

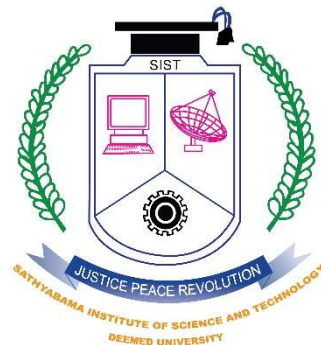
FEASIBILITY STUDY ON IMPLEMENTING MODULAR CONSTRUCTION TECHNIQUES IN HIGH-RISE BUILDING IN INDIA

A Thesis

Submitted in partial fulfillment of the requirements for the award of
Master of Architecture degree in Building Management

by

K PRINCELY (39840014)



**DEPARTMENT OF ARCHITECTURE
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

MAY 2021



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BONAFIDE CERTIFICATE

This is to certify that this Report is the bonafide work of **PRINCELY K (39840014)** who carried out the Dissertation entitled "**FEASIBILITY STUDY ON IMPLEMENTING MODULAR CONSTRUCTION TECHNIQUES IN HIGH-RISE BUILDING IN INDIA**" under our supervision from January 2021 to May 2021.

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ABSTRACT

Construction industry is considered as one of the most important industries in India. It is well known that most construction projects are done through conventional technique but Modular construction technique is a new one for the construction industry. As opposed to conventional onsite building, modular construction is a game-changing technology because it provides quicker construction, cleaner production, improved quality control, and lower environmental impacts. Due to their inherently topological modular nature and increased number of repeatable modules, high-rise buildings will optimize these benefits.

The aim of the project is to study the present situation of the modular construction industry in India. And studying the Feasibility on implementing modular construction techniques in high-rise building in India are to be given. This paper examines the design and construction techniques of existing modular construction for high-rise buildings in other countries, as well as the feasibility of introducing modular construction techniques in India.

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Chapter 1

INTRODUCTION

1.1 Introduction

With rapid urbanization and population growth, more people live and work in cities. This has led to an increased need for taller buildings in urban environments and a lack of affordable housing in cities. The construction industry continues to grapple with rising labor costs because of shortages in skilled labor and persistently stagnant construction productivity. These market dynamics present an opportunity for innovation.

Modular and off-site construction can help to address these challenges. Modular construction has origins dating back to the 17th century beginning predominantly with single-family homes. Today, modular construction is used in many applications, including residential, commercial, health care, and others. Most existing modular buildings are low or mid-rise, however there have been several high-rise volumetric modular buildings constructed abroad in the last decade and demand appears to be increasing.

This research report explores the current state, drivers, benefits, and barriers to the growth of high-rise volumetric modular construction. This report shall include findings from workshops and interviews with modular manufacturers, designers, regulators, and industry trade groups as well as existing research in modular construction.

1.2 AIM

To identify and investigate the possibilities of implementing modular construction of high-rise building in India.

1.3 OBJECTIVE

- To Study the Existing Modular Construction Technologies
- in the construction industry
- Analyze the Level of Implementation of Modular Construction Techniques in India.
- Analyze the challenges Faced in Implementing modular construction Techniques for constructing high-rise buildings in India

- Research and Identify the Mitigation Measures that are adopted in other countries for Modular Construction.
- Investigating the feasibility of Adopting identified mitigation measures for successful modular construction of High-rise building in India.

1.4 SCOPE OF WORK

The scope of the Thesis Study is focused on the technical aspects of current modular systems and case studies of high rise modular projects from around the world. Interviews shall be conducted of adopters, manufacturers, contractors, industry representatives and lenders that would likely be involved in the development of a high rise modular project.

Based on the literature review and interviews, key measurement metrics will be tested in the Qualitative and Quantitative models to evaluate project level data and modular advantages relative to standard onsite construction.

1.5 RESEARCH METHODOLOGY

The framework consists of two main steps, qualitative and quantitative. Both qualitative and quantitative research designs, also known as the mixed method, was adopted as a research methodology for this research. A mixed method approach strengthens the research since both qualitative and quantitative data are analyzed

Phase I utilized a qualitative telephone interviews to explore the barriers to implement the Modular construction technology in India through the qualitative analysis. Phase II utilized an on-line survey administered among the industry professionals with experience. The survey was partially structured with some questions left open for discussion to gather more data. After gathering the data from the professionals, this study sought to explore the feasibility of implementing Modular construction technology in India.

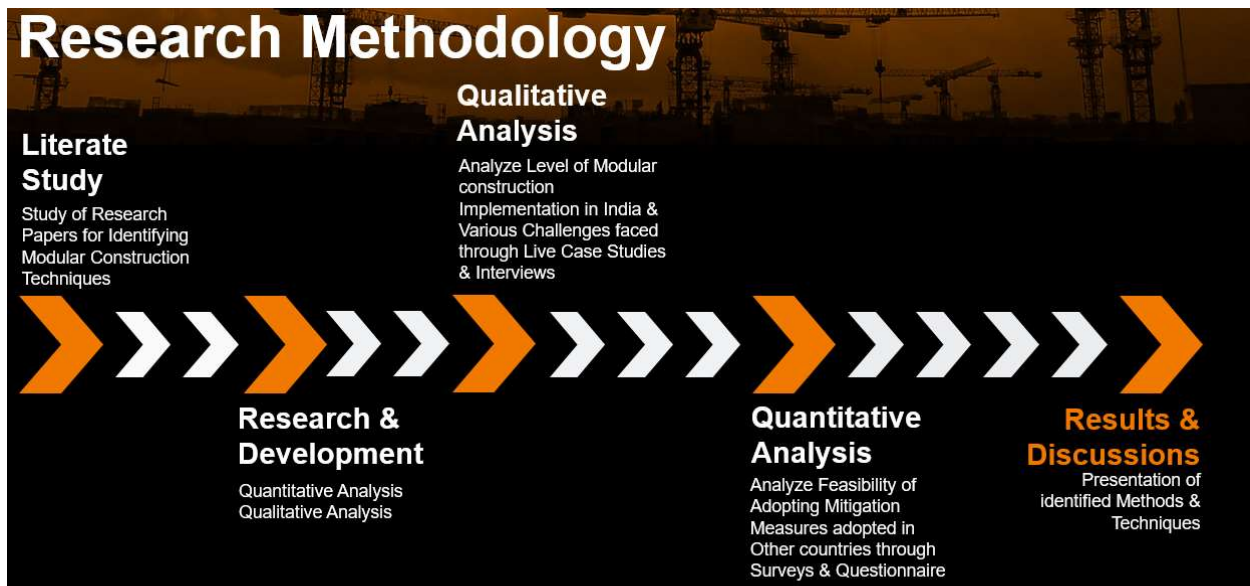


Figure 1. 1-1 - Research Methodology

1.6 LIMITATIONS

The scope of the study is limited to the following:

- Impact of Skilled Worker shortages in India.
- Extent of Interview and Surveys is limited to Email, Phone calls & Online Surveys only.
- Strategies for overcoming skilled worker Shortage shall be analyzed to reduce the impact.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

More people are living and working in cities as a result of rapid urbanization and population growth. This has resulted in a greater demand for higher buildings in urban areas, as well as a scarcity of affordable housing. Because of skilled labor shortages and stagnating construction productivity, the construction industry continues to face growing labor costs. These market conditions give an opportunity for innovation.

These issues can be addressed using modular and off-site construction. Modular building dates back to the 17th century, when it was mostly used for single-family homes. Today, modular construction is used in many applications, including residential, commercial, health care, and others. Modular building is being used in a variety of sectors, including residential, commercial, and health care. Although the majority of extant modular buildings are low or mid-rise, numerous high-rise volumetric modular structures have been built abroad in the recent decade, and demand looks to be increasing.

This study looks at the current state of high-rise volumetric modular construction, as well as the causes, benefits, and challenges that it faces. The results of workshops and interviews with modular manufacturers, designers, regulators, and industry trade associations, as well as current modular construction studies, will be included in this paper.

2.2 MODULAR CONSTRUCTION TECHNOLOGY

2.2.1 Modular Construction Technology

Modular construction is a way of constructing building structures utilising prefabricated modules manufactured off-site in a regulated manufacturing process. Modular building differs from traditional building in that the modules are made of steel rather than concrete, though it can also be made of other materials such wood, cross laminated wood, and fibre reinforced polymers. Modular structures are constructed using the same finishing materials as traditional construction and adhere to the same building rules and architectural criteria. They can, however, be more cost-effective because modular construction reduces capital investment and ensures that projects are completed on schedule and on budget. It also provides a safer working environment because all of the modules are constructed in a factory setting, minimizing the possibility of accidents and the associated liability for workers.

There are numerous benefits to modular building, ranging from faster project completion to less on-site disruption. Modular construction allows for higher quality control and streamlines the construction process, making it the obvious next step in the automation era. Modular construction shifts a large portion of the building from the construction site to a manufacturing facility, improving predictability, productivity, and lowering the hazards associated with construction. Because of the shorter construction schedules and faster return on investment, modular structures offer significant cost advantages (Return of Investment).

