – first, before the interviews in order to prepare the interview guide, and second, after the interview process to analyse interview findings (Snyder, 2019). Some of the keywords used to locate sources in the pre-interview phase were modular construction, offsite construction, industrialised building systems, prefabrication, precast concrete, mass housing, low-income housing, housing technologies, etc. Sources were selected on the basis on a number of criteria. Apart from checking whether the title and abstract were relevant to the purpose of our research and whether the source was peer-reviewed and cited by other authors, we discarded, except in some cases, sources that were too old (earlier than year 2000), prioritised those that were written in the Indian context and those in which information was presented in an organised manner. Sources were also selected from the reference list of relevant articles and reports (i.e., using the snowball method).

During the pre-interview phase, there was specific focus on identifying the 'challenges' presented in the literature with regard to the adoption of alternate construction technologies for mass housing. This helped shape the interview guide. In the post-interview phase, the focus of the literature review was to examine the validity and importance of interview findings. Therefore, keywords used to locate sources were based on the interview findings. Interview findings were rejected, accepted or further developed based on the literature review.

4. Findings – Challenges in the Adoption of Alternate Construction Technologies for Mass Housing in India

There are six major challenges to the adoption of alternate construction technologies for mass housing in India: (i) high initial investment, (ii) achieving optimal scale required for commercial viability, (iii) reorientation of planning and design, (iv) transportation of building components, (v) lack of skilled professionals, and (vi) consumer scepticism and questions on liveability. These are discussed in detail below. References to the interviews are marked according to the respondent type – private developers (PD), contractors (C), architects (A), academic (AC), government officials (G), media (M), civil society (CS), and international standard setting body official (SS). Appendix 1 provides further details on respondent types. Appendix 3 summarises key interview findings.

4.1 High initial investment

The overall costs involved in mass housing construction using alternate construction technologies may be classified into four categories. Depending on the degree of vertical integration, one or many firms in the supply chain may incur these costs.[12] These are:

i. initial investment in setting up a factory to manufacture building components; this includes the costs involved in the purchase of factory land, machinery, storage infrastructure, transportation vehicles, and other pre-production costs.[13]

ii. building component cost, which includes design, material, labour, storage and transportation costs in the manufacture of building components and transporting these to the project site

iii. cost of erection/assembly/concreting at the construction site to set up the building structure

iv. cost of finishing works

The high initial investment required in the factory set up to produce building components is a critical barrier in the adoption of alternate construction technologies (Pan et al. 2007) (Nanyam et al. 2017). For comparison, the capital cost of using precast construction for a project of about 1700 apartments of 40-60 square metres each (1BHK-2BHK) in Bengaluru was estimated to be INR300 million as compared to INR135 million for conventional cast in-situ (Macomber & Thapar, 2018). Some alternate construction technologies such as engineered formworks may not require a factory set up as the customised formworks for a project are typically purchased from specialised manufacturers. However, since the formworks themselves are expensive, the capital cost of using engineered formworks too is higher than conventional in-situ RCC construction (Kazi & Parkar, 2015) (Sorate, et al., 2014). Similarly, customised steel structural members used for light gauge steel frame (LGSF) technology may be manufactured by the contractor or purchased from a specialised manufacturer – in either case, the initial capital cost is high.

Land is expensive in India and factory land can constitute as much as 40 per cent of the total initial investment of setting up a factory (Mehta & Rajan, 2016) (Appendix 3.1.2). Factory land is more commonly leased for the period of the project rather than acquired permanently (C-10). For example, Navi Mumbai's town planning authority CIDCO leases land to contractors to set up a precast factory for its mass housing projects within a few kilometres of the project sites, something its counterpart in Mumbai (MHADA) is not able to do due to high land prices in Mumbai (G-3). In some cases, when adequate land is available at the project site, a temporary factory is set up at the site itself for the production of building components (Gils, 2017). In

[12] Laubier et al. (2019) classifies the business models as end-to-end providers (vertically integrated asset-heavy generalists) and ecosystem co-ordinators (asset-light overseers with a constellation of specialised partners).

[13] For large-scale mass housing projects that are located in the peripheral areas of a city, the development of trunk infrastructure at the construction site to supply public amenities like roads, water supply and electricity is another important initial investment. In most cases, this is a public investment undertaken by the urban local government/state government body.

most cases, however, the factory site is located far away from the project site in the outskirts of the city where land is cheap and readily available (Appendix 3.4.2). It is critical to optimise the location of the factory to manage costs. Cheaper land outside the city could translate into high recurring transportation costs while an expensive parcel of land for the factory close to the city centre can minimise transportation costs (Appendix 3.1.3). The typical weight of building components to be carried to the construction site (precast blocks, steel members, wall panels) varies among different technologies and can influence the location of the factory.

Purchase of machinery to produce building components is another expensive investment. While some international machine manufacturers have set up units in India that produce smaller parts the bulk of the machinery still has to be imported typically from Europe and the United States (Appendix 3.1.6) (C-2). If the uptake of alternate construction technologies increases, more machinery manufacturers may set up units in India, which would reduce the cost.

While these initial investments are large, banks are not particularly hesitant to lend to construction firms to set up factories for the production of building components although the cost of credit may be slightly higher (Appendix 3.1.7). The faster speed of construction that nearly all alternate technologies offer may actually help banks recover their loans earlier than anticipated. As can be expected, lending agencies prefer to finance large construction firms that can demonstrate their ability to manage large projects (Mao, et al., 2016).

In the industry's initial years of development, government may provide some financial incentives particularly to make the initial factory investment commercially viable for private sector construction firms (Appendix 3.1.10). Governments may, for example, lease land to factories at low rates, provide a higher proportion of funds upfront for public mass housing projects, or provide an interest subsidy on the initial capital investment. It may provide production linked incentives (PLIs) to encourage domestic firms to manufacture machinery which would help reduce cost. Incentives may also be given for the use of alternate construction technologies in the form of extra FSI or the benefits extended to green buildings (A-1, G-1, AC-2). Under the GHTC programme, developers who completed the construction of lighthouse projects within a year were to receive a financial incentive of INR1.5 million (USD20,000) – a somewhat larger amount may be necessary to really incentivise developers (AC-1). All six projects have missed their deadline partly because of constraints imposed by the COVID-19 pandemic.

4.2 Achieving optimal scale required for commercial viability

All manufacturing industries benefit from economies of scale, i.e., the cost per unit of output decreases with an increase in quantity produced. Alternate construction technologies can bring substantial gains by realising economies of scale in the construction industry. When manufacturing building components at scale, the construction industry can adopt mechanised production of standardised components, integrate and synergise the supply chain, and innovate and improve quality through increased competition – all of which will help drive down the cost of building housing units (Lou & Guo, 2020) (Roy & Roy, 2016).

However, the scale at which the use of alternate construction technologies in the residential construction industry becomes financially viable and comparable in cost to conventional in-situ construction is rather large (Appendix 3.2.1). For a monolithic concrete construction system using engineered formwork, at least 500 housing units may be required and, for precast, the required scale may be as high as 5000 housing units (Building Materials and Technology Promotion Council, 2018) (Bertram, et al., 2019) (Roychowdhury et al. 2020) (Appendix 3.2.2). The six lighthouse projects under the GHTC programme that seek to demonstrate the utility of six new construction technologies are also building about 1000 apartments each using these technologies (Global Housing Technology Challenge-India, 2021). The high scale requirement of using alternate construction technologies implies that they are relevant primarily for large-scale mass housing projects.

