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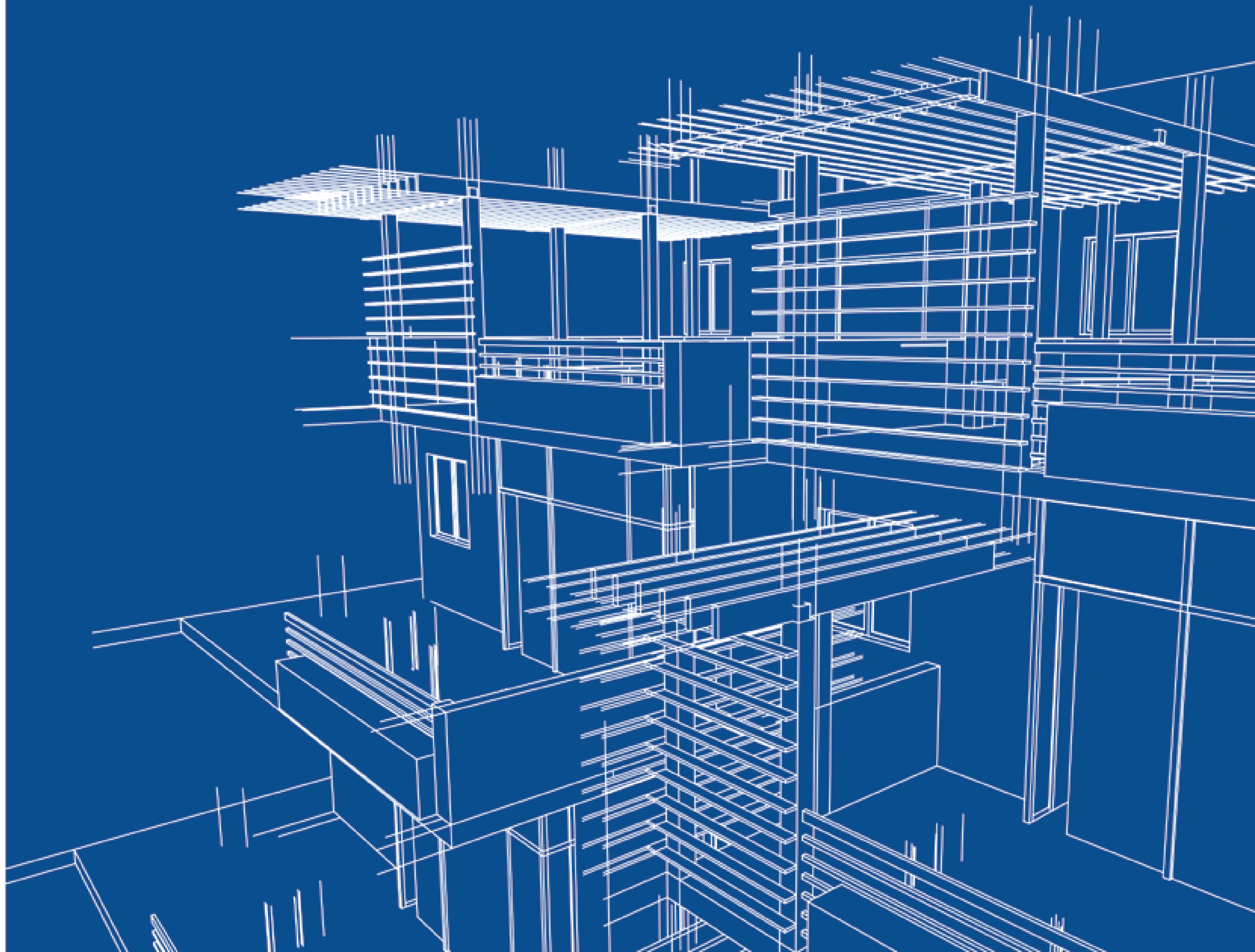
SAINT-GOBAIN

HDFC CAPITAL

Emerging CONSTRUCTION TECHNOLOGIES In Indian Residential Real Estate Sector



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EXECUTIVE SUMMARY

The construction sector, though one of the core sectors in India (contributing to 9% of its GDP[1]), lags in technology innovation and adoption. It is estimated that the real estate sector spends less than 1.5% of its revenues on technology, of which only about 0.7% goes into technology assisting construction and project management. Lower advancement and adoption of technology is a result of traditionally used fragmented processes undertaken by various agencies, contractors during a project lifecycle as well as the overall complexity of the industry.

In the recent past, innovation in newer construction technologies has been observed to help counter diminishing margins, low productivity, labour shortages, longer delivery timelines, inferior quality, safety concerns and sustainability gaps. Increase in cost of conventional construction methods due to significant labour shortage in the industry have made new technologies more attractive. With huge demand for housing, especially in affordable and mid-income segment, we foresee an extensive adoption of newer technologies by the developers and other stakeholders in next few years.

This report is jointly compiled by Saint-Gobain India Pvt Ltd. (Saint-Gobain) and HDFC Capital Advisors Limited (HDFC Capital) to give insight into the identified emerging construction technologies, including their salient features, processes, techno-commercial benefits, limitations, and current barriers in adoption. In addition to the team's own experience in handling the technologies, this report is generated through review of recent studies, primary and secondary research, site visits, discussions with technology providers and industry practitioners.

Key findings have been encapsulated as comparative among identified technologies across economical, functional and technical parameters of construction development. The report also touches upon the technologies which have the potential to shape the construction industry in future.

[1] https://www.investindia.gov.in/sector/construction

OVERVIEW OF THE CONSTRUCTION SECTOR IN INDIA

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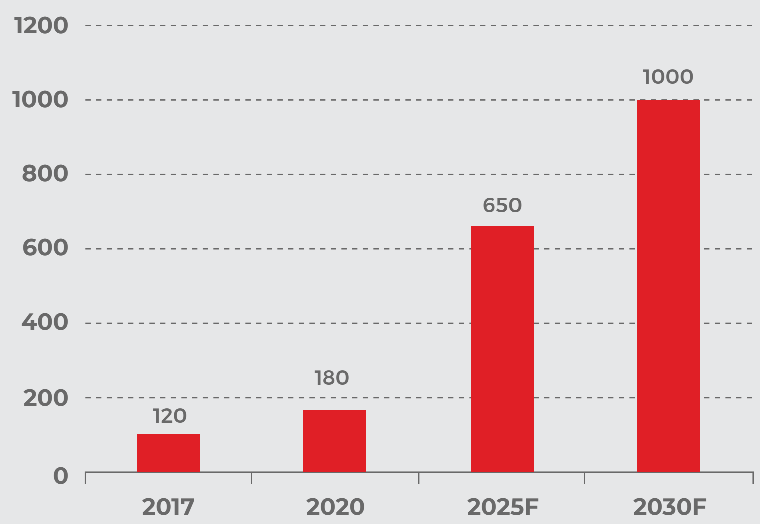
The construction sector is one of the important sectors of Indian economy owing to its contribution to the country's GDP, potential for creating employment and for attracting foreign investment and its linkages with other prominent sectors of the Indian economy (such as infrastructure, real estate, industries, etc).

With the contribution of both public and private investments, the construction sector has been growing exponentially over the past decade and is currently the **third-largest sector in terms of FDI (Foreign Direct Investment) inflow** (USD 54.87 billion from April 2000 to June 2022)[2]. The outlook of the sector remains bright, driven by the Government's focus on infrastructure development in the country.

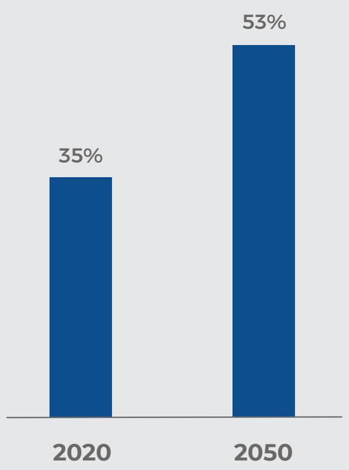
Construction in real estate sector has been evolving with new and superior technologies to cater to the rise in real estate demand in the country. Key drivers for real estate growth are increasing population, rising disposable incomes, improving living standards, rapid urbanisation trend (from 35% in 2020 to 53% in 2050[3]), increasing industrialisation, etc. One of the key drivers for increase in demand under affordable housing segment of the real estate is the "Housing for All" mission launched by the current Indian Government in 2015.

The real estate sector is expected to reach USD 1 trillion in market size by 2030 (from USD 200 billion in 2021) and is estimated to contribute 13% to the country's GDP by 2025[4] (from the existing ~7%). It is estimated that a single real estate project has linkages to over 250 ancillary industries thus creating significant employment opportunities directly and indirectly.



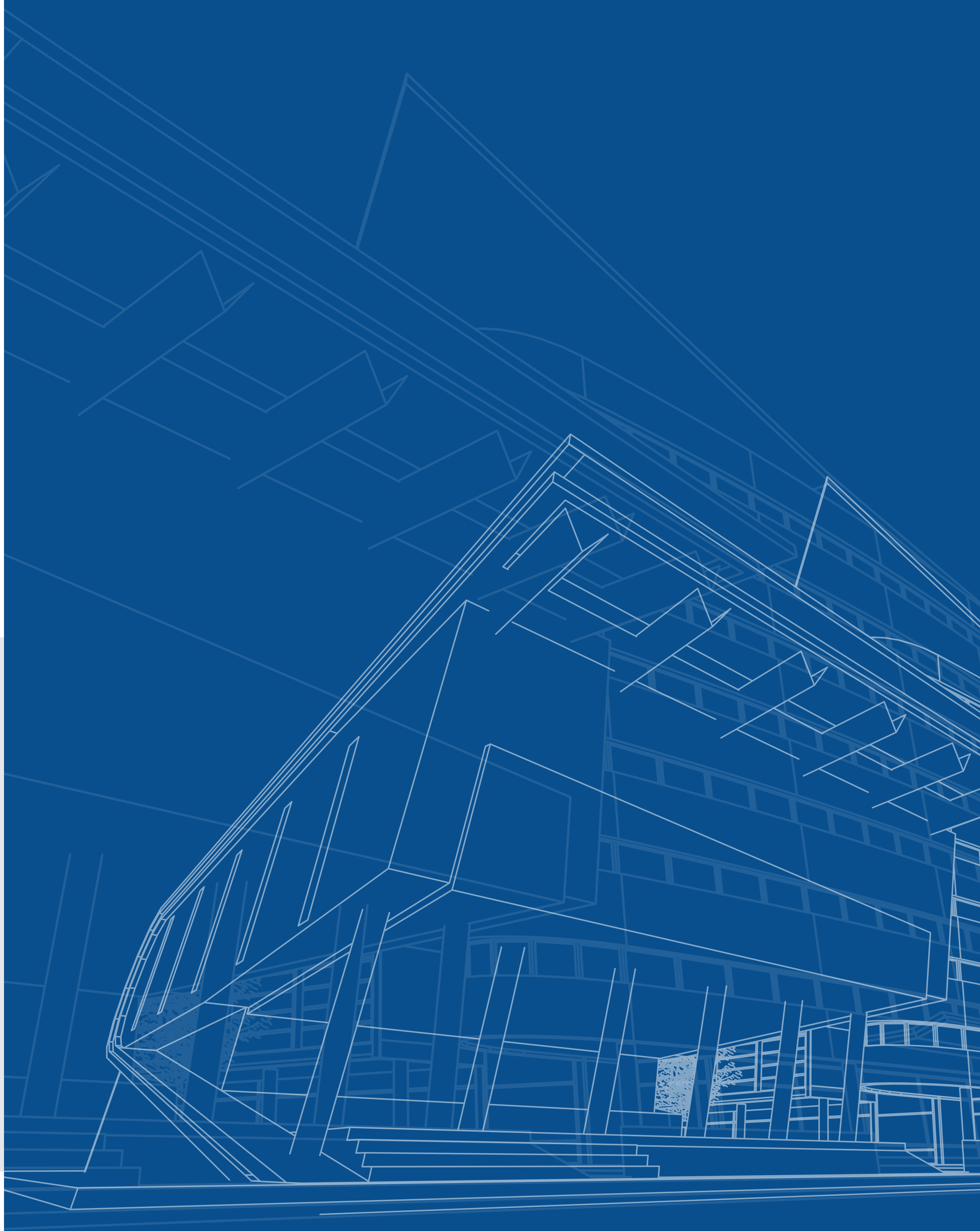
MARKET SIZE OF REAL ESTATE IN INDIA (USD BILLION)