2.2.1.1 Modular Construction Manufacturing Sustainability

- **Modular buildings are manufactured in controlled environments:** Waste is practically minimized by recycling materials, regulating inventory, and protecting building resources in the factory-controlled process, resulting in reduced waste. Offsite construction is up to 50% faster than traditional building. It also results in fewer site disturbances since it reduces the amount of raw materials delivered on a daily basis as a result of site requirements to fewer bulk deliveries to a factory, which immediately benefits the construction's carbon footprint and also reduces noise, dust, and other nuisances. On-site transportation and traffic are reduced, resulting in fewer staff.
- **Modular buildings are recyclable:** Because no structure can exist indefinitely, destruction (or recycling) can be built into the design from the start, as the modules may be disassembled and the construction materials re-used. Some modular structures are made from recycled materials from prior constructions. Modular buildings are easy to transport and adapt to changing needs because they are adaptable and flexible to changing needs. Minimizing pollution involves reducing trash generation and disposal in the manufacturing, producing little or no waste on site, recycling scrap metals, and reusing modules or components.
- **Offsite construction uses less energy:** When compared to a traditional-built project, a modular structure uses up to 67 percent less energy to construct. The building is not only environmentally friendly during construction, but it is also energy efficient throughout its lifetime. Energy-efficient technology, such as energy-efficient glass, geothermal systems, and solar panels, are now being put in modular structures.
- **Modular can be built to the exact same standards as traditional:** Buildings are designed and constructed to the same, better standards of sustainability as traditional building. Unlike traditional construction, modular buildings offer numerous cost benefits, owing to shorter project timelines and lower overall expenses.

2.3 CURRENT PRACTISES OF MODULAR CONSTRUCTION

2.3.1 A review on modular construction for high-rise buildings

There are three main construction approaches for stacking modular units based on core, podium and infilled frame systems.

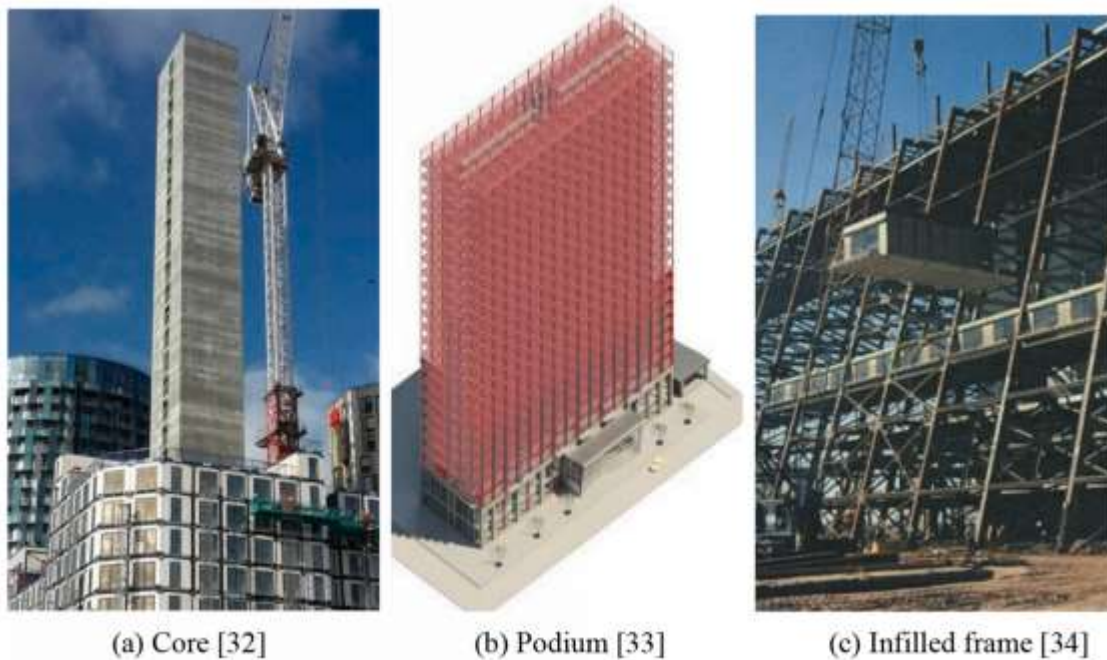


Figure 2.1 - Compressive strength vs structural elements

2.3.1.1 Core

All of the modules are grouped together around one or more of the stability cores. The modular unit is meant to withstand just vertical gravity loads over the entire height of the building, whereas the cores are designed to withstand lateral forces from wind and earthquake movements individually. All modules are clustered around one or more stability cores in the core-based approach (Fig. 1a). The modular unit is meant to withstand just vertical gravity loads over the entire height of the building, whereas the cores are designed to withstand lateral forces from wind and earthquake movements individually. As a result, the lateral diaphragms, as well as the connections between modules and cores, must be capable of transferring lateral stress to the core structure. Precast concrete or cast-in-situ steel–concrete composite walls can be used for the core, and extra bracing systems can be added to the floors and ceilings to increase the building's height. Outrigger systems are commonly employed for structures up to 70 stories tall. It can, however, be used for taller structures.

Not only does the outrigger system reduce building deformations caused by overturning moments, but it also improves force resistance efficiency.

2.3.1.2 Podium

The modular unit is put on top of a podium or platform structure that is constructed as a traditional steel, concrete, or hybrid steel–concrete structure in the podium-based technique. For taller buildings, the podium serves as a foundation for the modular units, which can be stacked or clustered around a core. Modular units may be supported by a primary structure at the podium or platform level. The supporting columns are placed at a multiple of the module width in this example (normally 2 or 3 modules). The beams are built to withstand the combined loads of the modules above them (normally a maximum of 4-6 storeys).

The supporting structure is a traditional steel framework with beams and columns aligned with multiples of the module width, providing open plan space on the ground floor and below ground levels. This type of construction is ideal for mixed-use buildings that include retail, commercial, and residential units, as well as residential units over commercial areas or parking lots, etc., especially in metropolitan projects.

Modules can be positioned further away from the façade line. A mixed-use development in Manchester is demonstrated. A traditional composite structure is used for the ground floor and below-ground automobile parking.

2.3.1.3 Infilled Frame System

Modular units are put between the beams and columns of a central framing structure in the infilled frame method. The overall stability of modular structures is maintained because the primary framework structure is created onsite using traditional methods.

2.3.1.4 Modular Buildings around World

Ten of the world's tallest modular buildings.

No.	Project	Storey	Year	Location	Modular type	Material	Highlight
1	Collins House	60	2019	Melbourne, Australia	2D panel and 3D volume	Concrete	The tallest building combined both penalised and volumetric methods
2	J57 Mini Sky City tower	57	2015	Changsha, China	2D panel	Steel	The fastest built buildings upon completion (in 19 days)
3	Croydon Tower	44	2020	London, UK	3D volume	Steel	The tallest volumetric modular building upon completion
4	Atira Student Accommodation	44	2018	Melbourne, Australia	2D panel and 3D volume	Concrete	Combining both penalised and volumetric methods
5	La Trobe Tower	44	2016	Melbourne, Australia	2D panel and 3D volume	Concrete	Combining both penalised and volumetric methods
6	Clement Canopy	40	2019	Singapore	3D volume	Concrete	The tallest volumetric modular building
7	B2 Tower	32	2016	New York, USA	3D volume	Steel	The tallest volumetric modular building upon completion
8	T30 Tower	30	2011	Xiangyin, China	2D panel	Steel	The fastest built buildings upon completion (in 15 days)
9	Apex House	29	2017	London, UK	3D volume	Steel	The tallest volumetric modular building in Europe
10	SOHO Tower	29	2014	Darwin, Australia	3D volume	Steel	The tallest volumetric modular building upon completion

Figure 2.2 - World's tallest Modular building

Despite the technical limitations of using modular construction technology in high-rise buildings, some modular high-rise structures have been constructed in recent years as a result of advances in manufacturing and material technology. However, there are just a few modular high-rise buildings in the globe (less than 1 percent).

Only ten of the world's highest modular buildings were examined and summarized in this article. Steel is utilized in the majority of modular high-rise buildings constructed using 3D volumetric modules, although concrete is usually utilized in modular high-rise buildings constructed using a combination of panelized and volumetric methods.

2.3.1.5 Modular high-rise buildings in Australia

Collins House in Melbourne is now the world's highest modular building, standing at 60 stories. Three of the world's ten tallest modular buildings were recently built in Australia, employing a unique structural unit called the Hickory Building System (HBS) designed by the Hickory Group (an early pioneer in modular construction in Australia) for high-rise prefabricated buildings.

The HBS system is made up of a number of precast panelized modules (such as load bearing walls, elevator and stair cores, and lightweight concrete floors) that are joined together on site using wet joints.

The HBS system not only decreases building time (from 30 to 50 percent when compared to traditional building methods) and material and energy waste, but it also improves quality and safety.

The podium-based technique was used to complete the 60-story Collins House project in 2019. Up to level 14, the podium structure was built with concrete using the traditional approach, while the succeeding storeys were built using the HBS method. The project took 29 months to complete, which is 30 percent faster than traditional approaches.



Figure 2.3 - Collins house in Melbourne

2.3.1.6 Modular high-rise buildings in China

Broad Sustainable Building was the first in China to use modular construction in high-rise structures (BSB)

More than 90% of a steel building's components [61], including structural sections like floor cassettes and framing systems, were built in a BSB central plant before being transported for onsite assembly using bolting methods.