One way to fulfil the high scale requirement for factory-based construction technologies is for a factory to supply to several mass housing projects in its vicinity (Appendix 3.2.3). This factory-centric model would allow small-scale mass housing projects to use alternate construction technologies which would help in the technologies' diffusion. Groups of developers, general contractors, industry bodies or even government agencies may come together to set up factories that supply to several housing projects within a city (SS-1). There is substantial growth potential, for example, to supply building components for bathrooms, kitchens and external walls to housing projects (Pan et al. 2007) (SS-1).

Another model for factory planning is to have geographically dispersed sub-contracted factories. Swedish construction firm Skanska, for example, has one-owned factory in Sweden that runs at 100 per cent capacity utilisation along with several sub-contracted factories in Poland and the Baltic States that are called upon to handle excess demand (Bertram, et al., 2019).

At sufficient scale, the per unit cost of building houses through alternate construction technologies would be comparable to the costs involved in conventional in-situ construction (Building Materials and Technology Promotion Council, 2018) (Jaillon & Poon, 2008) (PD-5, C-5, G-3). The high initial investment and building component costs are partially offset by reduced construction time, lesser re-work and lower finishing costs (Macomber & Thapar, 2018) (Jaillon & Poon, 2008). Shorter project duration translates into lower interest liability of construction firms. Better quality construction reduces expenses on re-work (Goodier & Gibb, 2007). Considering the various other benefits they offer – faster delivery, superior quality, better resource utilisation and waste reduction – there is a case to build mass housing using alternate technologies if the necessary scale for the deployment of the technology can be achieved.

4.3 Reorientation of planning and design

In conventional in-situ construction, planning and design is focused on step-by-step formwork, masonry and the concreting process at the site of construction. Since the construction is less mechanised, there is room for late modifications to the design and the planning does not necessarily need to be finely detailed. There are few considerations for designers other than

stability, durability and aesthetics in the case of an in-situ constructed building (Building Materials & Technology Promotion Council, 2021).

New technologies require a significant shift from this approach. When the construction process does not include the setting up of a factory (such as for engineered formworks that are usually procured from specialised manufacturers), the changes relate to the procurement of customised formworks and their efficient use at the construction site (Panchal, 2015).

For technologies such as precast that require a factory set up to produce building components, the changes are far-reaching. Along with a design intent that documents the building plan, a construction intent is devised that documents the plan for manufacture, delivery and installation of building components (Smith, 2010). Enhanced co-ordination is necessary and, therefore, the planning and design stage needs inputs from all stakeholders of the supply chain – general contractors, sub-contractors, manufacturers, suppliers, architects, engineers, etc., – to reduce errors in design, keep operational costs low, and increase productivity (World Economic Forum, 2016). Lack of detailed project planning led to several unanticipated challenges in the affordable housing project at Raipur, being built using precast technology (**see Box 1**).

Box 1: First timer challenges and role of project planning: Affordable Housing Project in Naya Raipur

An affordabe housing project under PMAY U scheme of 20,000 dwelling units each of LIG and EWS categories[14] is being built in the green field city of Naya Raipur. The Chhattisgarh Housing Board (CGHB) is the nodal authority constructing these housing units and acting as the development agency for the project. BSBK Ltd., an infrastructure contracting firm based in Bhilai, Chhattisgarh[15], was appointed the turnkey contractor for designing, and executing the construction[16] of these units, to be constructed using precast technology and slated to be constructed by April 2020. Based on interactions with officials from CGHB and BSBK, it emerged that the project has been delayed by more than 18 months at present. Although the pandemic and the national and localised lockdowns imposed in 2020 and 2021 have adversely affected construction activities for many projects across India, certain operational challenges being faced during the construction of this project came to light during interactions with officials from CGHB and BSBK.

[14] http://environmentclearance.nic.in/writereaddata/FormB/TOR/Brief_Summary/07_Jun_2016_114504473K76VC60QAnnexure-Briefsummaryofproject.pdf , accessed on 1 June 2021

[15] http://bsbkltd.com/ , accessed on 1 June 2021

[16] https://www.concreteissues.com/en/stories/1-18/good-products-reliable-services-and-an-excellent-worldwide-reputation-won-bsbk-s-heart/ , accessed on 1 June 2021

Diagram 5: Locations of Sectors 16, 30, and 34

Source: Google Earth and CGHB[17]

First, the project was spread out across three sectors (Diagram 5). As a result, expenditure on site offices, site stores, cranes required to hoist the precast panels, and other establishment costs were incurred at three locations instead of one. Although these costs were factored in the final bid prices submitted by BSBK, achieving the desired scale at a single site location instead of three would have helped to bring down the cost. Storage of finished precast elements like slabs, beams, and columns need special attention and arrangements to prevent damage. These arrangements also needed to be duplicated across the three sites and hence, increased the cost of construction. Second, the precast manufacturing unit was located at a distance. But the cost of transportation of the precast building components from the factory site to the building sites was not fully accounted for during budgeting. This led to a further increase in the cost of construction as compared to the planned expenditure projections. Third, no local workers were skilled in precast construction since this was the first precast project in Chhattisgarh; hence, workers had to be brought in from other cities further adding to the cost. In case of a breakdown in equipment, there was a severe dearth of skilled manpower to repair the specialised equipment used at the building and factory site. Fourth, significant issues were faced due to the absence of locally available spare parts and other materials such as specialised compounds required for the maintenance of construction equipment and for construction. These too had to be arranged from other places within India.

According to CGHB and BSBK officials, the project shows promise with a close to ideal slab cycle of four slabs per month, if compared to one slab a month using the conventional construction technique. However, the project faces significant cost challenges at present. This highlights the need for better project planning, especially for first time developers, on

[17] https://cghb.gov.in/Projects/Raipur/PMAY-MMAY/location_plan.jpg, accessed on 1 June 2021

many counts including better site identification, and seamless availability of raw materials, work force and equipment, to mention a few.

Source: Authors' research and expert interviews

Since the manufactured building components have to be stored, transported and assembled at the construction site, their design must be optimised for these processes. While conventional buildings have to be structurally sound only in-situ, building components must be structurally sound even while they are being lifted or lowered using cranes during transportation and assembly (Bertram, et al., 2019) (A-2, C-2). Therefore, other than the usual considerations of stability and durability in-situ, principles of Design For Manufacture and Assembly (DFMA) must be applied (AC-1) (World Economic Forum, 2016). In DFMA, every aspect of the building is deconstructed into building components like walls, columns, beams, and stairs, and is designed to ensure efficiency in material management, cost, transportation and assembly. A lot of the mechanical, electrical and plumbing (MEP) work may also be done at the factory rather than the construction site. Unlike conventional in-situ construction, late modifications in design are difficult to accommodate and can be prohibitively expensive (Smith, 2010) (Appendix 3.3.3). This makes timely detailed planning a key phase of the construction process.