Source: IBEF



URBANIZATION TREND

Source: UN Estimates



[2] Department of Promotion of Industry and Internal Trade Policy (DPIIT)- Quarterly Fact Sheet, June 2022 | [3] UN Estimates- World Urbanization Prospects, 2018
[4] Source: IBEF: https://www.ibef.org/industry/real-estate-india

CHALLENGES IN CONSTRUCTION SECTOR FACED BY RESIDENTIAL DEVELOPERS

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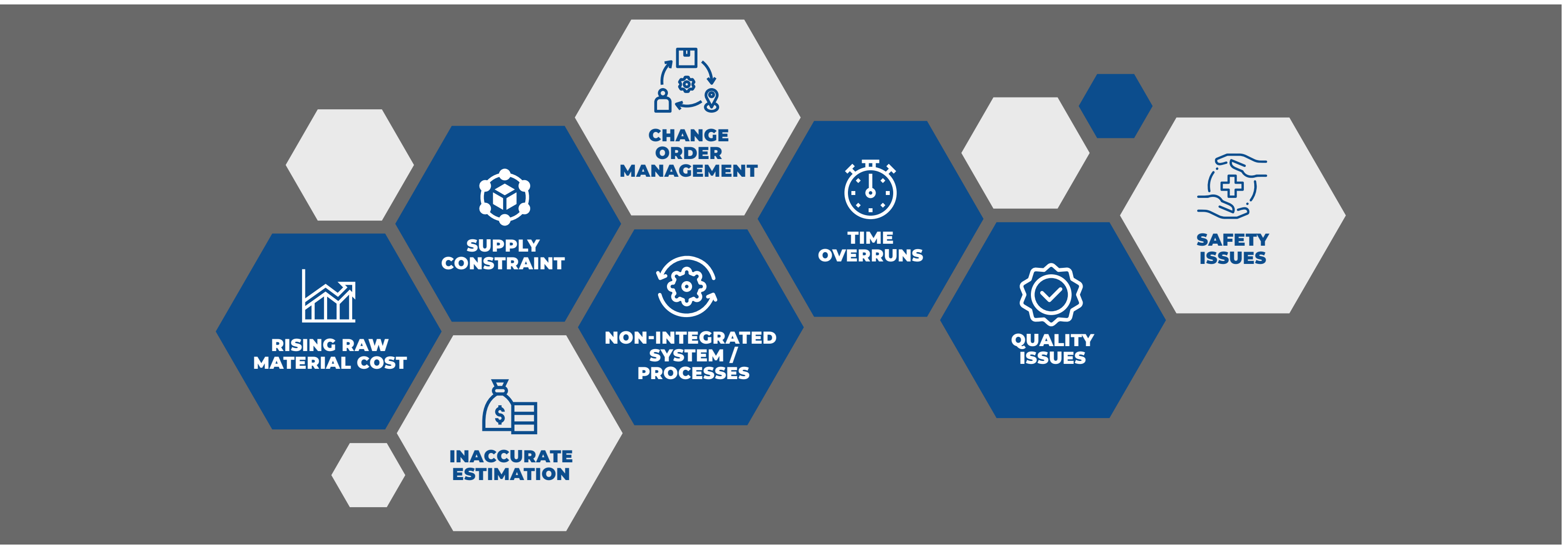


Cost Overruns: As per a global study conducted by KPMG in 2021, it was found that only 31% of all projects were within 10% of the estimated budget. In India, the average cost of construction has gone up by 10-12% compared to last year.[5] Any abrupt increase in the cost adversely impacts the margins, especially in price sensitive and fixed price projects. Key reasons for cost overruns are as below:

Rising raw material cost:

Construction materials account for almost two-thirds of the total cost of construction[6], of which steel and cement together constitute 20% to 25%. In the past two years, there has been cost uncertainty on a major scale (example- since Q1 2020 till Q1 2022 the steel prices was up by 45-47%, copper 70-75%, aluminium at 55-50%, and PVC items by 80-90%)[6]. Rising cost of materials and timely availability of materials has been one of the main causes for cost overruns.

Supply constraint and rising cost of skilled manpower:

Labour costs account for almost one-third of the total construction cost of a project. The cost of labour has risen around 10% - 15% over the last one year, primarily due to covid impact, migration and other associated reasons.[7] Traditionally, the construction industry has been labour intensive and with the employment push by the State and the Central Governments for creation of jobs in rural areas, the availability of skilled labour is a serious cause of concern. Specially post covid, scarcity of skilled manpower has led to significant increase in labour cost.

Factors that could be controlled by use of emerging technologies and digitisation:

Inaccurate estimation: Conventional thumb rule / schematic design basis cost budgeting results in inaccurate estimation and leads to surprises during project execution. Unlike any other production setup, every construction project is unique and hence the "one size fits all" approach does not work. Detailed accurate quantity estimates are important prior to start of a project. Quantity estimates, specifications, make of products, etc. along with appropriate contingency and escalations should be well factored before the start of a project.

[5] Colliers Research Report March 2022 | [6] India Infrastructure Research 2022 | [7] JLL Construction Cost Guide Book 2022

Use of recent digitised tools like BIM (Building Information Modelling) can assist in reducing estimation errors.

Change order management:

Non-integration to capture impact on cost and time due to design evolution and changes during design development and execution is another cause of inaccuracies in identification of cost impact. Established standardised approach should be adopted for any changes that may be desired during the construction stage to avoid any uncontrolled increase in the overall construction cost. Incorporation of project management tools and applications could help to bridge this gap.

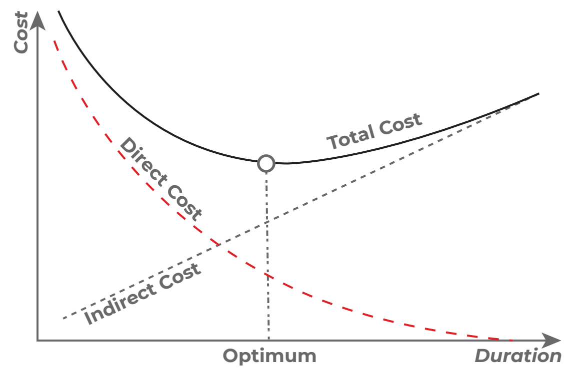
Non-integrated system / processes:

Disjointed approach among various teams for planning, design, estimation, procurement and site execution (among contractors and sub-contractors) leads to time and cost overruns. Digitisation tools could be implemented to ensure coordinated efforts amongst various stakeholders to ensure smooth running of a project.

Time Overruns: Extended delays in projects are endemic to the sector. An analysis[8] found that construction projects typically take 20% longer to finish than scheduled, frequently resulting in litigation.

In general, construction lacks integration and mapping of schedules for various sub-components like design, procurement and site execution with associated resource planning. A close monitoring and early warning signs (using project management tools) are imperative to delivering a project on time.

Delay in delivery of a construction project is also one of the key reasons for cost overruns. As seen in the graph, the indirect costs (rent, admin overheads, interest cost, material price escalation, etc.) increases over time.



Quality Issues: Quality issues arise primarily due to lack of required skillset to execute the job, lack of knowledge and negligence. Construction sector also lacks implementation of the right quality supervision processes, quality procedures and audit controls.

Quality lapses in real estate projects not only lead to delay and re-work, which may entail additional time and cost, but also endangers the life of the end user. Quality supervision workflow tools and applications could be very useful to identify and closure of non-conformances on real time basis.

Safety Issues: Construction sites are prone to serious hazards, such as falling from rooftops, unguarded machinery, being struck by heavy construction equipment, electrocutions, exposure to silica dust, and asbestos, etc. Adequate sign boards, tool kit talks, PPE's, regular safety awareness programs and audits are essential to avoid any accidents and ensure timely delivery of a project. It becomes utmost important to always ensure a safe working environment to prevent any accidents and further enhance labour productivity.

[8] McKinsey Report 2016- The next normal in construction

CHALLENGES FACED BY OCCUPANTS / RESIDENTS

CHALLENGES FACED BY OCCUPANTS / RESIDENTS:

A user research study was undertaken by Saint-Gobain to get feedback from the occupants of affordable and low mid-income residential housing complexes which are more than 15 years in Tier 1 and Tier 2 cities.

The survey revealed some of the key challenges / issues faced by the occupants that caused discomfort and inconveniences affecting their quality of life. Some of the key challenges reported were:





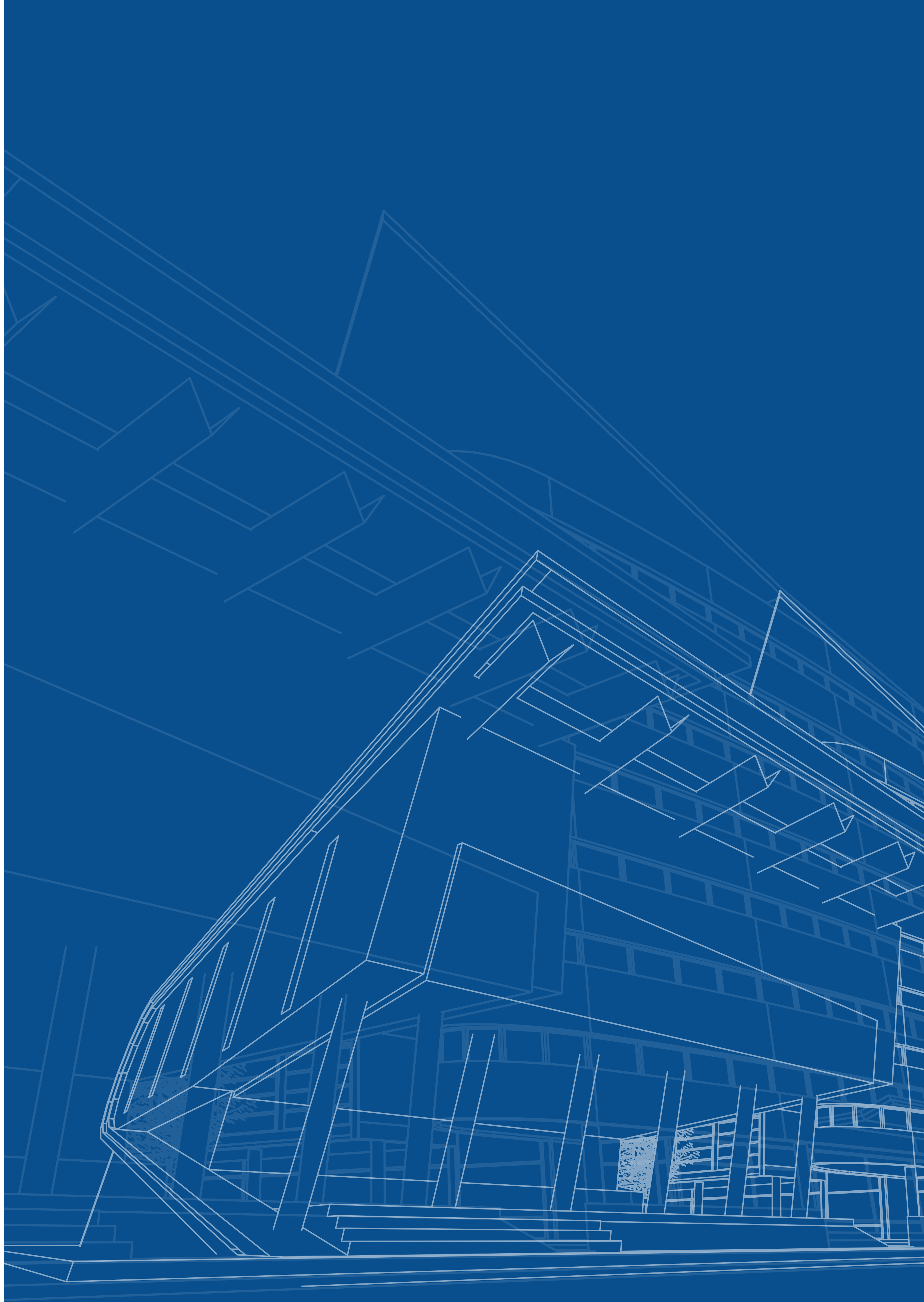

- Construction quality is the primary issue faced by the respondents. **~88%** of the respondents complained with respect to water leakages, dampness, cracks on walls and ceilings, primarily due to the poor construction quality.

- The second most reported issue was related to design and space constraints. **~84%** of the respondents complained about poor ventilation, absence of balcony, utility areas, restricted parking and common areas.

- Drainage was reported as the third most common issue. **~72%** of the respondents faced water clogging and seepages due to improper drainage systems (particularly prevalent during rains).

- **~28%** of the respondents faced issues related to improper maintenance and **~6%** of the respondents complained about noise transmission from the neighbouring flats.

Other issues were related to comfort such as lack of common areas, discontinuous water supply, etc.



EMERGING CONSTRUCTION TECHNOLOGIES

EMERGING CONSTRUCTION TECHNOLOGIES

Since the development of portland cement in the 19th century, concrete is the single most used building material across the globe. In India, reinforced cement concrete (RCC) framed structure is the most ubiquitous construction method for medium to high rise buildings. Typically, RCC framed structures consist of structural framework of RCC columns (vertical members), beams (horizontal members) and floor/roof slab. The vertical spaces between the beams and columns are typically infilled with masonry (brick/AAC block) or wall panels.

Conventional RCC construction is time consuming and has issues of quality control and wastages. Other critical issues with RCC include shortage of raw materials, inconsistent production and problems of pollution and greenhouse gas emissions. In the past few decades, there is growing impetus to develop innovative technologies to replace conventional practices. The focus of such alternative technologies is to: (a) optimize the use of conventional materials by increased industrialization of construction activities, (b) improve speed, safety and efficiency of construction site activities by bringing in mechanization, and (c) use of sustainable materials based on renewable resources or recycled materials.

To overcome the challenges addressed by the occupants and the developers (as highlighted in the previous sections), all the stakeholders in the real estate sector are on the look-out for viable, fast and low-cost emerging design, project management and construction technologies.

Following is the list of few promising construction technologies, identified as emerging technologies and have been evaluated in this report:

CATEGORY	TECHNOLOGY
PRECAST CONCRETE	1. 2-D PRECAST ELEMENTS
	2. 3-D PRECAST VOLUMETRICS
FORMWORK SYSTEM	3. ALUMINIUM FORMWORK (ENGINEERED FORMWORK)
	4. TUNNEL FORMWORK (ENGINEERED FORMWORK)
	5. PVC BASED FORMWORK (STAY-IN PLACE FORMWORK)
	4. GLASS FIBER REINFORCED GYPSUM FORMWORK (STAY-IN PLACE FORMWORK)
STEEL STRUCTURE	7. PRE-ENGINEERED BUILDING
	8. LIGHT GAUGE STEEL FRAMING

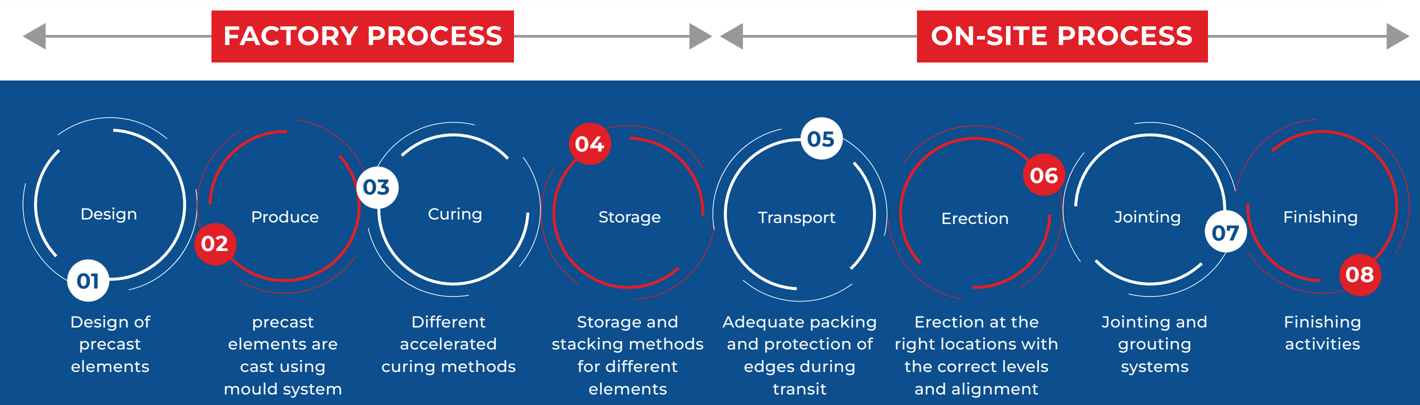
PRECAST CONCRETE - 2D PRECAST ELEMENT

2D precast concrete construction involves casting the main concrete components of a building such as walls, slabs, stairs, column, beam, etc., in a casting yard or in a plant in controlled conditions. The components are then transported to the project site and erected using cranes. The final finishing is usually done on-site. The choice of setting up a casting yard near the project site or sourcing from a precast plant usually depends on the scale of the project.

Precast concrete construction is a method that has been available for many years. However, it has been gaining more popularity in recent years due to the advantage it offers in terms of speed of construction and on account of shortage in construction labour.

Precast buildings can be either total precast, partial precast or hybrid systems. In buildings completely made of precast, all components such as footings, beams, slabs, columns, walls, facades, etc. are cast off-site and then assembled and connected on site using various connectors (dry/ mechanical/ emulative). Partial precast buildings may include a combination of precast members and cast-in-situ elements. In a hybrid system, precast members are used along with steel, masonry, etc.

Construction process:



S	W	O	T
Better quality (precision & finish)	High initial investments (require economies of scale)	Huge housing requirement	Bad past experience with substandard technology & execution (specially in joints)
Faster construction (robust planning and scheduling)	Limited modifications (during and post delivery)	Labour shortage	Lack of standardization and codes
Better safety conditions	Limited architectural flexibility	Large size projects	Depleting natural resources
Economy of time and cost (for optimal scale)	Lack of awareness and acceptability	Exposure to global market	
Low Maintenance		Demand for speedy and quality construction	
Universal application			
Weather independent			
Reduction in plastering and finishing activities			
Lesser labour requirement			

Key constraints / barriers in adoption:

- **High CAPEX -** A precast plant may entail higher setup costs depending upon whether it is on-site or factory-based plant, number of moulds/ beds, degree of automation, etc. However, considering the total cost of ownership, savings in terms of time, quality of construction and maintenance, precast concrete construction gives return on investment and profitability in medium to long run. Reduction in construction time allows faster occupancy and earlier realization of revenue for builders. Additionally, for large projects, mass production and repeatability of units brings in economies of scale.

- **Limited building design flexibility/Low margin for error -** There is low flexibility to accommodate changes in the project design post commencement of manufacturing. Shop drawings based on design are prepared and the precast production plans are frozen for execution. Any changes required due to faulty planning, changing market dynamics or user requirements become difficult to address once the component is produced. The requirements for drawing documentation are very heavy (close to 80%) at the start of construction. All inputs from designers, vendors and end users need to be frozen prior to construction. Errors in drawing are difficult to be addressed post production, as they cannot be corrected locally at site and need to be sent back to the production plant. Precast is economically unviable in irregular buildings as economies of scale cannot be achieved.

- **Joints and connections issues / seepage problems -** Joint connections between precast members are critical to be executed with precision in order to avoid water seepage issues. Many precast buildings have reported severe water leakage and seepage issues through external joints and connections. Joint treatment between panels is expensive, complicated and time consuming and hence results in increased risk leading to inefficient execution. Special consideration should be given to the junctions at the top and on the sides to prevent ingress of water. Execution skill, training and design acumen are still at a nascent stage in India leading to improper designing / execution thus increasing these problems.

- **Transportation and erection -** Lack of adequately sized vehicles to transport bulky members, poor road infrastructure and limited access to sites increases the cost of precast concrete construction. Road access might be restricted during peak hours at some places, thus putting more pressure and increasing co-ordination requirements between production, supply chain and erectors. Care should be ensured during transport to avoid damage to the panels. The precast plant location (on-site / of-site) has to be ideally selected, keeping in view optimal transportation and erection costs.

- **Lack of Knowledge, Awareness & Regulation -** IS Standards on precast construction especially for high-rises are in early stages. Global codes like ACI (American Concrete Institute) codes need to be referred towards design of such buildings especially for the connections. The lack of appropriate standards may lead to lack of standard building system and sub-standard locally manufactured fixtures for connections, etc. Hence, the cast-in-situ fittings and connections for the precast construction are currently imported. Currently, precast awareness in the design community is low and there is insufficient experience among designers & architects which results in resistance to change from conventional methods. Lack of specialised contractors who are skilled in execution and erection of precast structures is another critical issue. Precast requires careful supervision and skilled workers for panel erection on site.