Over 30 pilot and commercial projects, including a 30-story hotel (T30 Tower) and a 57-story apartment building, have used BSB's penalised construction methodology (J57 Mini Sky Tower). Both the T30 and J57 Mini Sky towers are currently listed among the top 10 tallest modular buildings in the world.

The most notable characteristic of these towers is that they have broken the world record for the fastest building construction. The T30 tower took only 15 days to complete, while the J57 Mini Sky tower took only 19 days to build (with a rate of three floors per day).



Figure 2.4 - Collins House in Melbourne

2.3.1.7 Modular high-rise buildings in Singapore

Only one recent project (Clement Canopy Tower) was completed to the height of 40 stories, making it Singapore's tallest modular skyscraper. The world's tallest concrete building erected utilising the PPVC technology, this tower set a new record.

Using the core-based technology, the Clement Canopy project, which consists of twin towers with 505 residential units, was constructed from 1,899 prefabricated prefinished volumetric concrete modules with 48 various module shapes.

Before being delivered to the construction site and joined to the concrete core using wet joints, each module was prefabricated in an off-site facility with about 85 percent finishes for walls, floors, ceilings, and MEP systems.

This project highlighted the advantages of employing the PPVC approach in terms of construction time savings (30%) and environmental impact reduction (up to 70 percent onsite waste 30 percent off-site waste)

2.3.1.8 Conclusion

When compared to traditional onsite construction, modular building has showed considerable benefits in terms of saving time, lowering costs, and, most critically, decreasing environmental impacts.

Although modular construction is common in low-rise structures, its use in high-rise structures is still limited. The technological constraints that are preventing modular construction for high-rise structures from becoming more widely adopted were emphasized and debated.

- Developing a composite module with lighter and stronger structural parts,
- Developing a smart joining methodology with improved strength and stiffness while remaining simple to install.
- Developing a computationally efficient computer tool for advanced analysis and everyday design of modular tall buildings, and
- Developing design guidelines for speeding the real-world use of modular construction.

Modular buildings can be made taller with new composite modules, faster (and cheaper) with clever joining techniques, safer with new design provisions, and more efficiently with computationally efficient tools by overcoming technical difficulties.

2.3.2. Literature Case Study

2.3.2.1 Zoho Tower

- ZOHOTower - In September 2014, Gwelo Developments, an Australian developer and function Object() { [native code] }, finished the construction of a 29-story modular tower in Darwin.
- The \$120 million project aimed to alleviate Darwin's chronic housing shortage amid the offshore gas boom.
- The building is home to Oaks Hotels and Resorts, a 4.5-star hotel with commercial and retail tenants on the lower levels and residences on the higher floors.
- Modular construction was used to alleviate the difficulties of these conditions due to a limited labour market and the site's soft soil qualities.

- Upon completion in 2014, this structure set a new record for the world's highest modular building constructed utilising the volumetric modular approach.
- The SOHO tower is 29 stories tall and was built with a PPVC podium.
- A basement and eight levels of the podium structure were created with concrete using the traditional building method, while the other floors were built atop the podium using steel modules.
- These modules are made out of a lightweight concrete slab, concrete ceiling beams, and steel columns, and have dimensions of 10 4.2 3.9 m and a weight of 22 tonnes.

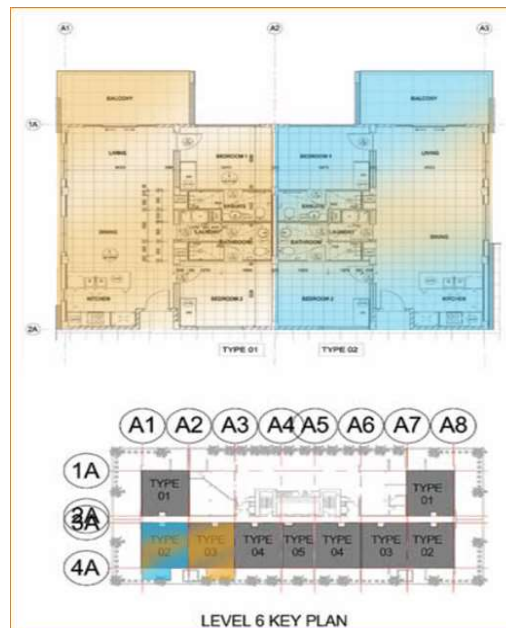


Figure 2.5 - Collins House in Melbourne

2.3.2.1.1 Structural Review – Tower Structural Scheme

In the design of this modular tower, Irwinconsult used both steel and concrete materials. Vertical loading is supported solely by steel columns during transit and installation. When these steel columns are put on site, insitu concrete is cast into them to create hybrid concrete-steel columns that operate as the tower's vertical load bearing elements for the duration of its service life. Vertical loading is supported solely by steel columns during transit and installation.



Figure 2.6 - Collins House in Melbourne

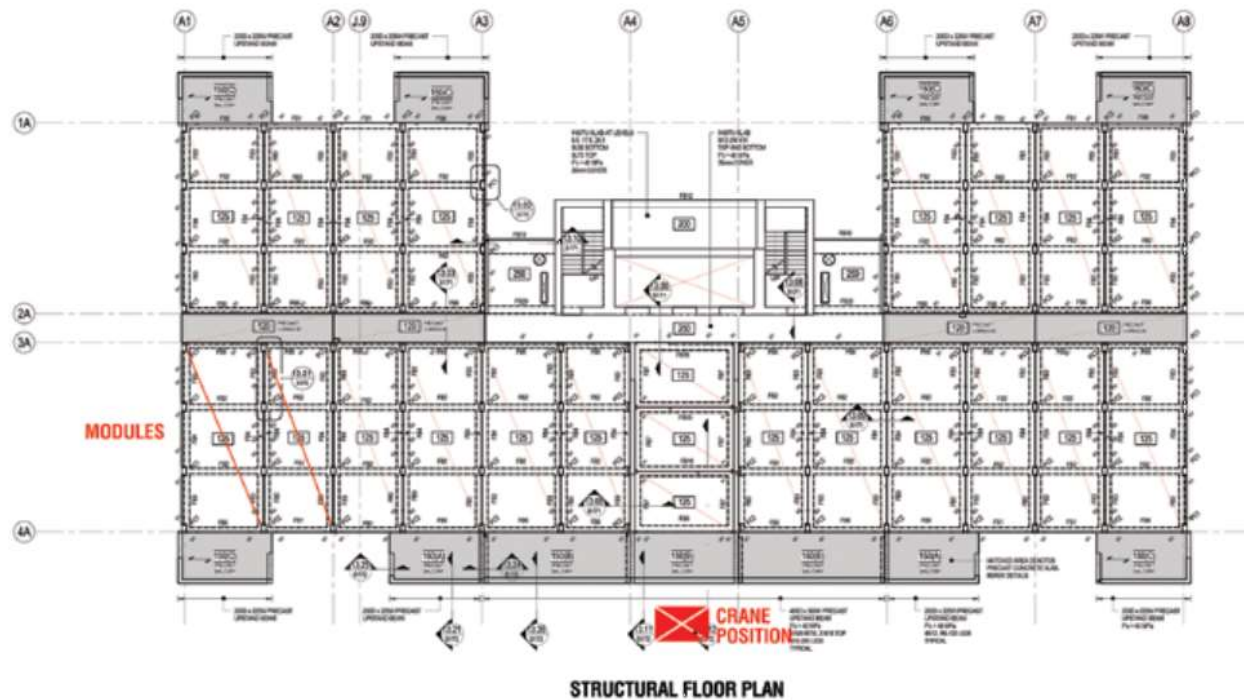


Figure 2.7 – Structural Floor Plan

2.3.2.1.2 Structural Review – Module Structural Scheme

The concrete and steel elements of the modular chassis were built in Ningbo, China. During shipment, the steel columns were constructed with enough structural capability to

allow the modules to be stacked four modules high. The module's floor is made of a lightweight concrete slab. To meet the enormous lateral loads during transportation, steel flat plate sections are used as strap bracing members along the walls. The structure's overall lateral stability is provided by a central concrete core. The loads are transferred from the concrete floor slabs of the modules to the corridor slabs and the outrigger walls that run from the central concrete core.