Building Information Modelling (BIM) is a software tool to manage the lifecycle of the construction of a building using digitised multidisciplinary data for improved planning, design, building and operations (Autodesk, 2021). BIM particularly complements the use of alternate construction technologies by optimising the sequencing of construction processes, improving material yields, simulating the assembly of building components, and reducing the risk of accidents (Gerbert et al. 2016) (Lou & Guo, 2020) (C-3, PD-3). While BIM has been around for more than the two decades, its adoption in India is still low (Jagadeesh & Jagadisan, 2019). This can be attributed to the high hardware and software costs, lack of professional training and experience in the use of the software, and comfort in operating with traditional methods (Sawhney, 2014) (PD-1, C-1, G-1). Developed countries such as the United States, United Kingdom, Germany, Australia, Singapore as well as China have rapidly adopted BIM with the governments of some these countries mandating its use for certain kinds of projects (Bose, 2019) (Paul, 2018).

While conventional in-situ construction requires supplies restricted to the current project, alternate construction processes require continuous and long-term supply of raw materials at the factory (Smith, 2010). Additional equipment and materials are required for waterproofing of precast construction and for assembly of building components at site (Mao, et al., 2016). If the tower crane is not present right at the time of arrival of building components, additional arrangements have to be made for safe storage of the building components (Smith, 2010). Usage of tower cranes is also much higher in precast construction. As a result, the operations cost is higher for precast technology compared to conventional in-situ construction (Mao, et al., 2016). As an example, the design and operations cost for precast construction of about 1,700 apartments of 40-60 square metres each (1BHK-2BHK) in Bengaluru was estimated to be 70 per cent higher than conventional in-situ construction. This was partially offset, however,

by lower finishing costs and savings from reduced construction time (Macomber & Thapar, 2018).

Conventional in-situ construction has few restrictions on design, materials and processes of construction since projects are tailor-made to individual specifications (Laubier et al. 2019). Alternate construction technologies, on the other hand, need standardisation in products and processes so machines may be able to produce set lengths, widths and assemblies (Smith, 2010). Gibb (2001) describes standardisation as 'the extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability'. Standardisation restricts variety to increase predictability. The predictability of products improves their compatibility and interchangeability while predictability of the processes helps make them more efficient (Roy & Roy, 2016). Standardisation, in effect, leads to productisation of construction, which means that standardised platforms with a narrower set of options are used instead of tailor-made specifications and unique designs and processes as in conventional in-situ construction (Laubier et al. 2019). Optimal standardisation in the residential construction industry can help unlock economies of scale as well as improve the quality of housing and the speed of construction (Lou & Guo, 2020) (Gibb, 2001) (Appendix 3.3.1, 3.3.2).

In conventional in-situ construction, the pace of construction can be adjusted to the rate at which the houses are sold. This allows the developer to plan the construction in phases and gives more time to mobilise funds by selling 'under-construction' houses. On the other hand, housing built using factory-based technologies must be built at a stretch since the idle cost of the factory is high. The high speed of construction implies that the sale of houses also has to be made faster to minimise inventory (PD-1, PD-7, C-10, C-13).

The far-reaching changes in the approach to planning and design imply that the adoption of alternate construction technologies, especially for those that require a factory setup, will be a slow and phased process. As highlighted in section 4.5, construction professionals will have to develop new skills. Companies will need to plan extensively before the project commences, make changes to their contracting and sub-contracting models, and adopt information technology for project management (World Economic Forum, 2016). Construction firms may choose to adopt a high degree of backward integration to control the quality and avoid unexpected delays in construction (**see Box 2**) or build a network of contractors and sub-contractors to carry out the projects. The industry as a whole will need to come together to increase standardisation in products and processes – especially of interfaces of building components, interoperability of software systems, and definition of costs. (World Economic Forum, 2016).

Box 2: Backward integration supporting adoption of pre-cast/alternate technology: Dream Acres Project, Sobha Developers

Sobha Developers is a private real estate developer and among the ten largest in India by revenue. It usually builds high-income category houses. In 2015, it launched a mass scale housing project for the middle-income group in Bengaluru. The size of apartments varied between 645 sq. ft and 1,210 sq. ft and were priced between INR3.3 million and INR6.2 million.[18] A total of 6,500 apartments across 16 towers were to be constructed between 2015 and 2024 using pre-cast technology. So far, three benefits of using pre-cast technology for the Dream Acres project have emerged.

The first pertains to faster construction. As per media reports, the first set of 200 apartments was completed in a year, 20 months faster than would have been possible using conventional construction techniques and, as a result, apartments were handed over to the buyers before the committed possession dates (Zee 2016).[19] From interactions with senior managers in charge of the planning and cost functions of the Dream Acres project, it emerged that the project so far was able to achieve a four-day slab cycle instead of a 25-day slab cycle. According to them and Gils (2017), this was possible due to effective planning and a smooth supply chain of precast elements supported by the manufacturing of precast elements at the factory within the Dream Acres site. This reduced the need for expensive inventory mangement, transportation and on-site quality control. It also reduced the requirement of a dedicated on-site land parcel for storage. Sobha Developers undertakes most of the activities required for the development of a project in-house by their employees (Macomber and Thapar 2019).[20] This enables better control over the project design and construction planning.

The second benefit pertains to environmental gains. According to Sobha officials, less fresh water was consumed in the construction of this project compared to similar Sobha projects constructed using conventional techniques.

The third benefit is a reduction in the cost of construction. According to Sobha officials, the Dream Acres project involved an overall reduction in cost of construction compared to similar conventional technology projects. However, Macomber and Thapar (2019) report that, based on company documents, they found that the reported cost estimates were 32 per cent higher in the case of precast technology vis-à-vis conventional technology, for another Sobha Developer project – 'Dream Gardens' launched in 2018, which has only 1,780 units of a similar size and price bracket, as Dream Acres.[21] The indicated positive cost impact for

[18] https://www.magicbricks.com/sobha-dream-acres-panathuAC-3angalore-pdpid-4d4235303832373635, accessed on 9 August 2021

[19] https://www.youtube.com/watch?v=qcKqbwdTYHA, accessed on 9 August 2021

[20] https://www.hbs.edu/faculty/Pages/item.aspx?num=55042, accessed on 5 August 2021

[21] https://www.magicbricks.com/sobha-dream-gardens-thanisandra-bangalore-pdpid-4d4235313835393231, accessed on 9 August 2021

the Dream Acres project could be due to the scale of the project, which is about four times that of Dream Gardens.

It is important to note that in addition to the benefits, there also existed a challenge. The challenge was consumer hesitancy regarding pre-cast technology. Sobha officials and local brokers mentioned that the marketing and sales team had to convince prospective customers who had reservations regarding the technology. Considerable effort was spent on educating the consumers about the precast technique and in building consumer confidence. Based on interactions with local brokers, it emerged that there were a few complaints as well regarding the quality of construction from the occupants of the Dream Acres project. This underscores the need for stricter quality control over various facets of the construction process.

Nevertheless, at an overall level, the Dream Acres project is an example of the potential of precast technology as a viable and sustainable choice for faster and timely construction of mass scale housing projects, when backed by efficient planning and an efficient supply chain. The project demonstrates that the adoption of alternate technologies such as precast by the private sector need not be explicitly supported by government subsidies and incentives, if the scale of the project and existing conditions justify the use of such technology.