Project Examples:

Housing Project at Kharghar, Navi Mumbai

Government Affordable Housing at Raipur

PRECAST CONCRETE - 3D VOLUMETRIC CONSTRUCTION

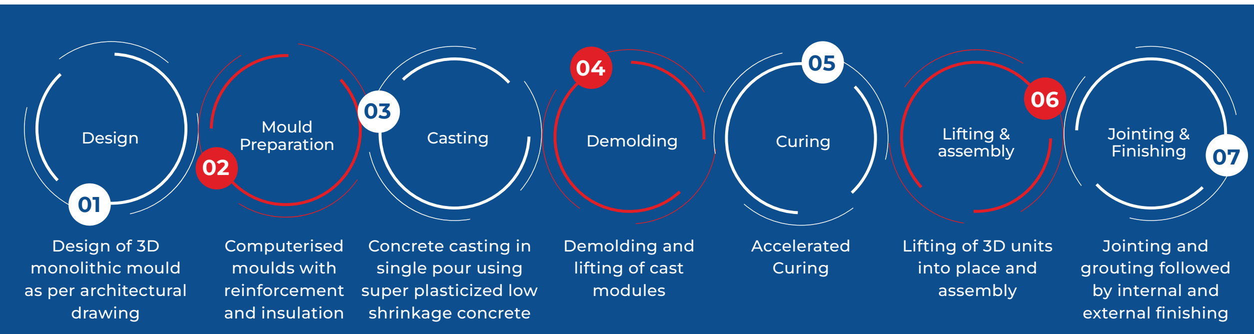
In 3D monolithic modular precast construction or 3D Volumetric construction (3DV), the structural modules with walls and slabs are cast monolithically in plant or at the casting yard prior to transport to the project site. Such modules can be brought to site as basic shell structure or as a final module with services and/or finishes installed ready for assembly. This method is also known as Prefabricated Prefinished Volumetric Construction (PPVC).

This method is an established system for building construction in Europe, Singapore, Japan, Australia, etc. It is a cleaner, safer, and innovative construction approach that can improve workflow continuity and productivity, minimize construction wastes, reduce the number of on-site trade contractors, etc. Unlike conventional construction methods where works are executed in a consecutive manner, 3DV allows construction to proceed concurrently, which can shorten the construction schedule significantly.

Hybrid model: To achieve efficiencies, combining 2D & 3D precast is also possible wherein a mix of 3D modules and 2D panels are used. For example, wet areas are manufactured as bathroom pods, while the remainder of the building is made from 2D panels. This may optimize the process for the two different types of areas of the building (complex and high on services areas getting manufactured as modules may bring high-productivity improvements and flexibility in other areas). However, the manufacturing process required to deliver both solutions become more complex, as it requires higher coordination in the supply chain.

Construction process:

Source - Hommission



S	W	O	T
› Better quality and safety (90% construction in controlled environment) › Higher precision levels (+/- 3mm) › Cleaner (dust and pollution free) construction site › Faster construction (robust planning and scheduling) › Economy in time and cost (for optimal scale) › Low Maintenance › Reduction in plastering and finishing activities › Lesser joints, better watertightness of building (monolithic casting) › Lesser labour requirement	› Heavy crane requirement (~ 200 t capacity) › High initial investments (require economies of scale) › Lead time for custom design of moulds › Limited/ no modifications (during and post delivery) › Limited architectural flexibility › Lack of awareness and acceptability › Lack of exposure to the technology (architects, engineers and institutes)	› Huge housing requirement › Labour shortage › Large size projects › Exposure to global market › Demand for speedy and quality construction	› Lack of standardization and codes › Seismic performance validation › Depleting natural resources

Key constraints / barriers in adoption:

- **Increased initial cost and logistics challenges:** Numerous studies claim that the high initial cost and logistics are the major constraints in the adoption of 3DV precast construction methodology. Initial cost for 3DV mainly involves expenses related to setting up of casting modules as per the architectural design requirement. If factory-based casting is adopted, the cost related to transportation as well as the risk due to transportation damage needs to be accounted for. Other transportation restraints include the need for appropriate vehicles, traffic control requirements in densely populated areas and wide approach roads to the site, along with limitations on the maximum distance of the construction site from the factory.

In India these constraints are mitigated by setting up a casting yard as close as possible to the site to reduce transportation effort, but this requires additional open space and facilities for curing which increases lead time and expenses.
In India specifically, the hoisting capacity cranes for handling the modules weighing ~25T is a factor that limits use of 3DV for high rise buildings.

- **Extensive coordination required prior to and during construction:** Compared to conventional construction methods, 3DV requires different construction aspects to happen concurrently and collaboratively. This requires extensive coordination between different project stake holders to execute the design, manufacturing, transportation, and installation of the precast modules, right from the early stage of a project. The additional project planning and design efforts required can be effectively handled using BIM along with communication among various stakeholders. Offering training courses for the project team and workers would enhance their knowledge and skills and improve coordination.

- **Lack of experience in terms of design and implementation:** Lack of experience and confidence among the stakeholders is a very critical issue as it may lead industry practitioners back to the conventional construction method. To mitigate the same extensive training programs are required.

- **Requirement for early commitment:** Early involvement and commitment of all stakeholders is necessary in 3DV construction since the precast moulds and components need to be ready before the project starts. The inflexibility in design at any later stage is a critical limitation that inhibits implementation of such construction methods in many cases.

- **Design flexibility:** Design constraints such as limitations on room size, total weight of the modules, need for repeatable design in all storeys, limited architectural features, etc. are impediments to adoption of 3DV construction in India. In Singapore, government regulations on logistics such as weight of the structure, truck capacity and traffic regulations for transportation has led to design and manufacture of smaller room modules.

- **Lack of codes and standards:** Currently in India, there is no established standard or guidelines for 3DV construction method. Development of a building code/ guidelines for this method will improve confidence on the installation and structural performance acceptance among builders and end users. For example, in Singapore to ensure that the different 3DV systems being used are reliable and durable, Singapore BCA (Building and Construction Authority) has set up a 3DV Acceptance Framework[9] consisting of building regulatory agencies as well as industry experts.

[9] https://www1.bca.gov.sg/buildsg/productivity/design-for-manufacturing-and-assembly-dfma/ppvc-acceptance-framework

Project Examples:

Residential Housing Project at Boisar, MMR

Bangalore Development Authority, Housing villas

ENGINEERED FORMWORK – ALUMINUM FORMWORK

Monolithic construction is the one wherein walls and slabs in the building are cast together in a single pour of concrete using high precision. Using re-usable formwork (aluminum and steel) in monolithic construction is an established method in many countries (including India) which replaces the conventional beam-column structure that uses regular steel or plywood shuttering.

Aluminum Formwork uses strong, re-usable aluminum formwork components to cast the walls and slabs of an entire floor simultaneously.

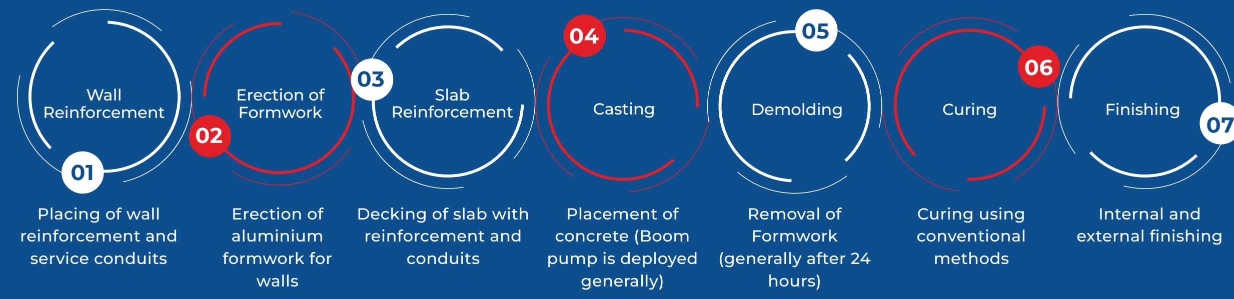
This is one of the construction technologies which has been most adopted by many real estate players for development of mid to large size projects with typical floors having multiple repetitions.

The basic element of the Aluminum formwork is the panel which is an extruded aluminium rail section, welded to an aluminium sheet. This produces a lightweight panel with an excellent stiffness to weight ratio, yielding minimal deflections under concrete loading. Panels of various grades are manufactured in the size and shape to suit the requirements of specific projects. The panels are manufactured within factory environment and made from a high strength aluminium alloy with a 4 mm thick skin plate and a 6mm thick ribbing behind to stiffen the panels.

Aluminum formwork is suitable for constructing a large number of houses in a short period of time using room-size forms to construct walls and slabs in one constant pour of concrete. The detailed formwork drawings would be generated from the design drawings and precise scheduling for assembly, concreting and dismantling needs to be followed.

Aluminum formwork can be adopted for different architectural layouts and are versatile to a broad range of applications like bay window, staircases, balconies, etc. If required, this type of construction completely avoids brick or block masonry and all components are cast using concrete.

Construction process:



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- Simple and repetitive nature of assembly
- Repetition of formwork ranges from 100-200
- Quality and consistency of dimensions
- Faster construction
- Light weight, no need for heavy lifting equipment semi-skilled labour
- Erection using semiskilled labour
- Monolithic structure gives good lateral load resistance for seismic and cyclone design
- Suitable for most architectural layouts
- No joints - limited risk of leakage
- Alteration of the frames possible for other design

W

- Relatively higher initial investments (require usage for minimum repetitions)
- Not suitable for low rise / small buildings
- Visible finishing lines on concrete surface at panel edges
- Difficulty in maintenance of preinstalled MEP
- Limited modifications (post completion)

O

- Huge housing requirement
- Large size projects
- Large quantum of vertical construction in real estate sector
- Demand for speedy and quality construction

T

- Depleting natural resources

Key constraints / barriers in adoption:

Currently, Aluminum formwork is gaining popularity in India as a cost effective and rapid construction method for large scale projects. It is best suited for multistoried construction with repeatable floors. Since Aluminum formwork is more expensive than conventional construction, it is suitable where construction quality and timely project delivery is of topmost priority.

Key constraints / barriers in adoption:

- The building being completely of concrete, the method is not environment friendly and there is minimal scope for including sustainable construction products;

- Concrete walls are not thermal efficient and may affect the thermal comfort of the built area. Proper planning and ventilation are required to improve the thermal performance of Aluminium formwork buildings; and

- Alterations and modifications by the occupant are not possible and regular preventive maintenance is required to avoid blockage issues in the preinstalled MEP service lines.