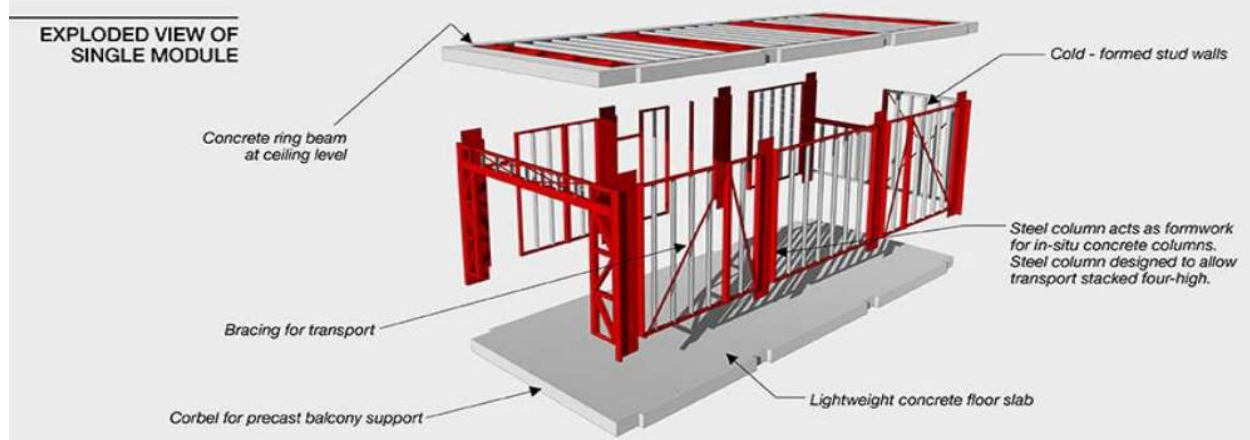


Figure 2.8 – Exploded view of single module

2.3.2.1.3 Floor System

The modules' floors are made of a 125mm thick concrete slab. The concrete slab was designed by Irwinconsult with perimeter and cross beams that aligned with the vertical load bearing location of the columns. The overall thickness of the concrete slab was lowered as a result of this arrangement, resulting in a weight decrease as well. The lightweight concrete mix design for the floor slab was aimed at achieving an initial density of 1600 kg/m³ while maintaining the requisite strength. In actuality, achieving this goal proved challenging, therefore the module design was altered. To maintain stringent quality control, a separate batching plant was put up for the lightweight concrete mix design.

Floor Structural Component	Section Profile
Floor	Concrete Slab
Floor Finishing	Tile/Polished Concrete Slab Floor

Table 2.1 – Exploded view of single module

2.3.2.1.4 Construction and Quality Performance

The disadvantage of employing this approach is the additional time required for the in-situ concrete elements to be prepared, poured, and cured. Although, by constructing the module's chassis to resist the stacking weight of four modules, in-situ concrete pouring and module installation could be done simultaneously. Furthermore, the concrete core might be built separately, behind the stacking of the modules. The adjustment and installation of modules took a lot of time and effort. The modules were constructed and built in Ningbo, China, and shipped via sea freight to Darwin. Typhoon circumstances occurred during the shipping of some modules, causing damage to several of them.

2.3.2.2 461 DEAN, NEW YORK CITY

461 Dean is located in Brooklyn, New York City as part of the Pacific Park development project (previously known as Atlantic Yards). The building was built with the goals of providing cheap housing to the expanding New York City market and demonstrating the potential and benefits of using modular construction techniques on high-rise structures. The structure is made up of 930 modules that make up 363 flats. The 32-story modular building is now the world's tallest modular structure.

Project Name	461 Dean
Location	New York, USA
Owner	Forest City Ratner Companies, Greenland Holding's and Skanska (previous)
Architect	SHoP Architects
Structural Engineer	Arup
Construction Company	Forest City Ratner Companies and Skanska (previous)
Construction Commencement	2012
Construction Completion	November, 2016
Project Value	B2 BKLYN Tower (unknown) Pacific Park Development (\$4.9 billion)
Number of Floors	32
Number of Modules	930
Project Size	32144.5 m ² (346000 ft ²)

Table 2.2 – 461 Dean Project Details

2.3.2.2.1 Structural Review – Tower Structural Scheme

The building is built on a steel-framed modular system with a lower platform that supports 19 floors of modules above. These modules are arranged primarily in the shape of three distinct building masses (left, center and right). The main bracing system is located in the center of the structure and is made up of individual braced frames that are connected at the roof level by a hat truss.

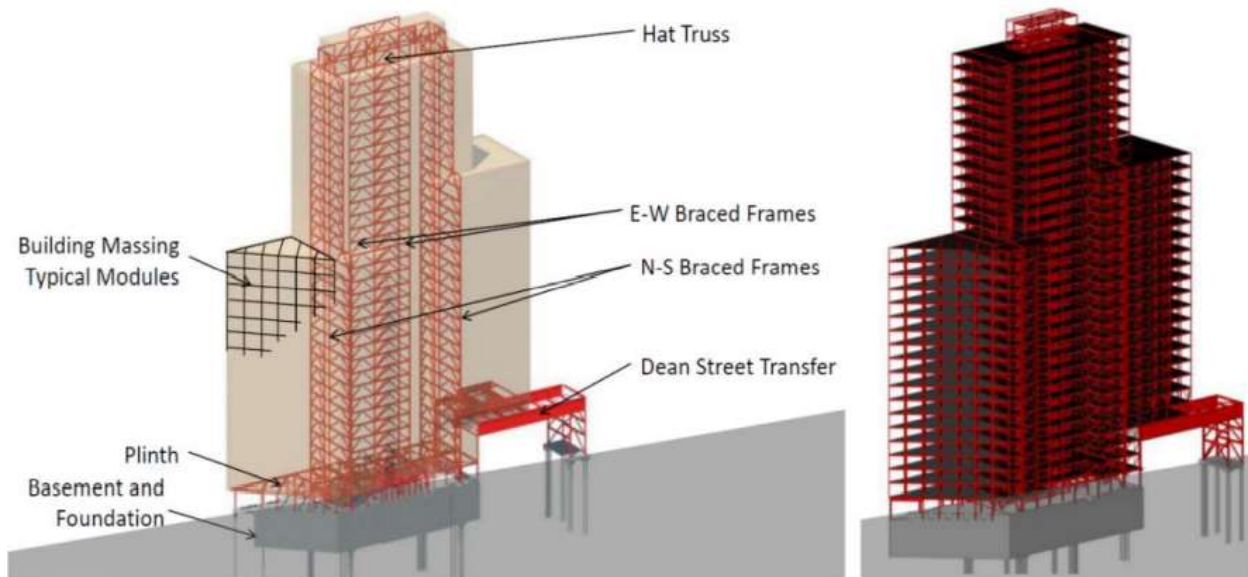


Figure 2.9 – Structural Layout

When exposed to service circumstances, sufficient module-to-module (lateral and vertical) connections allow the modules to support their own stability without the assistance of the braced frames. The B2 BKLYN Tower's general floorplan is shown. The floorplan with the most modules is the largest, with 36 modules in total.

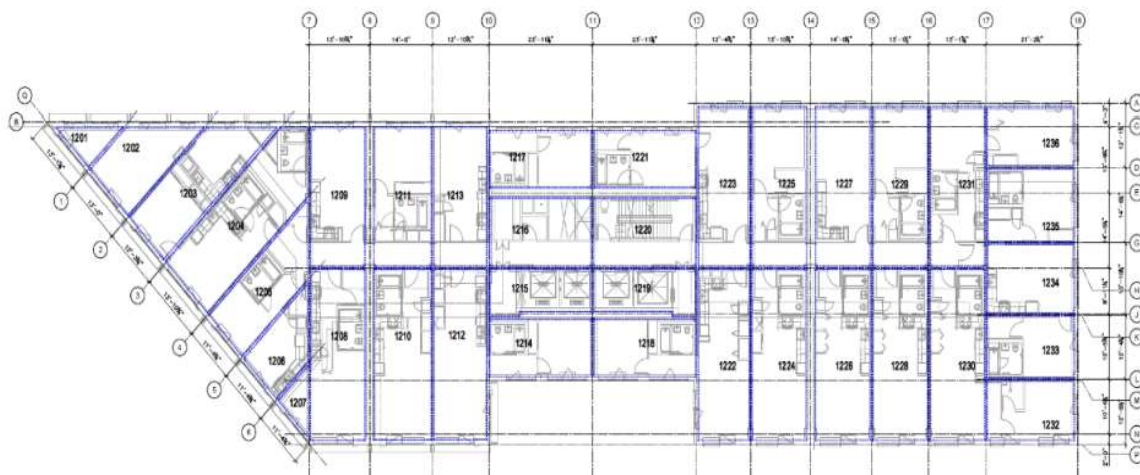


Figure 2.10 – DEAN Floor Plan

2.3.2.2.2 Structural Review – Tower Structural Scheme

A total of 225 individual modules were designed for the B2 BKLYN Tower, ranging in weight from 7 tonnes to 24 tonnes, based on the numerous architectural aspects desired. This is the base chassis for the modules that make up the B2 BKLYN Tower.