Source: Authors' research and expert interviews

The industry also needs to encourage information exchange and sharing of best practices. There is a lack of useful documentation and case studies of past projects that have used alternate construction technologies (A-2, CS-3, C-1). Industry groups such as CREDAI and NAREDCO and government agencies like BMTPC have an important role to play in developing and propagating the use of such reference material (C-1, CS-3). Some international firms such as Skanska (Sweden), Laing O' Rourke (UK), and Shimizu (Japan) have developed automated documentation of their projects that records detailed information and helps improve efficiency of workflows (A-2). For cost analysis, construction firms currently use a combination of the Delhi Schedule of Rates (2019), firm's proprietary data, and the quotes offered by vendors (Appendix 3.3.5). Regional industry organisations can use local cost data to come up with more accurate regional estimates of the cost of building components that allow more accurate financial analysis to decide on whether to adopt new construction technologies or continue with conventional methods (C-1).

Government, on its part, will have a key role in the research and development of these technologies and their construction processes. Most of these technologies have been developed in the West and there may be a need to make adaptations to Indian conditions (A-2). There is also some ambiguity on the liveability of buildings constructed using alternate technologies and more research is needed on these topics as discussed in the section 4.6.

Building codes formulated by the government will also influence design practices and the degree of standardisation achieved by the industry. For example, Singapore's Building and Construction Authority has enforced codes on buildability to improve ease of construction, increase productivity and reduce reliance on foreign labour. In the process, the codes have

influenced the construction industry to adopt DFMA principles, adopt higher repetition of grids and repeated component sizes, and raise the degree of standardisation in the industry (Building and Construction Authority, 2017).

Government will also influence the industry through its public procurement process. At present, several small-sized construction firms without adequate experience and expertise in the use of alternate construction technologies are able to corner tenders for large-scale mass housing projects by quoting low prices (government projects help small firms build their portfolios) (CS-3, SS-1) (Roychowdhury et al. 2020). But since the economics of such projects is not viable, these firms may compromise on the design, quality of materials used, and construction processes. (CS-3). This sets a low bar in the planning and design of projects that use alternate construction technologies and gives rise to scepticism about their potential.

Instead of opting for the L1 system of tendering, where the bidder with the lowest commercial bid wins the project, government agencies need to gravitate to the QCBS (quality and cost-based selection) where greater weightage is given to qualitative aspects such as the skills and experience of a participating bidder rather than solely relying on the commercial bid. QCBS looks at several facets of an organisation, viz., trained manpower, quality and age of assets/equipment, quality, and quantum of credit lines from financial institutions, etc. Most government agencies procuring for consultancy assignments already have QCBS as the method of choice; however, for works contracts, these agencies still rely upon the L1 route to procure contractors (Department of Expenditure, Ministry of Finance, 2017) (AC-1).

4.4 Transportation of building components

Factory-based technologies involve the additional step of transporting building components from the factory to the construction site. Depending on the technology used, the challenge of transportation varies (Smith & Quale, 2017). For stay-in-place formworks and steel structural systems whose size and weight are less, transportation is relatively cheap but for precast slabs and modules, the size and weight and, consequently, the transportation costs are high (Smith, 2010). In general, the higher the usage of precast concrete components in a building, the higher will be the transportation cost (Smith, 2010). Building components must be designed keeping their handling and transportation in mind, as discussed in the previous section. (Bertram, et al., 2019) (A-2, C-2).

The distance between the factory and the project site is a key factor that determines the costs and ease of transportation (Smith, 2010). The distance should preferably be less than 50 kilometres and should not exceed 200 kilometres to keep transportation financially viable (Smith, 2010) (Appendix 3.4.1). There is a trade-off between the transportation cost and the land cost for setting up a factory. Cheaper land for setting up a factory is available well outside city limits but that would mean increasing recurring transportation cost. An attempt to decrease transportation cost by buying land close to the city would mean a high initial investment for purchasing factory land. Therefore, construction firms and manufacturers have to optimise the location of the factory with respect to the project site (Appendix 3.4.2). Land between twin cities such as Mumbai-Pune are suitable for situating a factory as they have access to projects in both cities (PD-1). Navi Mumbai's town planning authority CIDCO has been able to lease

land to contractors to set up factory within 1-5 km of the project site that has helped keep transportation costs low. Its counterpart in Mumbai has found it difficult to do so due to high land prices in the city. In the affordable housing project at Naya Raipur that is being built using precast technology, the large distances between transportation of building components from the factory to three different construction sites increased the total project cost substantially (see Box 1). If a temporary factory can be set up at the project site, the transportation cost for building components can be nearly eliminated (Gils, 2017). In developed countries, portable machines for precast manufacture or 'mobile factories' have tried to eliminate the hassle of transportation but they have no real presence in India yet (BFT International, 2016) (Appendix 3.4.4).

The quality and density of India's road network has improved substantially over the last few decades and minimal losses occur due to bad roads during the transportation of building components, although the last few miles leading to the project location may not be of the best quality (Ministry of Road Transport & Highways, 2017-18) (AC-3, G-3, A-1, C-5). Transportation in trailer trucks helps keep the impact of jerks low and damage minimal but roads must have adequate turning radius and obstruction-free heights for their use (Fraser, 2015) (Appendix 3.4.3). Additional challenges are imposed by restrictions on the movement of trucks only during night hours in metro cities and the requirement of state/national permits for their movement (Sherfudeen et al. 2016) (India filings, 2021).

In sum, transportation of building components is a challenge because of the costs it imposes while the logistical challenge of shipping is a manageable one (Appendix 3.4.4).

4.5 Lack of skilled professionals

Technological innovation in any industry is generally accompanied by a change in the skill requirements of the workplace (Bughin, et al., 2018). As the workplace itself moves from the construction site to a factory setting for several construction professionals, substantial changes in skill requirements may be expected.

In some vocational jobs, such as carpentry and plastering, the skill requirement may not change but the context in which they are applied will change (Vokes & Brennan, 2013). In precast construction, electricians and plumbers perform most of the work inside a factory. At the construction site, the workers assemble factory-made formworks or precast elements rather than build the formwork using timber and steel (Building Materials & Technology Promotion Council, 2021). An affordable housing project in Pimpri-Chinchwad using aluminium formwork suffered due to lack of training as site workers struggled to maintain the quality of formwork during shuttering, which ultimately reduced the formwork's repeatability. Trainers from the foreign formwork manufacturers had to be ultimately called in to train the staff. Similarly, the lack of experienced local workers is a major challenge that the affordable housing project at Naya Raipur has faced (see Box 1).

In high skill professions, such as architects and construction managers, enhanced knowledge on collaboration between disciplines, information technology, planning and design, and lifecycle of the building will be necessary (Vokes & Brennan, 2013). Architects and engineers

will need to skill in DFMA and the use of standardised components, general contractors will need to reorganise their labour model and subcontractor networks as their service offering is commoditised and building material manufacturers will have to shift to producing newer materials required in the new construction process (Laubier et al. 2019). There is a lack of construction professionals skilled in executing projects using alternate construction technologies. This is a major barrier in the adoption of the technologies in India (Bendi et al. 2020).

Government intervention may be necessary to bridge the skills gap. Under the GHTC programme, the Government of India has launched a short online certificate course for civil engineers and architects on innovative house construction systems (Building Materials and Technology Promotion Council, 2021). Similar and more wide-ranging efforts are needed. Alternate construction technologies must be an important part of the curricula of engineering undergraduates, skill universities and Industrial Training Institutes (ITIs) so that succeeding generations of construction professionals are adept in using these technologies (Goodier & Gibb, 2007) (PD-3). Theoretical knowledge with practical training and industry exposure will help produce a versatile and skilled workforce (Vokes & Brennan, 2013) (PD-1). Vocational workers must be encouraged to take up public/private certificate courses, training and apprenticeship programmes to improve the quality of workmanship and access higher paying opportunities.