Project Examples:

Residential Project at Virar, MMR

Residential Project at Noida, NCR

ENGINEERED FORMWORK – TUNNEL FORMWORK

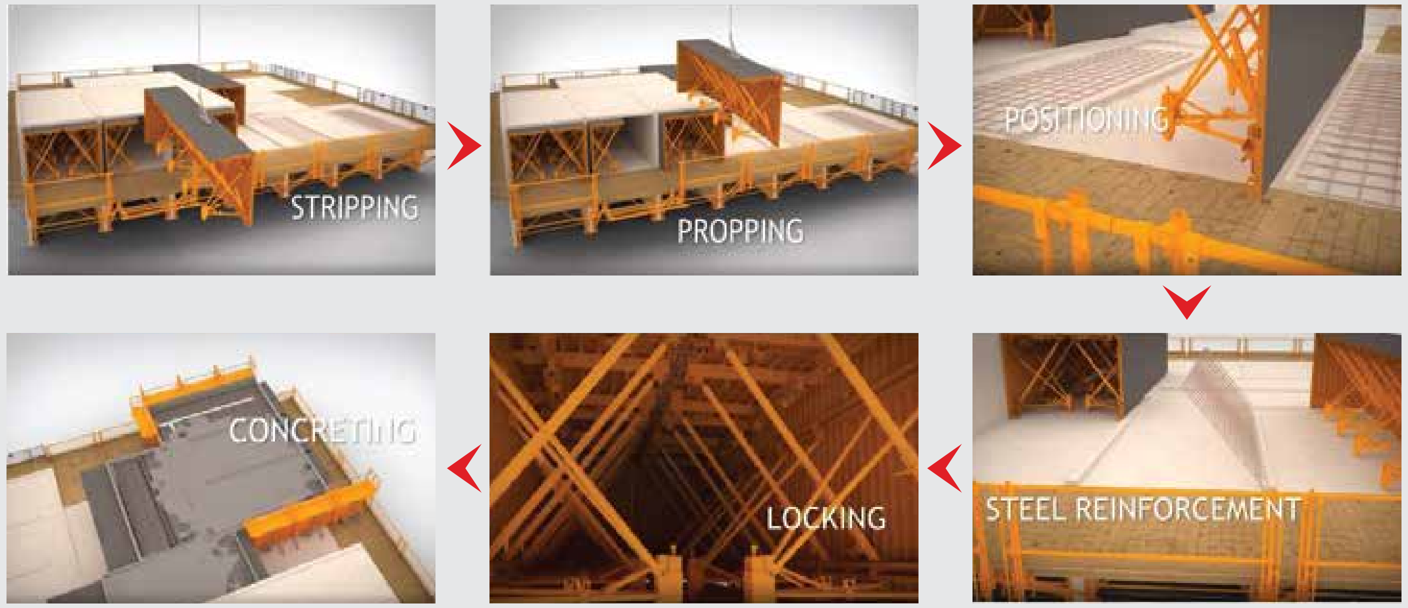
Tunnel Formwork involves monolithic casting of concrete walls and slabs in one go at site using re-usable, room-size engineered steel forms. The formwork consists of two half shells (L-shaped) which are placed together and then concreting is done over it to form a room size module.

Typically, 3 walls and 1 slab are cast together, and the fourth (usually external) wall is of AAC blocks or any other infill wall. Several such modules make an apartment unit.

Tunnel formwork has fewer components compared to aluminum formwork and is one of the fastest construction practices currently in use. In an ideal scenario, tunnel formwork can achieve a slab cycle of 1-2 days.

Typical cycle includes casting and simultaneous testing to ensure adequate concrete strength for safe formwork removal based on previous day's concrete pour. Then, the formwork is struck and manually pushed on to the dismantling platform, picked by crane, scraped, oiled and repositioned. The reinforcement and services fixing for the next position is completed simultaneously. All reinforcement gets fixed, openings and other details completed for next pour of concrete. Concrete pouring continues for 2-3 hours.

Construction process:



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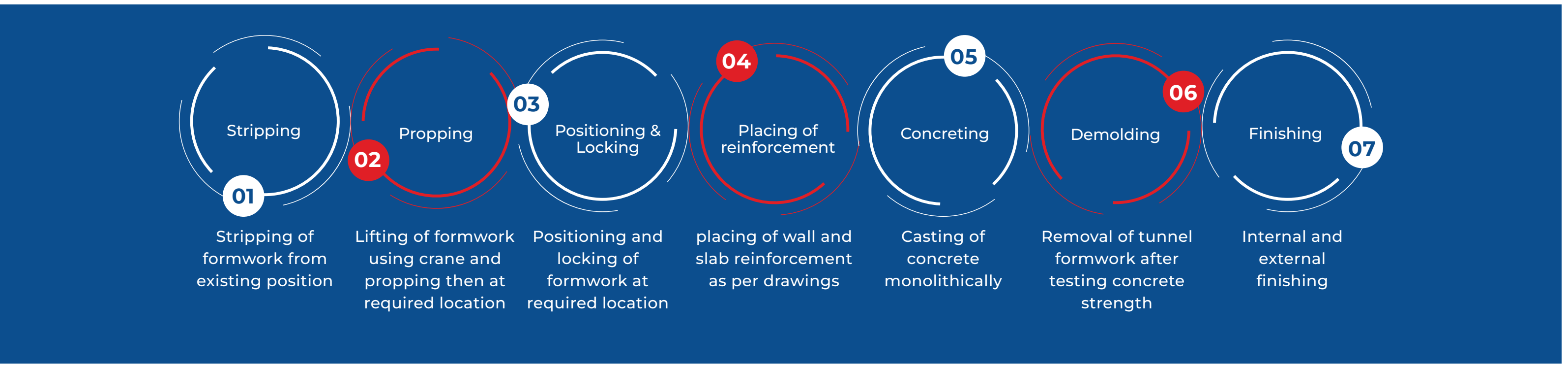


S	W	O	T
Rapid construction - short slab cycle (1-2 days) More than 500 repetitions can be executed Quality and consistency of dimensions Large number of modular units bring economy in construction Lesser semi-skilled labour requirement Box type monolithic structure gives good lateral load resistance for seismic and cyclone design	High lead time to custom design the formwork High initial investments (require usage for minimum repeatitions) Not suitable for small buildings Limited architectural features, sunken slabs, projections Limitation on room sizes Handling of heavy formwork Design limitations to include repeatable box type structures Difficulty in maintenance of preinstalled MEP LImited modifications (post delivery)	Huge housing requirement Large size projects Large quantum of vertical construction in real estate sector Demand for speedy and quality construction	Depleting natural resources

Key constraints / barriers in adoption:

Tunnel form is typically used in India for the construction of cellular structures with high degree of repetition such as hostels, hotels, residential apartment blocks etc.

Some of the key constraints in widespread use of Tunnel formwork systems, especially in residential segment are:

- Higher cost compared to conventional methods makes it unsuitable for small projects. Higher initial investment is required for the formwork and construction equipment for handling and hoisting the heavy formwork;
- Design limitations including only box type layout with minimal architectural features. Tunnel formwork is not appropriate for all projects since room dimensions are limited based on dimensions of formwork (e.g.. min. room width of 210 cm and max. span of 1.5 to 2 times the floor height). Large halls and open free areas cannot be built using this method;
- Alterations and modifications by the occupant are not possible in the internal RCC walls and regular preventive maintenance is required to avoid blockage issues in the preinstalled MEP service lines;
- Vulnerable to leaks at joints between internal-external walls and when sunken slab is done separately; and
- Cash flow management due to the rapid construction rate.

Project Examples:


Affordable Housing Township Project at Pune


Light House Project at Rajkot, Gujarat

STAY-IN PLACE FORMWORK - PVC BASED FORMWORK

Stay-in-place (SIP) formwork refers to structural walling components that serve as permanent, durable formwork for concrete walls. SIP formwork systems are widely used in Australia, Canada and Europe and could be made of different materials like rigid poly-vinyl chloride (PVC) components, fiber cement boards, Expanded Polystyrene (EPS) blocks/panels, steel cages, etc. When hollow foam blocks/panels are filled with reinforcement and concrete it is known as Insulated Concrete Forms (ICF).


PVC Stay-in-place formwork construction


SIP construction with ICF technology

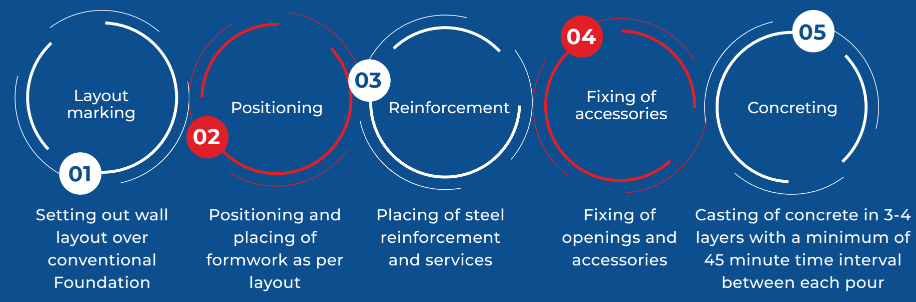

Galvanized steel SIP construction

Once the SIP formwork is kept in place and aligned, the cavities are filled with normal or lightweight concrete along with reinforcement. Once the concrete is set, the formwork can act as insulation or part of structural system. Some SIP formwork can also offer solutions for floor/roof using reinforced cement concrete.

The speed of construction is faster than conventional since the formwork is already part of the system. There is no additional formwork needed, only some support to ensure alignment of the wall panels may be required.

Construction process:

The typical steps involved in construction using PVC SIP formwork technology are described below.



The SIP can be used as both load bearing walls for small buildings and as infill wall within RCC or steel buildings in high-rise buildings. Technology is ideally suitable for low-rise structures.

S	W	O	T
Speed of construction	Suitable primarily for low-rise buildings	Huge housing requirement	Uncertainty in performance aspect of the system (post occupancy)
No plastering and painting required	Use as infill walls in high rise may not be cost effective	Demand for speedy and quality construction	
Light weight easy to handle	More site activities involved - require better quality supervision	Use of recyclable plastic product for PVC based formwork	
No requirement of heavy equipment	Panel cutting activities on site leading to waste disposal		
Minimal initial investment	Minimal architectural flexibility		
Minimal design restrictions	Improper sealing of joints - leakage issues, wall deterioration		
No minimum required repetition	Factory produced components - transportation issues		
Suitable for both small and large projects			
Water saving (no curing requirement of infill concrete)			
Quality and consistency of dimensions			
Lesser labour requirement			

Key constraints / barriers in adoption:

- Primarily suitable for low rise buildings only and therefore difficult to adopt in mass group housing projects;
- For smaller houses, difficulty in remodelling and altering the concrete filled walls acts as a detrimental factor;
- Some of the technologies like ICF are costlier than conventional masonry. The lower energy costs brought about by the insulation is not well accounted for;
- Service conduits need to be preinstalled before concreting. This will make repairs and maintenance difficult;
- Some formwork like PVC needs considerable site cutting. This causes issues in quality control as well as wastage leading to disposal issues on site;
- Very smooth surface of some formwork makes finishing and painting difficult; and
- Difficulty in incorporating architectural elements.

Project Examples:

Light House Project at Lucknow, UP

Retail building at Palghar, MMR (non-residential)

STAY-IN PLACE FORMWORK: GLASS FIBER REINFORCED GYPSUM PANELS

The formwork in Glass Fiber Reinforced Gypsum (GFRG) construction consists of hollow panels made of modified gypsum reinforced with chopped glass fiber. The cavities in the panel can be filled with concrete and reinforced with steel bars.