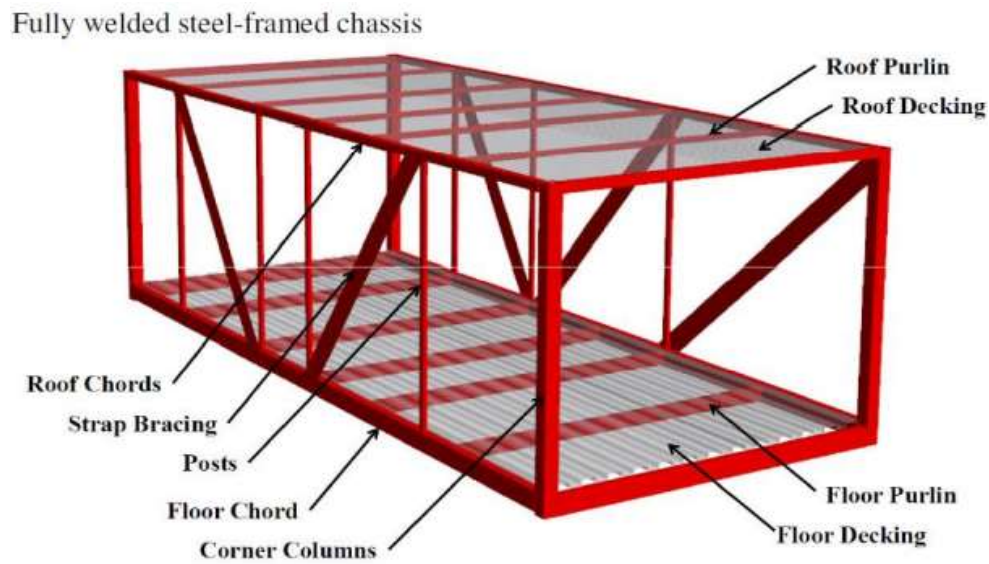


Figure 2.11 – Module Frame

Chassis Structural Component	Section Profile	Size (Typical)	
		(inch)	(mm)
Column (Corner)	Square Hollow Section	6 x 6	150 x 150
Column (Intermediate)	Rectangular Hollow Section	3 x 2	75 x 50
Chord (Bottom)	Rectangular Hollow Section	8 x 4	200 x 100
Chord (Top)	Square Hollow Section	4 x 4	100 x 100
Weatherproof Membrane	Class A Building Wrap	2 layers of 5/8	2 layers of 16
Strap Bracing	Flat Plate	10	250

Table 2.3 – Structural component Specification

To handle the redirected load, the base chassis uses a fully welded, open-ended module design with thicker members in the end frames and robust connections. The corner columns of the chassis are made up of huge 150mm x 150mm SHS, with interconnecting links made up of 100mm x 100mm SHS (roof chords) and 200mm x 100mm RHS (floor chords). The corner columns of the chassis are made up of huge 150mm x 150mm SHS, with interconnecting links made up of 100mm x 100mm SHS (roof chords) and 200mm x 100mm RHS (floor chords). The decking and the closed SHS of the roof chord elements form a lateral diaphragm that transmits lateral loads to the tower structure's braced frames. The finished module chassis are seen.



Figure 2.12 – Module Chassis

2.3.2.2.3 Structural Review – Wall System

The wall system of the base module used in the construction of the 461 Dean Tower is presented



Figure 2.13 – Module Wall System

The configuration of vertical members in the side panels is laid out in the form of a Vierendeel Truss system within the open-ended module design. The side panels' intermediate posts are 75mm x 50mm RHS. To act as strap bracing elements, thin gauge steel in the form of 250mm flat plates is placed diagonally in along the side panels.

2.3.2.2.4 Structural Review – Roof System

The roof system of the base module used in the construction of the 461 Dean Tower is presented

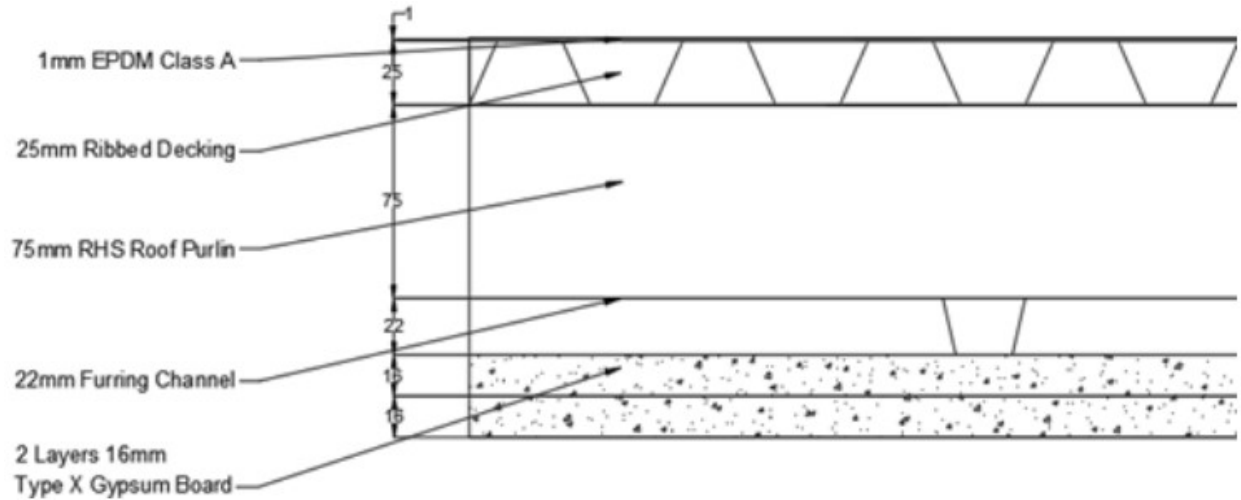


Figure 2.14 – Module Roof System

Roof Structural Component	Section Profile	Size (Typical)	
		(mm)	(inch)
Weatherproof Membrane	Ethylene Propylene Diene Monomer (EPDM)	1	0.045
Outer Shell	Ribbed Cladding	25	1
Purlin	Square Hollow Section	75 x 75	3 x 3
Furring	Furring Channel	22	7/8
Ceiling Board	Gypsum Board (Type X)	2x layers of 16	2x layers of 5/8

Table 2.4 – Structural Roof Specification

2.3.2.2.5 Performance Review - General

Forest City had originally said that the tower would be completed in 18 months and at a significantly lower cost than typical construction methods, but owing to contractor conflicts and other challenges, the building time for 461 Dean was nearly doubled. The first module was delivered and installed on December 12th, 2013 (one year after the planned start date), and the structure was topped off in May of 2016 and completed nearly three years later in November of 2016. Contract disputes between Forest City and Skanska were the primary cause of the project's long delays and interruption. Forest City argues that Skanska failed to complete the contract, while Skanska maintains that Forest City's design of the modules was flawed, resulting in cost overruns on their end. Skanska signed

a fixed-price contract, according to Forest City, and any cost overruns are Skanska's responsibility. Forest City's design, according to Skanska, lacked adjustability because only one source of adjustability was supplied, when standard steel frame buildings would have four sources of flexibility.

2.3.2.2.6 Construction and Quality Performance

Severe misalignment concerns arose during the construction of 461 Dean. On the 10th floor, the misalignment of the modules is clearly visible, as pictured. Because of the misalignment, the building was exposed to weatherproofing concerns throughout the module installation phase. During the court processes, it was discovered that the match plates (3/8" thick) used to connect the modules were defective.

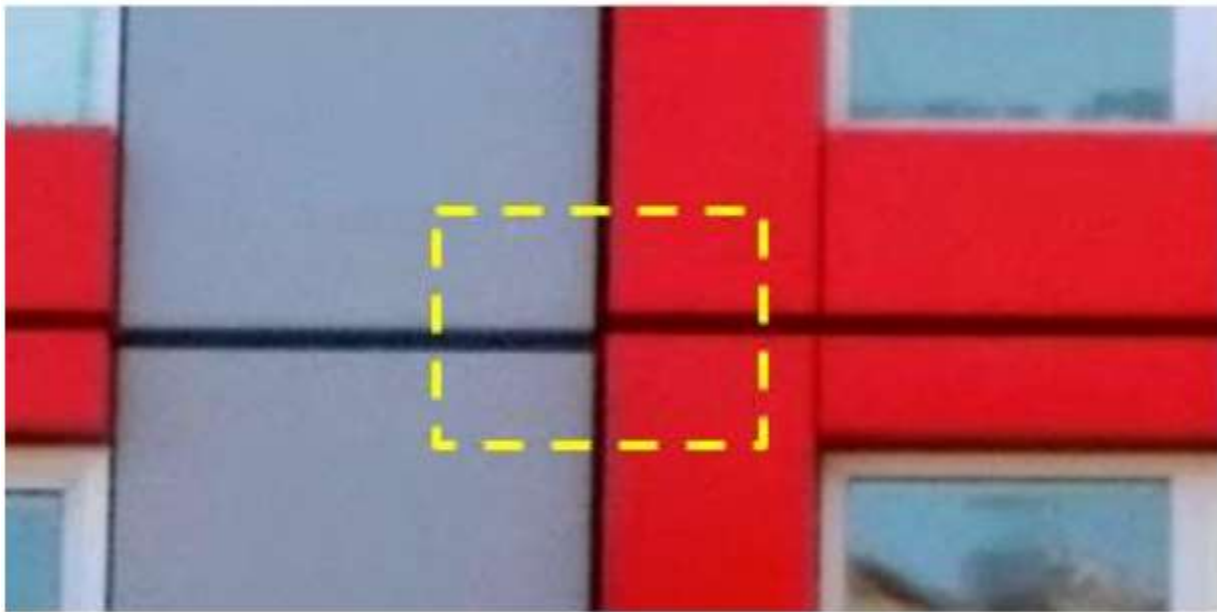


Figure 2.15 – Misalignment issues

2.3.2.2.7 Conclusion

The 461 Dean project is currently the tallest modular structure in the world. The large, hefty steel components that make up the module chasses have enough strength to bear the vertical loads. The building's lateral loading capability was ensured using an effective, if complex, exterior skeleton bracing system. Apart from the marvels of height, the 461 Dean Project is not the best example of modular construction in multistory structures. Ineffective module design has resulted in significant module misalignment, as well as

other structural challenges such as weather-proofing challenges during construction. Fortunately, the designers were able to correct the misalignment difficulties by modifying the current design.