Construction firms will also need to invest in re-skilling their employees for the shift in responsibilities. These can be offered in the form of flexible online training for professional development (Vokes & Brennan, 2013). Generally, there is a favourable response to skilling programmes among employees and construction firms such as Sobha and Prestige have grown a loyal employee base through such initiatives (Macomber & Thapar, 2018) (PD-4, PD-3). Training should be followed up with opportunities to implement the learnings. While BIM training regularly takes place in some public sector building agencies, its adoption for project management has remained low (G-1).

Thus, a comprehensive strategy for education and training in the use of alternate construction technologies at the university and as part of professional development will be necessary for adoption of the technologies in India.

4.6 Consumer scepticism and questions on liveability

Industrialised construction technologies have been around, not just for decades, but centuries – from building components shipped for the dwellings of British colonialists in the sixteenth and seventeenth centuries, to assembly line production of homes in the early twentieth century, to war-time and post-war housing (Smith, 2010). Hindustan Prefab Limited was set up in 1948 by the Government of India to meet the housing needs of migrants from the newly created Pakistan (Hindustan Prefab Limited, 2016).

Despite its long history, industrialised construction is viewed as an ‘emerging’ alternative to conventional in-situ construction for mass housing. There is still widespread consumer scepticism about the quality and performance of buildings constructed using alternate

technologies (Sherfudeen et al. 2016). This scepticism is rooted in two factors. First, wall panels used in some precast and steel structural system technologies are much lighter in weight due to the use of light-weight materials such as gypsum and cement boards compared to concrete-filled walls and give an impression of being fragile and low quality (Rahman, 2014) (Sherfudeen et al. 2016) (PD-5). The hollow knock on the walls and the inability to drive nails contributes to this notion (G-3, AC-3, CS-1). Buying a house is a significant investment and an aspirational purchase for most Indians and they are reluctant to spend on a product that may be perceived to be of lower grade (Appendix 3.6.1). Second, precast houses built in the second half of the 20th century were poorly built and suffered from water seepage, poor thermal comfort, and early deterioration (BRE Scotland, 2001). These early precast buildings have contributed to negative perceptions of alternate construction technologies among homebuyers (Laubier et al. 2019) (BRE Scotland, 2001). However, as adoption of housing constructed using alternate technologies increases and their superior quality and durability are demonstrated, this perception is likely to change. The lighthouse projects under the GHTC programme have an important role in building consumer confidence to purchase houses constructed using alternate technologies.

While the quality of buildings constructed using alternate technologies is generally superior to conventional buildings, there is some ambiguity on liveability. Waterproofing issues are routinely encountered in the use of precast and LGSF technologies when constructed poorly (G-3, C-9, AC-3) (Bendi et al. 2020) (Basu et al. 2020) (Sherfudeen et al. 2016). Thermal comfort in buildings varies significantly depending on the design and the materials used (Roychowdhury et al. 2020). More research is needed to ascertain the extent of thermal comfort in these buildings in Indian conditions (CS-3). A post-occupancy assessment of the GHTC lighthouse projects by third party observers and researchers and unhindered publication of the data will help optimise these technologies sooner as well as increase the confidence of the consumers and private sector construction firms (PD-5, CS-3). Since most of these technologies have been developed in the West, there may be a need to adapt them to Indian conditions (A-2, CS-4).

5. Concluding Remarks and the Way Forward

The four categories of alternate construction technologies discussed in this paper offer improvement in speed, quality and resource management in building mass housing compared to conventional in-situ construction. However, their adoption for residential projects has remained low. In this paper, we have highlighted six major challenges that have prevented the wider diffusion of alternate construction technologies for mass housing projects in India: (i) high initial investment, (ii) achieving optimal scale required for commercial viability, (iii) reorientation of planning and design, (iv) transportation of building components, (v) lack of skilled professionals, and (vi) consumer scepticism and questions on liveability. Each challenge warrants the attention of the government, industry and policymakers that see potential in the diffusion of these technologies. Table 1 summarises the policy measures that may be taken to increase adoption of alternate construction technologies in building mass housing.

Table 1: Policy measures for increasing adoption of alternate construction technologies in mass housing

Goal	Proponent(s)	Target group(s)	Policy Objective	Policy Measure
Improve financial viability	Government	Contractors	Favour alternate technologies in public procurement of mass housing	Set conditions for faster delivery, better quality, low environmental impact in public procurement of large-scale affordable housing projects
	Government	Private developers	Increase uptake of alternate technologies in privately developed large-scale affordable housing projects	Policy nudges such as simplification of regulations and more effective information and outreach programmes
	Government	Manufacturers	Develop an ecosystem of industry players in alternate technologies around urban centres	Encourage investments in the production of structural components, building materials
	Government	Manufacturers, Contractors, Developers	Reduce the burden of high initial investment	Interest subsidy on initial capital investment
	Government	Manufacturers, Contractors	Provide more liquidity for initial capital investment in public procurement of mass housing	Increase proportion of upfront payment in public procurement of mass housing
Improve operational viability	Manufacturers, Contractors, Developers	Manufacturers, Contractors, Developers	Improve readiness of construction firms to implement alternate construction processes	Digitise construction processes, inculcate DFMA principles, detailed planning, close monitoring of construction process
	Government	University students	Expand talent pool skilled in alternate technologies	Increase emphasis on alternate technologies in curricula of civil engineers, architects
	Government, Industry groups	Vocational workers	Train workers for new construction environment and improve quality of construction	Launch public/private certificate courses, training and apprenticeship programmes for vocational workers
	Government, Industry groups, Developers	Homebuyers	Build confidence among homebuyers to purchase houses built with alternate technologies	Information, outreach and demonstration efforts to showcase alternate technologies
Improve uptake among home-buyers	Academia, Industry groups, Government	Homebuyers	Demonstrate improved quality of houses built with alternate technologies	Collect, analyse and disseminate post-occupancy data
	Academia, Industry groups, Government	All relevant stakeholders	Improve understanding of which technologies are better suited to Indian conditions	Research efforts towards ambiguous issues such as lifecycle cost estimates, post-occupancy experience, overall carbon footprint
Comprehensive assessment of technologies	Developers, Contractors, Industry groups	Academia, Industry groups	Generate case studies and best practices in the use of alternate technologies	Produce detailed documentation of lifecycle of projects and develop mechanisms to share data to promote research
	Government, Industry groups	All construction firms	Infuse innovation to improve existing methods	Knowledge transfer and adaptation from successful international examples

Source: Authors

5.1 Improving financial viability

The financial challenges of high initial investment and achieving optimal scale required for commercial viability are interrelated. The high initial investment becomes viable if the optimal scale of project(s) is reached. In other words, a large number of apartments collectively provide the necessary repetitions required to achieve economies of scale that would make the high initial investment financially viable. Therefore, under current conditions, the use of these alternate construction technologies is more relevant for large-scale mass housing projects or several small-scale housing projects in close vicinity.