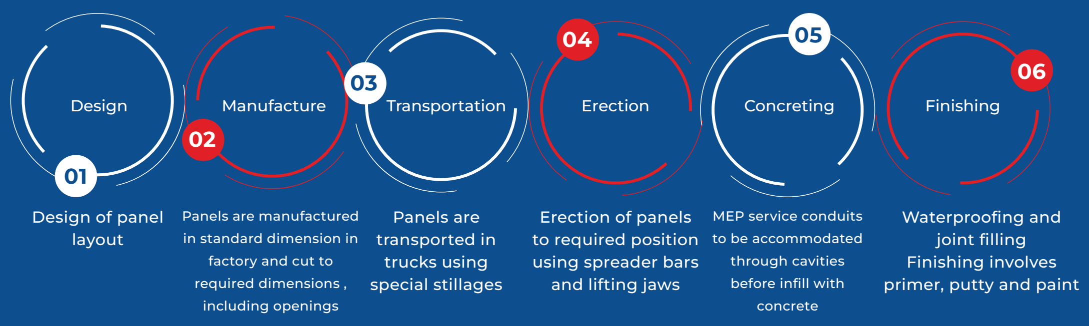
Typically, the panels are of thickness 124 mm, height 3m and length up to 12m. The large panel size allows for fast and efficient construction. The panels can be used for the construction of external and internal walls, floor and roof slabs, staircases and compound walls.

GFRG panels filled with reinforced concrete possesses substantial strength to act as load bearing elements and also as shear walls capable of resisting lateral loads due to earthquake and wind. The Bureau of Indian Standards (BIS) has published codes of practice for design and construction of GFRG buildings is in place. (IS 17400:2021 and IS 17401:2021)

Elimination of beams and columns in the structure reduces cost and minimizes formwork requirement. Reduction in the usage of steel, sand, cement and water makes GFRG a more sustainable construction technique. The overall reduction in weight of building and thereby design seismic forces reduces foundation size for the building.

GFRG buildings can be designed to be load bearing up to G+6 in seismic Zone 5 and up to G+10 in lower seismic zones. Considering efficiency in transportation and panel cutting activities, GFRG is suitable for high rise buildings with repeatable floors.

Construction process:



S	W	O	T
Speed of construction	Difficulty in transporting and installing large panels	Use of industry by product gypsum - sustainable construction	Acceptance to the technology
Gap provides better thermal insulation compared to conventional bricks/ blocks	Damage of panel during transportation	BIS code for design and construction	Raw material availability
Panel can be used for all components - wall, slab, staircase, etc.	Storage space requirement	Green building certification	
Fire and termite proof	Specialized design	Demand for speedy and quality construction	
Lower building weight	Training of labour		
Seismic resistant	All cutting to be done from factory - difficult to correct or modify on site		
Lesser labour requirement	Prone to leakage at joints - workmanship for waterproofing is critical		
	Panel quality variability		
	Mold formation		

Key constraints / barriers in adoption:

GFRG is a fast and sustainable alternate construction technique that is gaining popularity in India. Some of the constraints that affects the adoption of GFRG are:

- GFRG construction is vulnerable to water leakage and dampness in both external wall joints and wet areas unless specialized care is taken in joint treatment and waterproofing.

- Proper planning and dimensioning of layout is required to minimize the number of joints in a wall and efficient co-ordination is required to avoid on site cutting of panels. Both these aspects are critical for avoiding leaks;
- GFRG panels being heavy, handling and hoisting of panels need special care and training. Improper hoisting can cause damage to panel and pose safety concerns;
- Storage of panels in a covered area not exposed to rain or humidity is important to ensure panel quality;
- Transportation of panels and use of crane necessitates large open area and wide approach roads for the site;
- Design and construction of GFRG building requires training for structural engineers and contractors;
- Panels are customized and pre-cut at factory according to the design (including the openings), hence it is not possible to make changes during the installation stage;
- MEP services should be pre-installed through the cavities before concreting. Post construction maintenance and repair is challenging; and
- The span of a slab (floor/roof) should be restricted to a maximum of 5 m. Large open rooms would require additional RCC beams and columns.

Project Examples:

Hostel buildings at IIT Tirupati (non-residential)

Demonstration Housing Project at Nellore, AP

STEEL STRUCTURE - PRE-ENGINEERED BUILDING

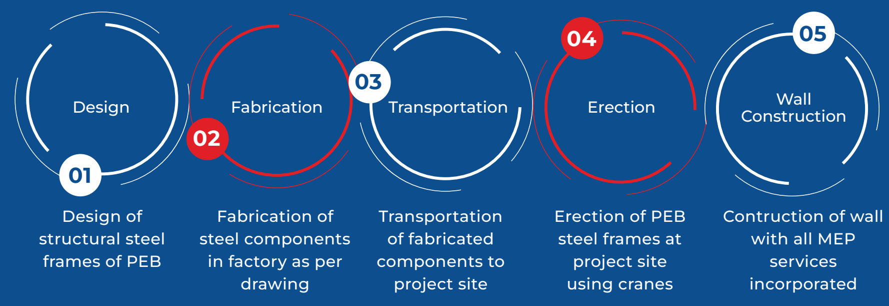
Pre-Engineered Buildings (PEB), also called engineered metal buildings, involve steel components predesigned and prefabricated in factory and assembled on site. PEBs are fabricated using inventory of standardized components that can satisfy a wide range of structural and aesthetic design requirements. The building can be fitted with other structural and non-structural components including mezzanine floor, infill walls, canopies, etc. The components can also be designed to receive various kinds of curtain walls, precast components and other walling and roofing systems.

An efficiently designed pre-engineered building can be lighter than the conventional steel buildings made using off-the-shelf steel sections by up to 30%.

PEB offers a number of advantages like faster construction, cost-effectiveness (for building with larger spans), high quality, low maintenance, consistent span, and flexibility in design. The components of a PEB can be almost 100% recycled for alternate uses after the service life of the building.

PEB systems are extensively used in industrial construction and its adoption is also picking up in non-residential constructions (like commercial office buildings) in India. The crude steel production capacity of India for the year 2021 stood at 118.2 Mn tonnes[10]. The current Pre-Engineered steel building manufacturing capacity is approximately 0.35 Mn tons per annum. For buildings beyond 10 storeys, PEB may not be cost effective.

Construction process:



A wide variety of materials can be chosen for construction of walls in a PEB such as AAC blocks, solid concrete blocks, fiber cement boards, conventional brickwork etc. Prefabricated wall panels such as cement sandwich panels are also commonly used on account of the easy installation process with additional advantages of light weight, thermal efficiency, etc. Sandwich panels usually have an outer layer of boards (cement/fibre/MgO) sandwiching inner core of lightweight concrete. The sandwich panel systems are usually drywalling system with interlocking groove mechanism that allows easy and fast assembly of walls.

S	W	O	T
› Faster construction › Efficient system using standardized components - minimum wastage › Higher precision - accuracy up to 1mm in components › Flexibility in design, large spans › Easy to incorporate thermal and acoustic insulation to wall elements › Easy to remodel and reuse components › Seismic resistant › Adaptability - easy extension horizontally and vertically › Dismantling and recycling post demolition	› Higher cost of construction › Training of labor › Use of heavy equipment and cranes › Require well defined logistics with sequence of inventory and its delivery (any missing component can delay the whole process of erection) › Prone to corrosion of members unless treated properly › Interface between PEB and wall elements - risk of water leakage › Steel loses strength at high temperature - Need for fire protection	› Global push to explore alternatives to concrete based construction › Post disaster rehabilitation work › India 2nd highest manufacturer of steel globally › National Steel Policy in place to develop a self-sustained domestic market for steel	› High, fluctuating cost of steel › High embodied energy of steel- not sustainable

[10] Ministry of Steel

Key constraints / barriers in adoption:

PEB construction is extensively used in India for industrial buildings, warehouses, parking lots, commercial buildings, etc. There is scope for widespread use of PEB in residential segment with the impetus on fast-track construction in mass housing projects. Some of the constraints that affects the adoption of PEB are:

- Volatility in steel prices is one of the biggest impediments of using PEB in India. Fluctuations in the pricing of steel results in the final cost price of the key raw material to be much higher than the initial projected price. This affects the profitability of PEB and its wide acceptance in residential construction;

- PEB in residential buildings requires smaller span compared to large industrial and warehouse structures. This poses logistical challenges in fabrication, delivery and coordination;

- If not properly maintained, the steel frames are susceptible to corrosion. This necessitates special coatings to resist the corrosion of steel;

- Steel being good at conducting heat, reduces the thermal comfort in the building. Additional thermal insulation materials need to be incorporated into the wall elements to improve thermal efficiency;

- During fire, the steel components lose strength rapidly, which may cause local and global buckling of the main framing members. Additional fire protection like concrete embedment or intumescent paint is necessary in PEB buildings, which increases the cost;

- The interface between PEB and various components need special care to ensure all gaps are closed with suitable waterproofing and insulating materials. Special products like mastic pads, filler strips and trims need to be used appropriately at all joints and connections;

- Steel components allow higher passage of sound compared to conventional brick and block masonry. Therefore, acoustic insulation must be incorporated within the wall section. Condensation issues when using composite wall systems within PEB also exists. This needs to be addressed using vapor barriers and proper ventilation.

Project Examples:

Light House Project at Indore

Delhi Public School, Jhansi

STEEL STRUCTURE - LIGHT GAUGE STEEL FRAMING SYSTEM

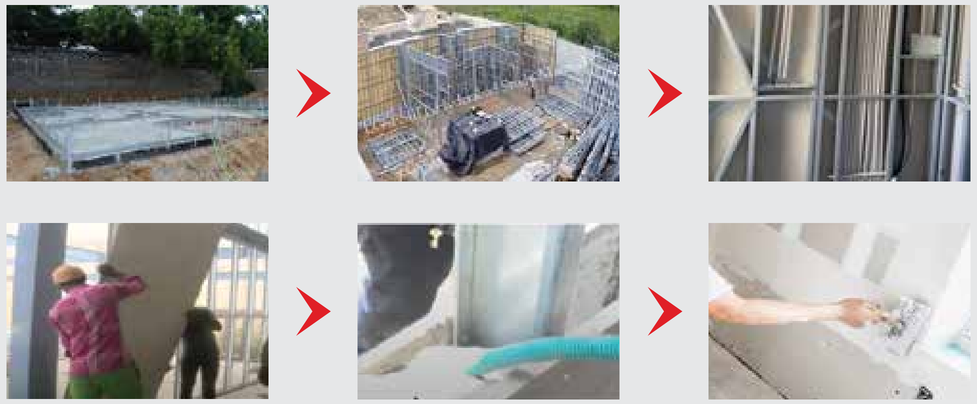
Buildings with Light Gauge Steel Framed (LGSF) structures are constructed using factory made cold formed galvanized steel components as the primary building material. Cold formed steel members are made by bending a flat sheet of steel at room temperature into a shape that has more load bearing capacity than the flat sheet itself.