2.3.3. Live Case Study

Live Case study is to understand the current practices of Modular Construction Techniques in India and up to what extent it has been grown in Indian Construction Industry.

2.3.3.1 Avitis Hospital

AVITIS SUPER SPECIALTY HOSPITALS PVT LTD, Nemmara, Palakkad – India.

A world class health care facility being established in the district of Palakkad, Kerala. The foundations stone for the hospital was laid on the end of 2016 and it was operating on 2018, 200 beds hospital, this project is a hybrid utilizing conventional and modular construction.

Avitis is proposed as a 200-bed facility that will provide a comprehensive range of tertiary super specialty medical care in its initial phase of operation. The Reinforced concrete structural elements constitute the basement floors and ground floor. The upper floors above the ground floor are of steel modular system. Modules are manufactured from Palakkad factory.

No of Modules : 200 modules

Manufacturing time : 70 Days

Erection Time : 18 Days

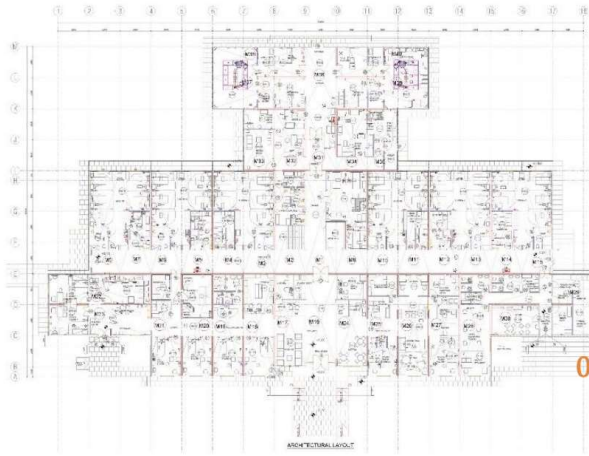
Start to finish : 12 Months

The brief was to plan a hospital with standard facilities and yet same time be able to accommodate as much as possible patients. To speed up construction technology, BR life awarded the hospital construction project to Modular Concepts India Pvt. Ltd.

Contract Title	:	AVITIS SUPER SPECIALTY HOSPITALS PVT LTD, Nemmara, Palakkad - India
Client	:	AVITIS SUPER SPECIALTY HOSPITALS PVT LTD
Design Build Contractor	:	Modular Concepts, LLC
Scope of Work	:	Design & Build – Pre-Fab, MEP, medical eng. and Civil Work
Year of completion	:	December 2018

Table 2.5 – Avitis Project Detail

Original design



Modified to Modular

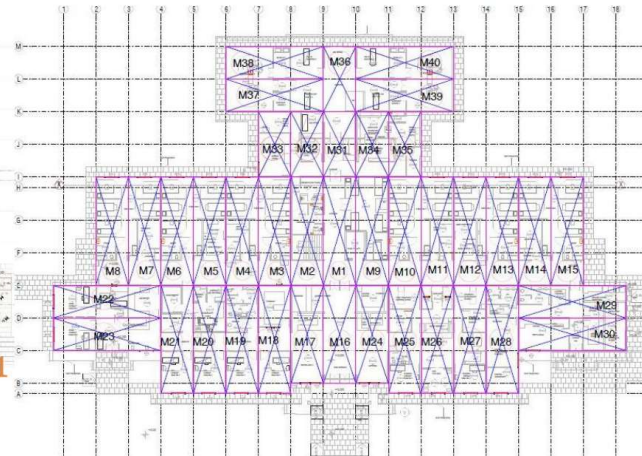


Figure 2.15 – Avitis Floor Plan

Research & Concept Design: Using the clients Conceptual Design Modcon has developed working drawings for the purpose of final approvals and manufacturing using their in house design teams.

Hot rolled Steel frame (HRS): The Module structure has been made of steel base frame, columns, floor frame designed for the gravity and lateral loads

Floor Frame: The floor frame is made up of CFS sections and joists has been placed on equal spacing as per design. Floor joist is fixed on base frame by connector.

Cold Formed Steel walls (CFS): The wall panel frame is made up of CFS sections and has been paced on equal spacing as per design. Wall panel is fixed between base and roof frame by connector.

Ceiling Joist: The ceiling frame is made up of CFS or HRS sections and joists shall be placed on some spacing as per design. wall panel is fixed between base and roof frame by connector.

Combined module of CFS panels with HRS frame: When all the elements are complete, we install Straps required for lateral force as well as for lifting.

2.3.3.2 Structural Review

Internal Walls: Internal walls are normal dry wall partition with light gauge steel track and stud framing and Gypsum Board Sheathing

07-Internal Wall

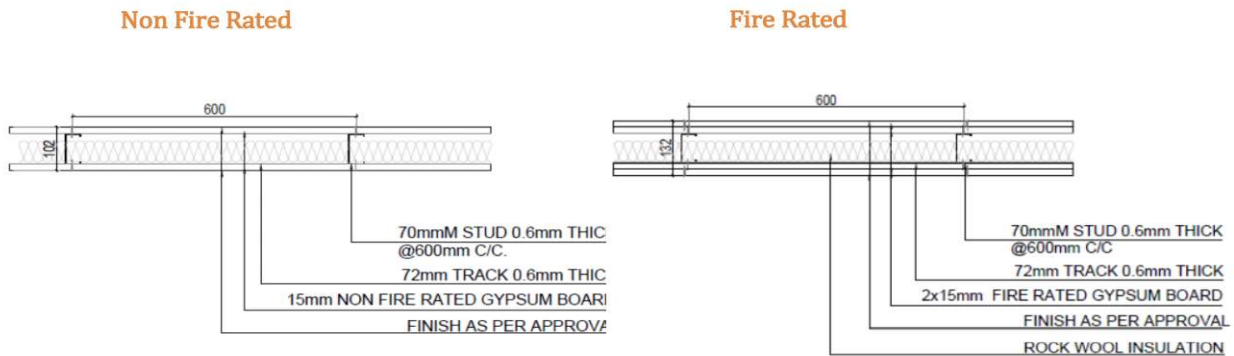


Figure 2.16 – Internal Wall

External Walls: External walls mostly used are dry wall system and treated as per external façade requirements. Our standard system is to use cement board as external sheathing with EIFS (external insulated façade system) treatment to make façade weatherproof, long-lasting and have better thermal performance.

08-External Wall

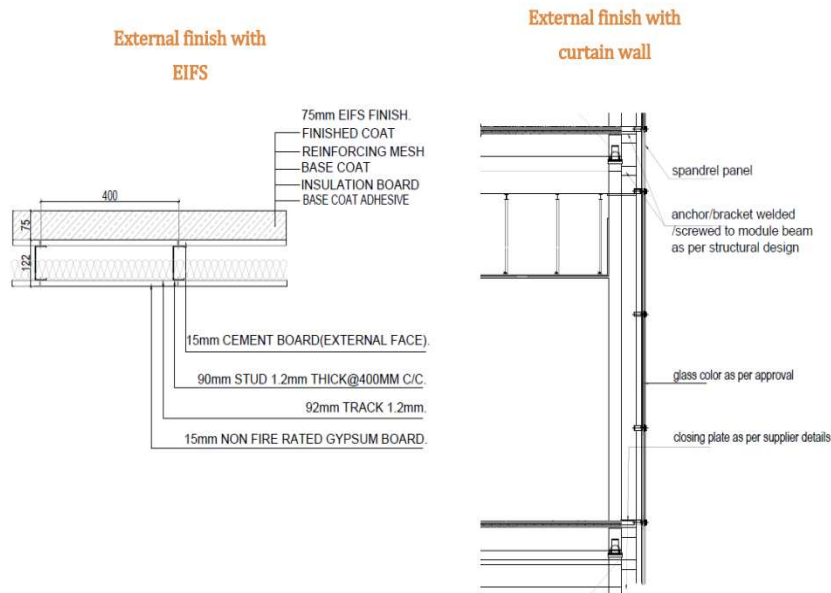


Figure 2.17 – External Wall

Ceiling: Suspended ceiling of desired type can be suspended from the joist of module roof frame. Generally used ceiling are 60 x 60 Grid Acoustical ceiling, 60x60 Metallic clip-in ceiling, Plaster board ceiling with coves.

09-Ceiling

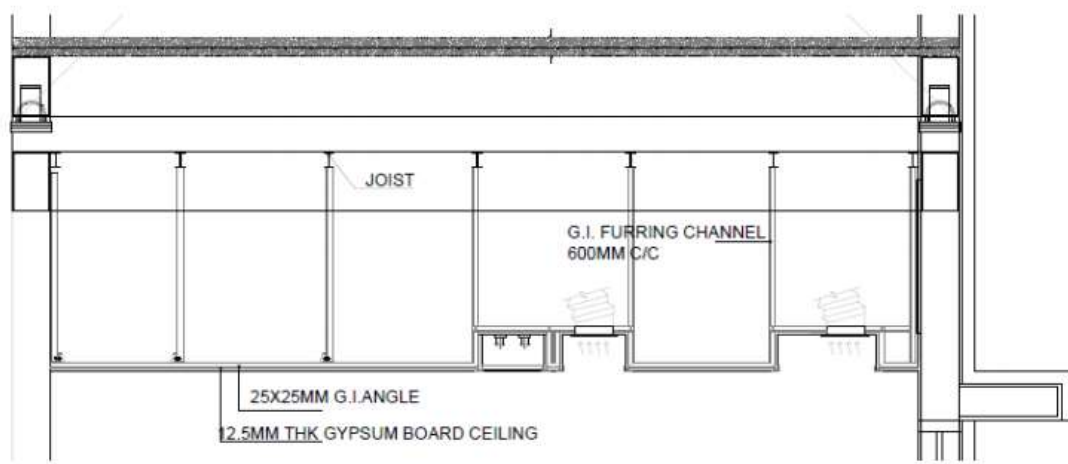


Figure 2.18 – Ceiling

Floor: Based on load and use of category concrete with Deck slab or Cement board with sandwich panel floor system are used over joist on floor panel. Over both the system Vinyl, Tile and other floor finish are applied.