The government can play a key role in increasing the adoption of alternate construction technologies for large-scale mass housing projects where the use of alternate construction technologies is likely to be financially viable. For projects that are developed by national/state/local governments, imposing conditions such as reduced construction time and high environmental and quality standards in public procurement can implicitly favour alternate construction processes. Singapore's Building and Construction Authority imposes standards on 'buildability' to ensure ease of construction and higher productivity.[22] The standards have increased the uptake of precast and prefabricated construction in the industry as precast systems are rated higher on buildability than conventional in-situ construction (Building and Construction Authority, 2017). Precast components constitute about 70% by volume of the entire structural concrete used in public affordable housing projects in the city-state.[23] Singapore's firm push to adopt prefabricated technology was motivated by its objective of reducing reliance on foreign workers.

For large-scale mass housing projects developed by the private sector, mild policy nudges, such as simplification of regulations (reducing compliance burden for change of land use and building plan approvals, ensuring fast disbursement of GST input tax credit, and other reforms) and information and outreach programmes, can increase private developers' interest in the new technologies.

Government can adopt an ecosystem approach for encouraging multiple small-scale housing projects in an urban centre to use alternate construction technologies. The state industrial policy or city development plans may encourage investments in the production of structural components, formwork systems, and building materials that are used in alternate construction processes at an urban centre (such as by providing some tax/fee exemptions and incentives and expanding public infrastructure for manufacturing). For example, the Malaysian government provides a 60 per cent investment tax allowance on capital expenditure to manufacturers of basic components of alternate construction technologies (Deloitte, 2020).

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[22] Code of Practice on Buildability by the state's Building and Construction Authority defines buildability as the extent to which the design of a building facilitates ease of construction as well as the extent to which the adoption of construction techniques and processes affects the productivity level of building works

[23] https://www.hdb.gov.sg/about-us/research-and-innovation/construction-productivity/prefabrication-technology accessed on 12 October, 2021

Such a policy is likely to attract manufacturers to set up factories and encourage developers and contractors to adopt alternate construction processes. A steady pipeline of projects that use alternate construction technologies for a 4 to 5-year period could help develop an ecosystem of supporting players (structural engineers, architects, suppliers, and consultants) to optimise processes, improve quality and shrink costs, creating a positive loop for the adoption of the technologies. This could also serve as a fertile ground for examination and research & development in new construction processes.

In public procurement of mass housing, a higher proportion of payment may be provided upfront to provide more liquidity to contractors/manufacturers for initial capital investment. Access to cheaper capital for manufacturing building components such as precast slabs and steel sections or to purchase alternate formwork systems can help in easing the burden of high initial investment for using alternate construction technologies. Affordable housing was granted infrastructure status in Budget 2017-18 to encourage greater access and cheaper capital for affordable housing projects.[24] However, this has not been realised and more focussed government intervention may be required (PD-7, C-10).

5.2 Improving operational viability

The transition from conventional in-situ construction to the use of alternate construction technologies will be a slow and phased process for any construction firm. Far more emphasis has to be laid on the design stage to inculcate the principles of DFMA. Digitisation of the process of building design (using software such as building information modelling) and the supply chain logistics will need to be strengthened. A granular feasibility analysis and detailed planning of the production of building components, their transportation and storage, and assembly at the construction site will be necessary to ensure efficient execution. Close monitoring of the entire process will be important for smooth execution. Construction firms can consider slowly increasing the proportion of the project built using alternate technologies during the transition period by, for example, starting with installing precast toilet blocks in apartment buildings. Bendi (2017) has developed a useful readiness framework for Indian construction organisations that plan to implement offsite construction.

Hiring high-skilled managers with experience in executing projects using alternate construction technologies can make the transition easier. The pool of talent available for such roles must expand by increasing the emphasis on new technologies in the academic curricula of civil engineers and architects and by increasing opportunities for on-the-job training at construction firms. With increased dissemination and awareness of new construction processes, the proponents of these technologies within the industry will also grow.

There is also a need to train vocational workers such as electricians and plumbers to the new environments in which they will apply their skills. The potential of new technologies to construct buildings of high quality will not be realised if the workmanship remains of low

[24] https://www.business-standard.com/article/companies/a-year-on-infrastructure-status-eludes-affordable-housing-118032701254_1.html, and https://timesproperty.com/news/post/benefits-of-affordable-housing-infrastructure-blid585 accessed on 12 November 2021

quality. Public/private certificate courses, training and apprenticeship programmes for vocational workers can help achieve the quality standards and provide them opportunities that pay higher. A larger transformation in the construction and building maintenance industry is needed that moves away from the status quo of low skill-low quality-low pay to high skill-high quality-high pay through increased skilling and specialisation.

During authors' conversations with experts, the issue of corruption in the real estate sector also came up as a challenge to the adoption of alternate construction technologies. Increased mechanisation in alternate construction processes is accompanied by transparent and efficient management of resources, which reduces the chances of leakage. Some stakeholders pointed out that a part of the resistance to adopt new construction technologies is due to vested interests that currently benefit from such leakages and lack of transparency in conventional construction (Tabish & Jha, 2018). There is need for a deeper investigation to ascertain the extent to which corruption in the real estate sector poses a challenge to the adoption of alternate construction technologies.

5.3 Improving uptake among home-buyers

Given the low adoption of alternate construction technologies for building houses, scepticism about the durability of the houses built using them is not surprising. As their adoption spreads, the inclination to purchase these houses can be expected to increase. Until that point is reached, the industry, government and individual firms will have to continue to educate potential buyers. Collecting and analysing post-occupancy data on apartments constructed using alternate construction technologies is important to build confidence in the technologies and improve their performance over the next few years. It is also important to consider the satisfaction of the occupants with more qualitative aspects such as apartment design, apartment location and distance to work, public amenities in the vicinity, etc., while formulating mass housing policies.

5.4 Comprehensive technology assessment through a participative approach

The GHTC programme and the six lighthouse projects to demonstrate the functioning of six different alternate construction technologies are welcome steps by the Government of India. The programme is expected to increase awareness and confidence in the use of alternate construction technologies in the residential construction industry. To mainstream these technologies, the government must build on this platform.

The next step must be a participative exercise in the assessment of alternate construction technologies. While the benefits and challenges of these technologies have become more evident, there are ambiguities in the post-occupancy experience, lifecycle cost estimates, overall carbon footprint, adequacy of building codes and other decisive factors. The four categories of technologies discussed in this paper deploy different methods of construction, use different raw materials, require different skills sets and have varying benefits and limitations. Besides, there is scope for optimisation and improvement of these technologies as well as for the development of entirely new technologies such as 3-D printing of houses. There is a need to continuously assess and discuss existing and new alternate technologies and their relevance

to Indian conditions rather than prematurely bet big on an underdeveloped technology. The gaps in existing knowledge need to be filled with openly available information, wider consultations across all stakeholders in the industry, and deeper examination of structures built using these technologies. Knowledge transfer and adaptation from successful international examples can also help.

Such participative exercises in technology assessment will increase awareness of the unforeseen effects of alternate construction technologies, help prioritise important areas for policy action, bring to the fore the complex effects in the industry of any policy that favours alternate construction processes, and increase homebuyer's confidence in purchasing apartments built with new technologies (Reber, 2007). They will also be instrumental in improving building codes and standards to optimise them for alternate construction technologies. Detailed documentation of the lifecycle of a project will provide data to investigate the performance of technologies and generate case studies and best practices that can increase the successful uptake of the technologies. As certain technologies are proved to be substantially superior to others over a period of time and as their use becomes more viable, their uptake is likely to grow rapidly to become a dominant method of constructing mass housing.