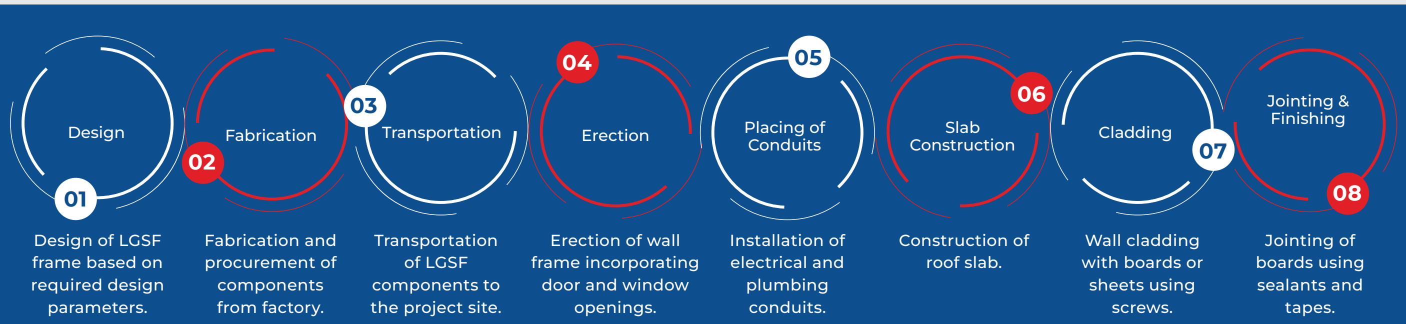
Process of manufacturing LGSF components

Source: Nipani

The material thicknesses for steel sheets used in LGSF usually range from 0.3mm to 3mm. Compared to standard hot rolled steel sections, which require controlled manufacturing environment with heat range up to 2300 F, cold formed steel members can be produced with no additional heat and by rolling the sheet through a series of dies. Cold formed steel sheets are typically low carbon steel < 0.1% carbon. LGSF framework on account of the profile shape, has high strength to weight ratio. Due to the reduction in weight of the wall, significant reduction in dead load allows for lower structural cost in both superstructure and foundation. A LGSF building is 35-40% lighter than a conventional concrete building.

LGSF construction process:





LGSF components are assembled at site to form the framework of walls and further sheathed with panels like fiber cement/ MgO/ Gypsum based boards to form internal and external walls. External walls material is selected to resist the wind load and conform to the functional requirements. Electrical and plumbing services along with insulation can be preinstalled into the wall system. LGSF walls can be designed to be load bearing for up to G+3 buildings.

The walls are usually infilled with lightweight concrete to avoid local buckling, perception of hollowness and sound travel. The flooring/ slab is usually constructed as conventional RCC slab or using deck sheet supported on floor joists with in-situ reinforced concrete on top.

LGSF construction is an established method of construction in Japan, Australia and North America. Codes and standards in these countries are well developed for design and construction aspects. The speed of construction using LGSF is high and a typical four storeyed building on-site can be erected within approximately one month. The floor or roof slab in LGSF construction is made typically using profiled steel deck sheet of 0.9 mm thickness with RCC screed above (usually 75mm thick with M25 concrete). Alternatively, floor slab can be erected using steel joists and fiber cement boards or plasterboards.

S	W	O	T
Lightweight, easy to handle - no heavy equipment	Suitable only for low-rise buildings	Huge housing requirement	High, fluctuating cost of steel
Faster construction	Use as infill walls in high rise may not be cost effective	Global push to explore alternatives to concrete based construction	High embodied energy of steel - not sustainable
High strength-to-weight ratio-smaller foundation, lower seismic load	Prone to leakage issues, wall deterioration (due to improper sealing of joints)	Suitable for fast post disaster rehabilitation works	
No minimum repetition required	Trained labor requirement	India 2nd highest manufacturer of steel globally	
Suitable for both small and large projects	Connections between wall to structural members (RCC / Steel frame) needs special care	National Steel Policy in place to develop a self-sustained domestic market for steel	
Reduction in concrete use	Steel loses strength at high temperature - Need for fire protection		
Dimensional accuracy	Permits more sound transmission than masonry - needs acoustic insulation		
Easy to stack and transport			
Design flexibility, easy to remodel			
Dismantling and recycling post demolition			

Key constraints / barriers in adoption:

LGSF is gaining popularity as an innovative and rapid construction material that allows design flexibility. The components being lightweight and stackable, can be easily transported to remote and hilly areas even in difficult terrain. LGSF is especially useful in post disaster rehabilitation work. However, the technology has not reached mainstream acceptability in housing segment due to various factors including:

- LGSF is a relatively cost-effective solution only for buildings up-to 4 storeys. Combining LGSF with RCC/ Steel framework as an infill wall does not utilize the load bearing capacity of LGSF wall system and becomes an inefficient construction method and is also expensive;

- Currently, there is a scarcity of trained labour for the fabrication and erection work related to LGSF members and associated boarding, finishing, etc.;

- End user concerns are generally related to fire performance, corrosion, thermal performance, lightning resistance, etc. Since steel loses its strength at high temperature, enough fire protection must be provided through encasement or fire-retardant paint. This may further increase the cost of LGSF buildings;

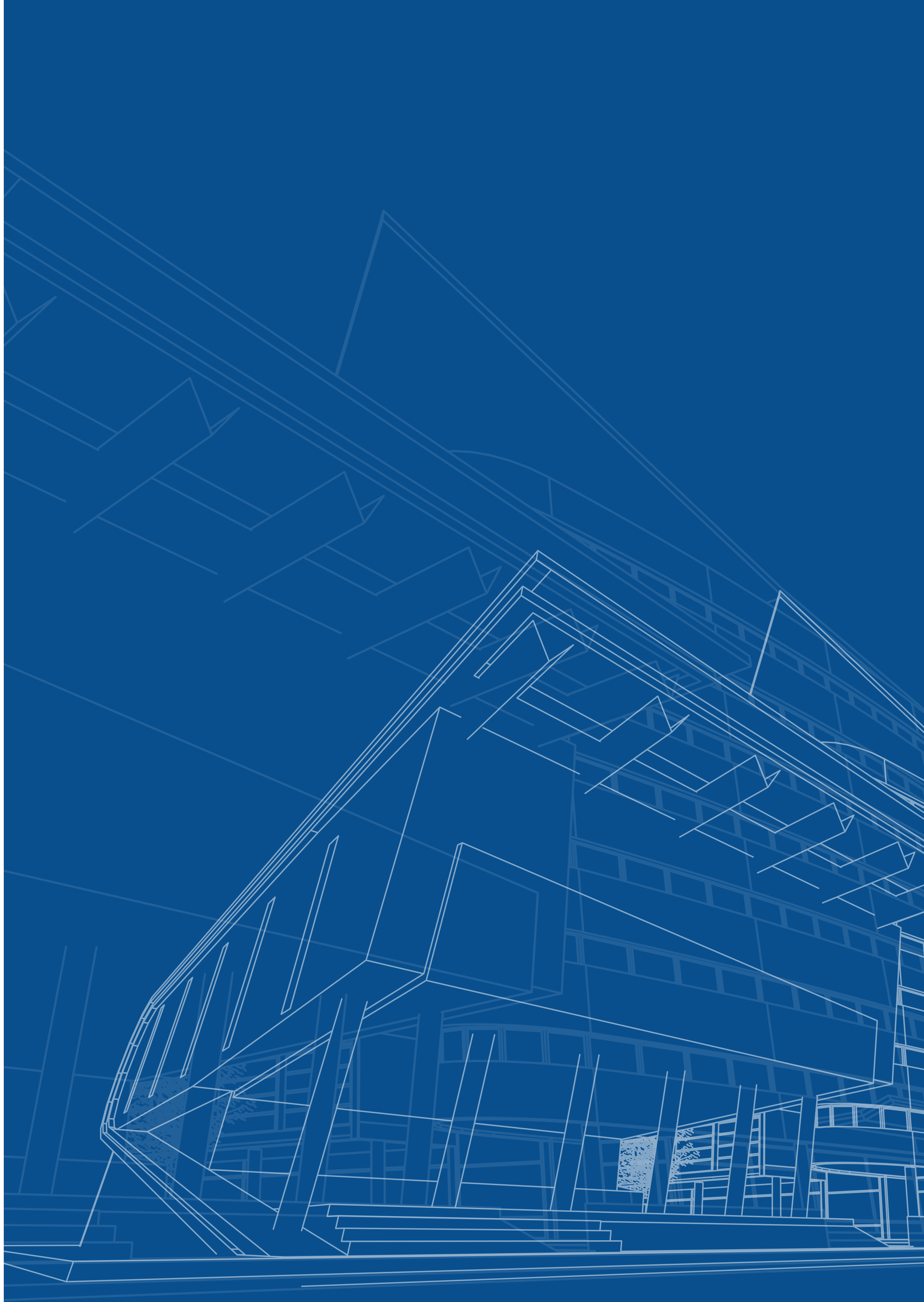
- LGSF allows higher passage of sound compared to conventional brick and block masonry. Therefore, acoustic insulation must be incorporated within the wall section; and

- There needs to be greater impetus from the industry and academic experts to address these aspects to improve the market acceptance of LGSF construction in the residential sector.

Project Examples:

Office building at Lucknow, UP (non-residential)

Office building at Dallipali, Orissa (non-residential)



TECHNO-COMMERCIAL COMPARISON AMONG IDENTIFIED TECHNOLOGIES

TECHNO-COMMERCIAL COMPARISON AMONG IDENTIFIED TECHNOLOGIES[11]

Legend: Rating

Excellent	Good	Average

Parameters	RCC frame with block infill (Conventional)	1 Precast-2d precast elements	2 Precast-3d volumetric	3 Engineered-Tunnel formwork	4 Engineered-Aluminium formwork	5 Stay in place PVC	6 Stay in place GFRG	7 Steel - PEB (w/ sandwich panel)	8 Steel - LGSF
Ideally suitable structure height	No limit	No limit	Limited by crane capacity	No limit	No limit	Not specified[15]	Up to 10 storeys[12]	No limit	Up to 4 storeys
SPEED OF CONSTRUCTION									
Lead time	Low	High	High	Medium	Medium	Low	Medium	Medium	Medium
Slab cycle (floor to floor)	High (15-20 days)	Low (1 - 3 days)	Low (1 - 2 days)	Low (1 - 3 days)	Medium (7 - 12 days)	Medium (7 - 12 days)	Medium (7 - 14 days)	Medium (4 - 5days)	Medium (4 - 5days)
Finishing time	High	Low	Low	Medium	Low	Low	Medium	Medium	Medium
Overall time advantage w.r.t. conventional	Base	High	High	Medium	Medium	Medium	Low	Medium	Medium
CONSTRUCTION PARAMETERS									
Logistic challenges	Low	Medium	High	Medium	Medium	Low	High	Medium	Medium
Factory based production	Low	High	High	Low	Low	Medium	Medium	High	High
Space requirement	Low	High	High	Low	Low	Low	Medium	Medium	Low
Labor requirement	High	Medium	Low	Medium	Medium	High	High	High	High
Heavy machinery	Low	Medium	High	Medium	Low	Low	Medium	Medium	Low
Safe construction process	Low	High	High	Medium	Medium	Medium	Low	Medium	Medium
On-site quality control requirement	High	Low	Low	Medium	Medium	High	High	Medium	Low
Additional finishing effort	High	Low	Low	Medium	Medium	Low	High	Medium	Medium
Passive/additional fire protection	Low	Low	Low	Low	Low	Low	Low	High	High
DESIGN PARAMETERS									
Training for architects & engineers	Low	Medium	Medium	Low	Low	Medium	High	Low	Medium
Design restrictions (architectural)	Low	Medium	High	High	Low	Medium	Medium	Medium	Medium
Restriction on alteration (post hand over)	Low	High	High	Medium	High	High	High	Low	Medium
PERFORMANCE PARAMETERS									
Chances of Leakage[13]	High	Medium	Medium	Medium	Low	Medium	High	Medium	Medium
Ease of maintenance	High	Low	Low	Medium	Low	Low	Low	Medium	Medium
Thermal comfort	Medium	Low	Low	Medium	Low	Low	High	High	High[14]
Acoustics comfort	Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low[15]
ENVIRONMENTAL PARAMETERS									
Materials with high embodied energy	Low	Low	Low	Low	Low	Medium	Medium[16]	High	Medium
Water consumption at site	High	Low	Low	Medium	Medium	Medium	Medium	Low	Medium
Noise and pollution at site	High	Low	Low	High	High	Medium	Medium	Low	Low
Operational energy	Low	High	High	Medium	Low	Low	Medium	Medium	Low
Recyclability[17]	Low	Low	Low	Low	Low	Low	Low	High	Medium
ECONOMIC ASPECTS									
Initial investment	Low	High	High	Medium	Medium	Low	Medium	Low	Medium
Economies of scale	No Limitation	>1 million Sq.ft	>1 million Sq.ft	>500 Repetitions	>100 Repetitions	No Limitation	No Limitation	No Limitation	No Limitation
Construction Cost per sqft[18]	Low	Medium	Medium	Low	Low	Medium	Low	High	High