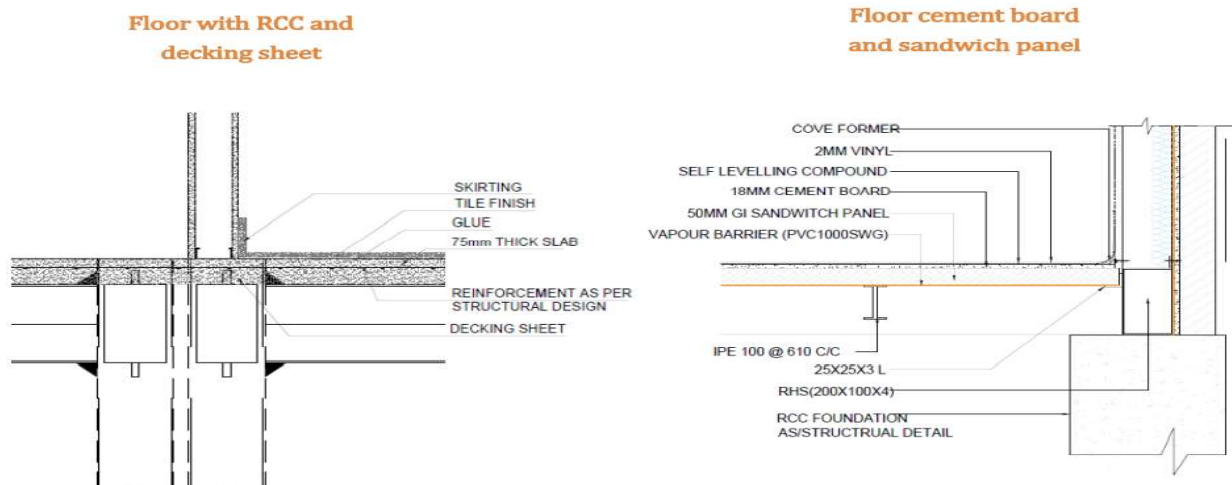


Figure 2.19 – Floor Panel

Module Connection: Module Column top are fixed with specially fabricated hooks which results in maintaining perfect alignment and helps in lifting process also. Upper floor Columns perfectly fits in the hooks at the top of lower modules. Wherever 2 or more modules are connecting a single shear plate is inserted in between hooks before placing upper modules to make joint act as one and proper transfer of vertical loads.

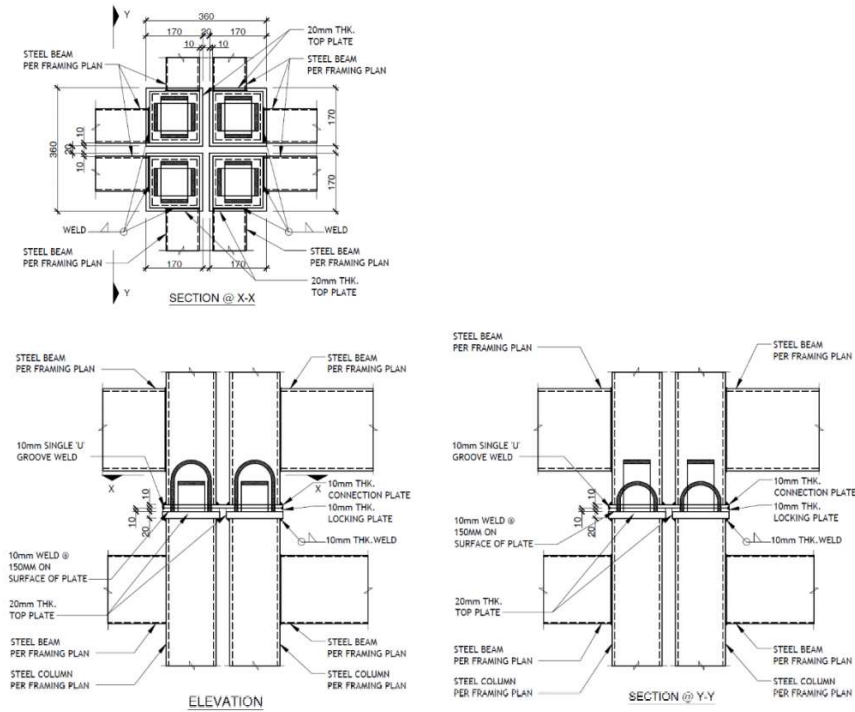


Figure 2.20 – Four Column Connection Detail

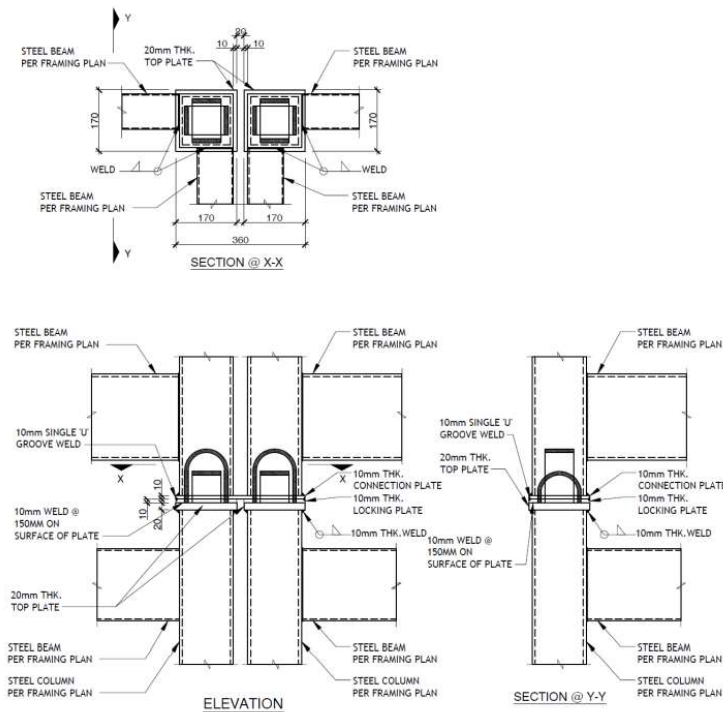


Figure 2.21 – Two column Connection Detail

2.3.3.2 Housing Board for EWS at Amaravathi

It is a real time project that is located near AMARAVATI (A.P). The building is A Residential Building Being Constructed by Govt of AP for Poor People under NTR Housing Scheme.

2.3.3.2.1 Introduction

There are 12 apartments per level, each with a carpet space of around 430 square feet for a one-bedroom apartment. Because all of the apartments in Series A are identical, precast technology became a realistic alternative. The series A (G+9 Floors), D, E1 & F (G+5 Floors) towers all climb roughly 60 feet above ground, with a 3.05m floor to floor height. Precast was to be used in the construction of 1.1 million homes. Tower A has a total built area of 4320 square meters.

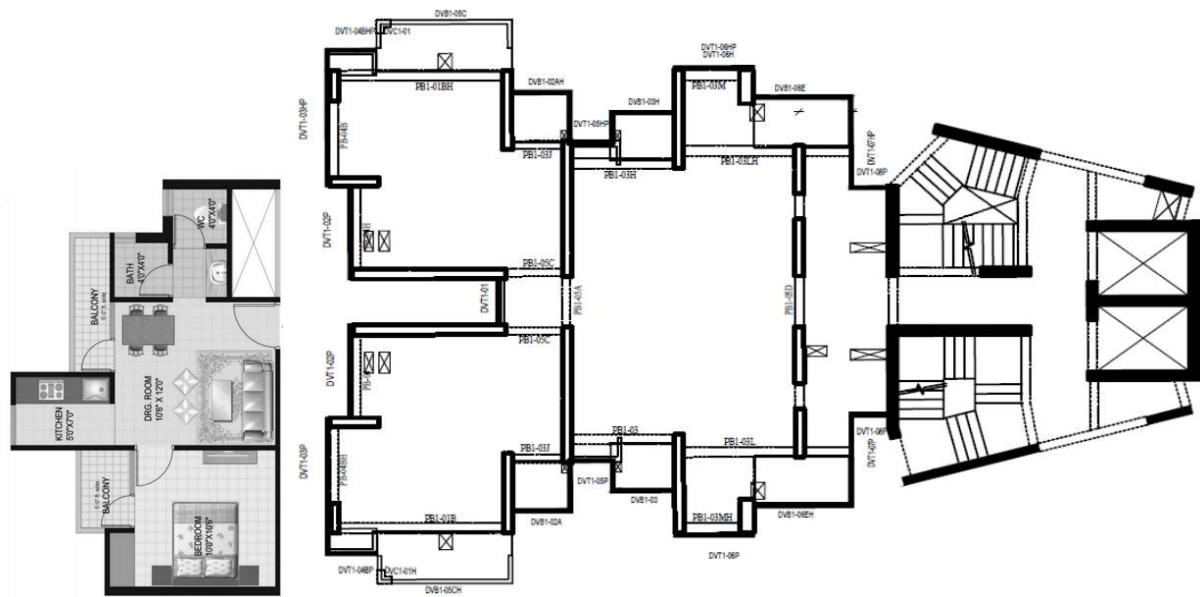


Figure 2.22 – Floor Plan of Housing Board for EWS

The project's foundation system was developed and built as a raft foundation. The foundation, substructure, terrace work, and all shear walls for all stories were done utilising the traditional CIS method in this hybrid design. The superstructure (from the first to the ninth level) was made primarily of precast beams, balconies, staircases, wall panels, and hollow core slabs. The vertical members (shear walls) were built in CIS with the economics and design in mind, as well as the erection plan for the other components.