This is, no doubt, a long-term view of the transition in building affordable housing in India. Given the current slump in the real estate market and the subdued demand for housing that has been aggravated by the COVID-19 pandemic, it is unrealistic to expect construction companies to invest heavily in the adoption of alternate construction technologies. Yet, the long-term benefits of a move towards increased mechanisation of residential construction can be substantial. As the need to deliver affordable housing of better quality at a faster pace grows over the next decade, this is a critical time for the government and industry to examine the issues that have prevented the wider adoption of these technologies and take concrete steps towards resolving them.

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Appendix

Appendix 1: Expert profiles

Respondent Code	Works with / as	Relevant Experience
PD 1	Private Developer	Part of the core team exploring mainstreaming of alternate technology
PD 2	Private Developer	Working in contracts department with developer, involved in an alternate technology housing project
PD 3	Private Developer	Senior management official with private developer
PD 4	Private Developer	Planning manager for a mass scale, affordable housing project with a private developer
PD 5	Private Developer	Worked in a senior management position with a private developer in the recent past
PD 6	Private Developer	Estimation manager (cost and quantity) of projects with a private developer
PD7	Private Developer	Managing Director of a private development firm involved in development of affordable housing using alternate construction technologies
C 1	Contractor	Contractor engineer involved in alternate construction technology projects
C 2	Contractor	Engineer involved with a contractor specialising in alternate technology construction
C 3	Contractor	Project manager on a housing project built using low gauge steel structural systems
C 4	Contractor	Project manager with a private contracting firm; at present, the project manager for an affordable mass scale housing project
C 5	Contractor	In-charge of a precast element manufacturing unit with a construction contractor
C 6	Contractor	Engineer on an affordable housing project using engineered formwork construction technology
C7	Contractor	Engineer on an affordable housing project using engineered formwork construction technology
C 8	Precast component manufacturer	Heads the precast division of one of the eminent material suppliers/turnkey contractors
C 9	Contractor	Engineer involved in a precast housing project
C10	Precast component manufacturer and contractor	Founder of a precast component company and construction firm
C11	Alternate technology manufacturing and construction firm	Structural engineer and designer working with an alternate construction technology manufacturing and contracting firm
C12	Independent infrastructure contract specialist	Experienced civil engineer involved in the development of affordable housing using alternate technologies for the government and the private sector
C13	Alternate technology manufacturing and construction firm	Leads the sales team at a leading alternate construction technology firm

Respondent Code	Works with / as	Relevant Experience
A 1	Architect	Architect involved in designing a precast housing project
A 2	Architect	Architect involved in a precast housing project
AC 1	Academic	Academician and researcher in the domain of construction technology
AC 2	Academic	Academician and planner on housing and land
AC 3	Academic	Academic and researcher in construction technology
AC 4	Developer and Academic	Experienced developer and academician in affordable housing domain
AC5	Academic	Academic and researcher in construction technology. Previously worked with a construction company
AC6	Academician	Academic and researcher in construction technology, working as an independent consultant for construction projects in the past
AC7	Academician and Private Developer	Presently academician with significant experience of working with a private developer of luxury housing and commercial properties
G 1	Government Public Works Agency	Engineer working with a government public works agency
G 2	Planner and Consultant with Ministry of Housing and Urban Affairs, Government of India	Involved with MoHUA's construction technology initiatives
G 3	Government Engineer	Senior engineer working with a government development agency involved with several housing projects using alternate technologies.
G 4	Government Technology Expert	Senior government official involved with mainstreaming alternate construction technologies
G 5	Government Engineer	Engineer with a state housing board
SS 1	Member of an International Standard Setting Body and Entrepreneur	Experienced construction and real estate industry professional
M 1	Researcher and Media Person	Experienced researcher in the real estate domain
CS 1	Civil Society Housing Expert	Affordable and low-income housing expert working with an NGO
CS 2	Civil Society Housing and Land Expert	Expert engaged with state government panel on housing and land
CS 3	Civil Society Housing Technology Expert	Experienced researcher, researching on new construction techniques from the perspective of sustainability. Involved in several policy panels.
CS4	Civil Society Housing Expert	Experienced independent consultant working with incubator of start-ups involved in development and construction of affordable housing

Appendix 2: Interview Guide

Questions in the interview guide were divided into four themes – finance, policy, planning and design, and building component production. These are given below.

Finance

1. Is initial investment a critical barrier for uptake of alternate construction technologies?
2. Are banks/markets willing to lend for projects using alternate construction technologies? Do they charge higher interest rates?
3. Are there any schemes that lower cost of finance for projects using alternate construction technologies?
4. Do shareholders of construction firms oppose a transition to alternate construction technologies?
5. What are the most expensive investments in adoption of alternate construction technologies?
6. A subsidy in which part of the alternate construction process will industry benefit from the most?
7. Can companies that are involved in housing construction for MIG and LIG groups raise sufficient funds to transition to alternate construction technologies?
8. Do lifecycle benefits such as lower maintenance cost, etc., suitably lower the cost of alternate construction processes in the long run?
9. Can a factory site help expand the construction portfolio of the company, thus bringing in additional revenue?
10. Are costs for services such as electricity and plumbing higher for buildings constructed using alternate technologies?
11. Is it harder to sell houses built using alternate construction technologies to homebuyers?

Policy

1. Can lighthouse projects such as those inaugurated recently under the Global Housing Technology Challenge help improve uptake of alternate construction technologies?
2. Can PPP with state governments in affordable housing using alternate construction technologies make the supply chain better prepared for adoption?
3. Can a standardised design for a LIG/MIG housing across a region help increase speed and lower the cost of construction?

Planning and design

1. Can successful cases of adoption lower client resistance to alternate construction technologies?
2. Can hiring consultancies decrease cost of employing skilled professionals for a construction firm?
3. Can re-skilling own employees help keep cost of transition low for a construction firm?
4. Is adequate cost data available to plan construction using alternate construction technologies?
5. What are the reasons for slow uptake of BIM (Building Information Modelling)? How can the uptake be increased? Can it be made mandatory for affordable housing projects?
6. Are factories hard to locate optimally to minimise transportation costs?
7. What are the constraints faced in alternate construction with regard to building regulations? Are extra approvals required? Are there any specific standards for alternate construction technologies?
8. Can standardised manuals for alternate construction reduce issues with interfacing systems?
9. How important is flexibility of design to the success of the project?
10. What are the changes expected in your profession with the mainstreaming of alternate construction technologies?
11. How aware are you of the existence/availability of contractors/manufacturers in the alternate construction supply chain?

Building component production

- Are raw materials specific to alternate construction (e.g., gypsum for GFRG) readily available at a reasonable cost?
- Does machinery for alternate construction have to be imported? Is the customs duty high? Are there restrictions on import? Are there any indigenous manufacturers of machinery? Can government support them help lower machinery cost?
- Is poor condition of roads a significant barrier to transportation of building components?
- Are the transportation and handling losses for building components significant? Does the use of safe systems for transportation impose a considerable cost?

Appendix 3: Interview Findings

3.1 Initial Investments

3.1.1. Seventeen respondents during the interviews agreed that initial investment is a significant challenge to the uptake of alternate construction technologies. The respondents were from all major stakeholder groups and nearly a third were contractors.