[11] For a mid to high rise building basis the plant/ mould capacities as required; except for LGSF, SIP, GFRG technologies (4 stories structure)
[12] Only 6 storeys in high seismic | [13] Subject to methodology, supervision, workmanship | [14] with insulation material

[15] Compendium of Innovative Emerging Technologies shortlisted under GHTC | [16] Lower if using industry by product gypsum | [17] Recyclability of the final product/structural element
[18] For G+12/ G+4 mid-income segment residential project in Tier 1 city with optimal economy of scale

INITIATIVES TAKEN BY THE GOVERNMENT FOR PROMOTING VARIOUS TECHNOLOGIES

INITIATIVES TAKEN BY THE GOVERNMENT FOR PROMOTING VARIOUS TECHNOLOGIES

As part of the Global Housing Technology Challenge-India (GHTC-India) initiative, the Indian Prime Minister has laid the foundation for six Light House Projects (LHPs) in six states.

Under LHPs, internationally tested technologies are being implemented for cost-effective, environmentally sustainable and faster construction.

There are several advantages envisaged from the technology used in these LHPs, the main ones being longevity, climate-resilience, affordability, protection and speed.

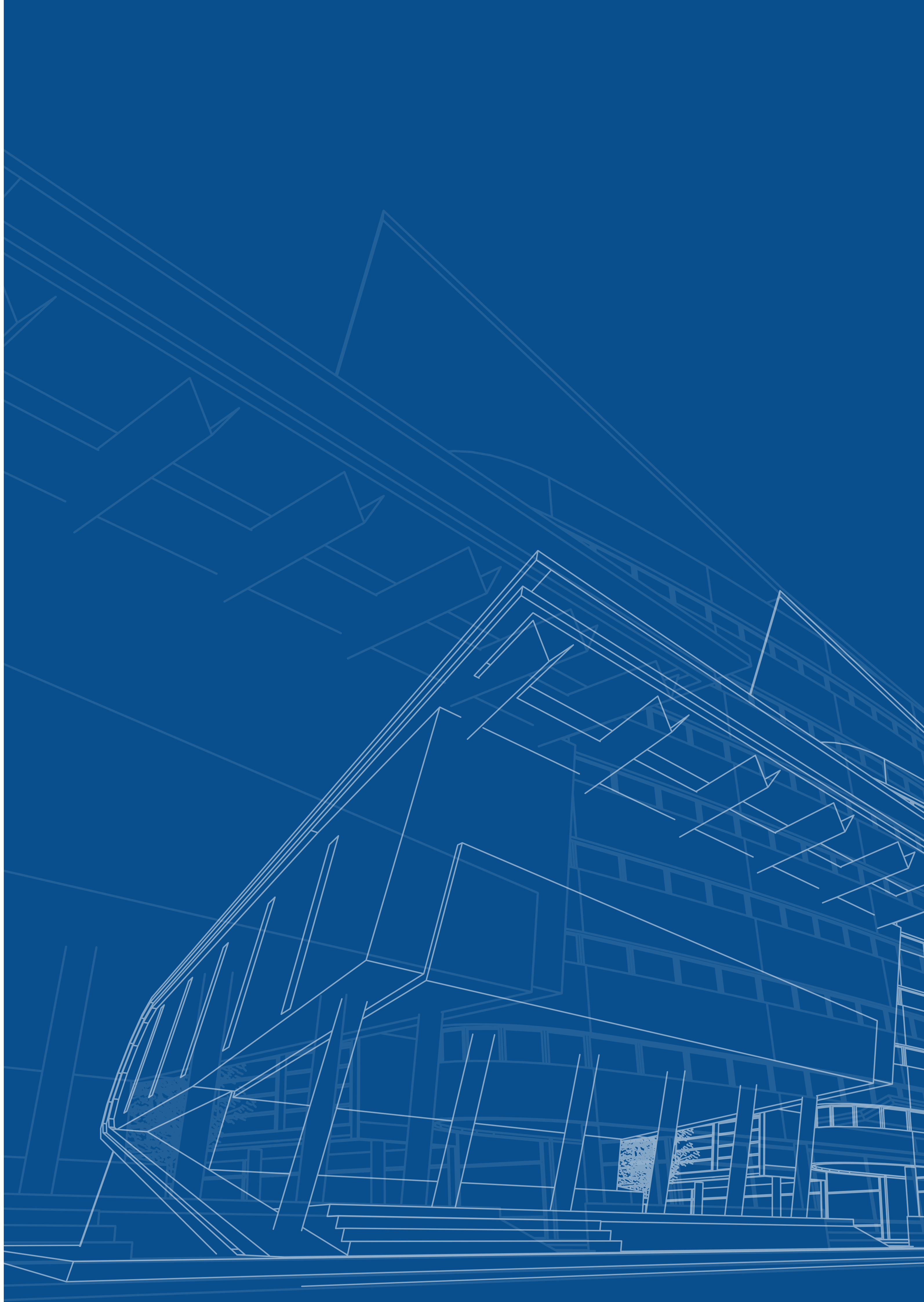
This technological transition will help achieve the 'Housing for All' vision of the Prime Minister. By using cutting-edge and alternative global technologies, the construction needs of a rapidly urbanising India can be accommodated.

A total of 1.23 crore houses have been sanctioned so far against the estimated demand of 1.12 crore. In more than 1.05 crore houses,[19] construction is in different stages, and almost 6.4 mn houses have been completed and delivered to the recipients.

BMTPC (Building Materials & Technology Promotion Council) is also a technical partner in the Global Housing Technology Challenge – India (GHTC-India), launched by the Ministry of Housing & Urban Affairs, Government of India.

Among the different technologies discussed in the previous section, 6 systems were selected by GHTC for pilot construction of ~1000 units each (called Light House Projects) at different locations across India to evaluate technical feasibility, adaptability to Indian geoclimatic regions and scalability aspects. They are as follows:

- 2-D precast elements (Location: Chennai)
- 3-D precast volumetric (3DV) (Location: Ranchi)
- Tunnel Formwork (Location: Rajkot)
- PEB with Prefabricated Sandwich Panel System (Location: Indore)
- PEB with PVC Stay in Place Formwork (Location: Lucknow)
- PEB with LGSF system (Location: Agartala)



[19] PMAY Urban (as of 7th Nov. 2022)

FUTURE OF CONSTRUCTION TECHNOLOGY

FUTURE OF CONSTRUCTION TECHNOLOGY

The construction sector has set out on its journey to technological advancement with tools for digitisation and automation. We are already witnessing numerous disruptive technologies like design and project management digitalisation, digital double, Artificial Intelligence (AI), robotics and 3D printing emerging as innovative tools which are the future of construction technology.
One of the notable disruptive technologies in the construction space is **AI based applications** using drones, 360° cameras and mobile devices. This technology adds value to every phase of the project lifecycle right from the site selection to design, execution and handing over. Set out below are a few of the key value adds and services offered by such applications:

- Preparation of topographical maps and land survey of a project site is an extremely critical, challenging and time-consuming component during the initial phase of a project. The applications can capture 2D and 3D terrain models, contours, automated CAD drawings, do cut-fill, volumetric analysis of site.
- Provide real-time monitoring of project progress for various stakeholders from remote locations, without their physical presence on site. It can provide impressive aerial views of the project site, 360o virtual walkthrough of site, automated construction progress reports and live streaming etc, thereby enabling an accurate understanding and progress dashboards to the stakeholders.
- Assistance in quality control by checking the dimensions & accuracy level by comparing with good for construction drawings through BIM, digital snag management tool.

- Useful in accessing difficult sections of project site where workers try to reach without undertaking proper safety measures. Therefore, the applications can help in eliminating unsafe acts and conditions at project site.
- In large and complex project sites, optimal usage of heavy machinery and equipment can be ensured by real time monitoring.

Building Information Modelling (BIM) is another notable technology and is one of the fastest growing tools in the last couple of decades in the construction sector. It has revolutionised the field of design and project management for construction projects. The physical and functional characteristics of buildings can be represented digitally using BIM, thereby enabling project managers and site execution teams to facilitate the smooth execution and operation of construction projects. Nowadays, 5D BIM is also widely being used which integrates Schedule (Time - 4D) and Budget (Cost - 5D) with the 3D Model. This enables the project manager to visualise the scheduled activities in advance before the actual execution of a project and

thereby detect any deviations with respect to the Baseline schedule in terms of progress or cost. BIM provides economic benefits through feasibility analysis and clash detection, design validation, delay prevention, collaboration, real-time phasing and coordination among project stakeholders.

Construction automation is being seen across production of construction materials, prefabrication, on-site construction, maintenance, demolition and recycling. Automation will help to solve many of the issues serious plaguing the construction industry like poor quality, shortage of labour, safety of workers, weather dependency, etc. Automation ensures shorter construction time and provides economic advantages. Automated instruments can reduce average time consumed for major activities by nearly 50% in comparison to manual labour. Although the adoption of robotics is low in India, in the past few years, the country has witnessed growth in the construction automation sector. Various start-ups have ventured into the field of construction automation to provide solutions like robotic spray-painting services, brick laying, end to end wall finishing activities like plastering, putty and painting, etc.

Concrete 3D Printing also known as additive manufacturing, is a manufacturing technology based on digital models that enable rapid prototyping with layer-by-layer printing. Concrete 3D printing is a new intelligent construction method that uses a special concrete mix as the printing material using extrusion-based process. Compared with traditional concrete casting techniques, the 3D printing technology has the advantage of being free from formwork with a high degree of automation that saves labour and time. It can also significantly improve the pace and quality of construction. Concrete 3D printing can be carried out for both off-site and on-site construction. Currently, concrete 3D printing is widely used in the manufacture of architectural elements having non-linear designs and patterns.

Internet of Things (IoT) can be defined as an infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and the virtual world and react. Based on the input data available, IoT system tends to learn and train itself through Machine Learning and Artificial Intelligence. The IoT data is then integrated through a BIM model for design, building performance optimisation, construction management and building maintenance and operations in the construction sector. IoT also plays a key role in monitoring the performance of smart buildings in terms of energy saving efficiency during the service life of a building. However, the application of IoT on a large scale in the construction sector would involve extensive training to the various project stakeholders for them to have a clear understanding of the system.

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