3.1.2. Eight respondents across stakeholder groups pointed out that land procurement for setting up a factory was among the most expensive investments in the industrialised construction process. The land cost may be twice as much as the remaining costs in setting up the factory, i.e., building costs, machinery and equipment costs, administrative costs etc. (C-2)

3.1.3. Seven respondents across stakeholder groups pointed out that there is a trade-off between the initial investment in factory land and recurring transportation cost to project site.

3.1.4. Two private developers, a contractor and an academic pointed out the new concept of asset-light 'mobile' factories that could be set up near the construction site.

3.1.5. Two private developers, two academics and a contractor remarked that procurement of machinery was an expensive part of the construction process using alternate technologies.

3.1.6. All 10 respondents across stakeholder groups who were asked about the machinery replied that most of the machinery for manufacturing components had to be imported, usually from Europe and the United States. An EWS housing project in Pimpri-Chinchwad is procuring aluminium formwork from Hyundai (South Korea) and Kumkang Kind (Malaysia).

3.1.7. Seven respondents across stakeholder groups who were asked about banks' willingness to lend to alternate construction projects felt that there is no hesitancy specific to the viability of alternate construction technologies. One respondent said that the cost of credit may be 1-2% higher than for conventional in-situ construction (C-10).

3.1.8. Banks may find offsite construction marginally riskier since most of the construction happens inside the factory and they may not have the option of completing the remaining on-site construction by recruiting another builder as happens with loan defaults in in-situ RCC construction (PD-5).

3.1.9. Four respondents pointed out that raising funds for initial investment is much easier for large construction firms than smaller firms

3.1.10. Ten respondents across stakeholder groups felt that some form of subsidy or tax concession could help the growth of the alternate construction industry while five respondents (two architects and a government official, a private developer,

an industry body professional) felt that a subsidy is not necessary. Of the former, five respondents felt that subsidy is needed in the process of setting up the factory.

3.2 Achieving optimal Scale Requirement for Commercial Viability

3.2.1. Nine respondents across stakeholder groups pointed out that the profitability of investing in a factory for a construction firm is determined largely by the scale of the housing project(s).

3.2.2. Two respondents provided an estimate of 5000-7000 housing units beyond which the use of these technologies becomes financially viable (C-9, G-3). Another respondent went on to state that their precast project of 25,000 housing units was able to reduce construction cost to INR2,100 per square feet compared to about INR3,000 per square feet for in-situ RCC construction (G-3).

3.2.3. Four respondents across stakeholder groups illustrated how factories could become more sustainable if they supplied components to multiple projects including those of other developers.

3.3 Shift in Planning and Design

3.3.1. Eleven respondents across stakeholder groups agreed that promoting common standards for building design and developing modular frameworks could increase speed and lower the cost of construction.

3.3.2. In the Middle-East, standardised designs have helped reduce the original cost of construction by as much as half in certain instances (PD-3)

3.3.3. Six respondents (two architects, a contractor, an academic and a civil society expert) agreed that late modifications to apartment design could be detrimental to the success of alternate construction projects. While some modifications to non-load bearing walls can be accommodated, major changes involving load-bearing walls can increase time and costs exponentially (C-3). However, late design modifications are relatively fewer in residential projects compared to commercial and industrial projects (AC-3).

3.3.4. Five respondents across stakeholder groups pointed out that there might be waterproofing issues in precast if not constructed properly.

3.3.5. Ten respondents across stakeholder groups pointed out that that the industry uses a combination of Delhi Schedule of Rates 2019, a firm's proprietary data, and the quotes offered by vendors for cost analysis of alternate construction projects. DSR-2019 data has to be adjusted for various regions and may not provide accurate estimates (A-1, AC-3).

3.3.6. It is also important to adapt western designs to Indian conditions (A-2).

3.3.7. Share of expenditures on design and planning are much lower in India compared to the West (CS-3).

3.3.8. Better skilled designers and architects are needed for electrical conduiting and plumbing to ensure easy long-term maintenance (A-2, C-3). While opinion was divided on the matter, more respondents felt that the cost of mechanical, electrical and plumbing (MEP) services are nearly the same as in-situ RCC construction (A-2, C-3).

3.3.9. The push for better quality of construction has to come from homebuyers (AC-7)

3.4 Transportation of Building Components

3.4.1. Three private developers, two contractors and a government engineer estimated the maximum distance between the factory and construction site should be between 50 and 200 km. It is possible to transport for longer distances as happens in the West but the cost can become prohibitively high.

3.4.2. Seven respondents across stakeholder groups pointed out that there is a trade-off between the cost of factory land and transportation to project site.

3.4.3. Large trucks are used for transportation to minimise jerks and potential damage to building components (C-5). These trucks need large turning radii and an obstruction-free path up to a height of about 20 feet (SS-1, C-5, AC-3).

3.4.4. Seven respondents (three contractors, two architects, one government engineer and an academic) pointed out that, other than the costs it imposes, transportation in itself is a not big challenge.

3.4.5. The rejected elements are usually demolished at site and sold off to scrap dealers (G-1).

3.4.6. Transportation is often sub-contracted to a logistics partner that specialises in the delivery of large items (C-2).

3.5 Lack of skilled professionals

3.5.1. Six respondents across stakeholder groups stressed that hiring experienced and well-qualified professionals was one of the most important parts of the construction process using alternate technologies. Four respondents felt that there is a dearth of skilled professionals in India.

3.5.2. Two private developers, two architects and an academic felt that it is important for construction firms to skill their employees in alternate construction.

3.5.3. Skilled and experienced professionals are capable of making the entire supply chain viable and reducing time and costs. Faults in execution, on the other hand, can increase time and costs exponentially during rectification and reconstruction (C-2).

3.5.4. Experienced professionals are especially helpful to firms that are venturing into alternate construction technologies for the first time (PD-1, C-9).

3.6 Consumer Scepticism

3.6.1. In developing countries such as ours, people have a deep emotional connect with their house and they often see houses built with new technologies as a cheaper, less-aspirational alternative to in-situ RCC, which is used in housing by higher income groups (CS-2, CS-1). Therefore, for adoption of alternate construction technologies to be successful, it must first become the choice for housing of higher income groups (CS-1).

3.6.2. The perception of alternate construction among homebuyers is that it is inferior in quality and structural stability to in-situ RCC construction (PD-5). Contrary to this perception, better quality of construction translates into fewer maintenance issues for buildings constructed with alternate technologies (A-S, AC-3).

3.6.3. There is also a need to educate consumers about these technologies, build confidence in them and encourage a lifecycle view of costs instead of just the upfront amount (CS-3, AC-1, PD-4). Visual content is often helpful to build consumer confidence in these technologies (PD-4).

3.6.4. While a majority of respondents emphasised the transformative potential of alternate construction technologies in providing cheaper, better quality and rapidly built housing, a few respondents were sceptical of the need to introduce these technologies in India (M-1, CS-2, CS-1). Until the more pressing issues of land availability and security of tenure are resolved, these technologies can bring little benefit (CS-2). They also emphasised that it is important to keep in view the people for whom these houses are being built and that a singular focus on efficiency can cause exclusions if people's preferences are not taken into account.

3.6.5. Communication with homebuyers about the benefits of new construction technologies must be in relative terms such as early possession, lower maintenance costs and lower electricity bills (CS-4).

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