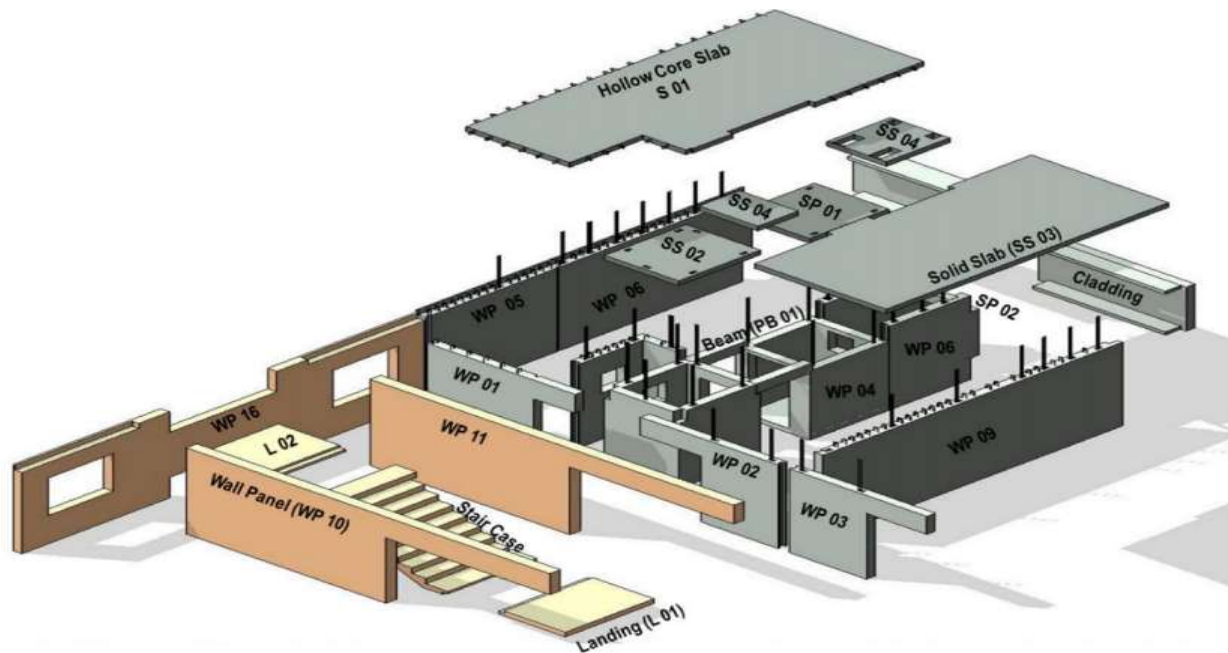


Figure 2.23 – Pre-Fab Structures

2.3.3.2.2 Structural Review – Precast Slabs

Hollow core slabs and solid slabs are the two most common slab types utilised in precast frames. Hollow core slabs are pre-stressed, precast concrete slabs featuring hollow parts in zero-stress zones. They lower the overall concrete dead load, minimise concrete requirements, and improve insulation. 150, 200, and 265 mm are the most common thicknesses used. At a time, 140m long slabs with a fixed width of 1.2m are casted. The slabs are sliced into smaller pieces after steam drying, depending on the needs of the job site. They are then transported to the job site and installed using tower cranes. Solid slabs are another typical style of slab. These slabs are commonly utilised for extensive spans in common areas and toilets where numerous MEP services must be accommodated.

2.3.3.2.3 Structural Review – Columns & Beams

In precast construction, columns (shear walls) can be made of CIS or precast. They're best used in commercial and industrial bay buildings that require thicker portions. Corbels are included with precast columns for easy beam column connections. Precasting also enables for the casting of triple-height columns, resulting in a speedier erection time.

In a precast structure, there are two primary types of beams. When the floor load is generally symmetrical, internal beams are utilised, and exterior beams are utilised when the floor load is largely non-symmetrical.

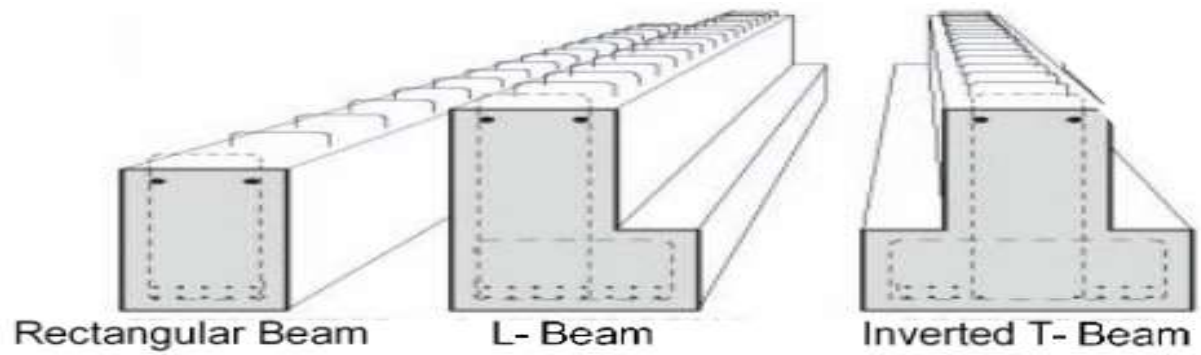


Figure 2.24 – Types of Beams

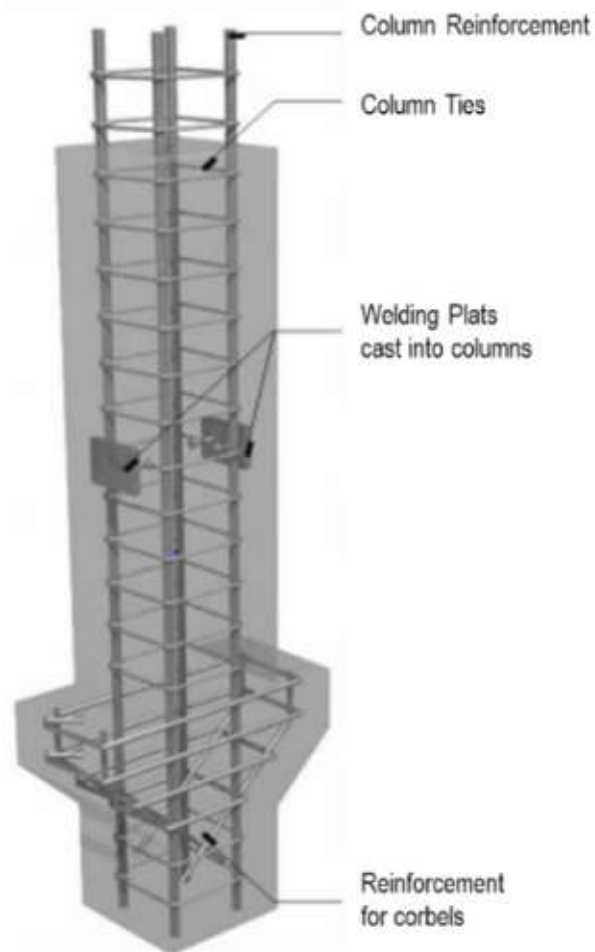


Figure 2.25 – Column Detail

2.3.3.2.3 Structural Review – Columns & Beams

These walls provide a superior finish surface, eliminating the need for plaster and touch-ups, and allow for precise and desired door, window, and ventilator openings. The overall lateral stability of the structure is also improved by these wall panels. As a result, precast wall panels and claddings are an excellent alternative to traditional infill blockwork or brick wall



Figure 2.26 – Precast wall Panels

2.3.3.2.4 Structural Review – Precast Staircase

Precast stairwells avoid the need for time-consuming on-site shuttering and strengthening while also providing a high-quality finish.



Figure 2.27 – Precast Staircase

2.3.3.2.5 Design & Connection Detail

Connections are required not just to transfer weight, but also to maintain the structure's overall monolithic behaviour. To resist seismic and other dynamic loadings, a full system of precast parts is combined to form a monolithic structure with suitable strength, stiffness, and longevity. Horizontal and vertical joints are the two types of connections. The following are some common details about connections.

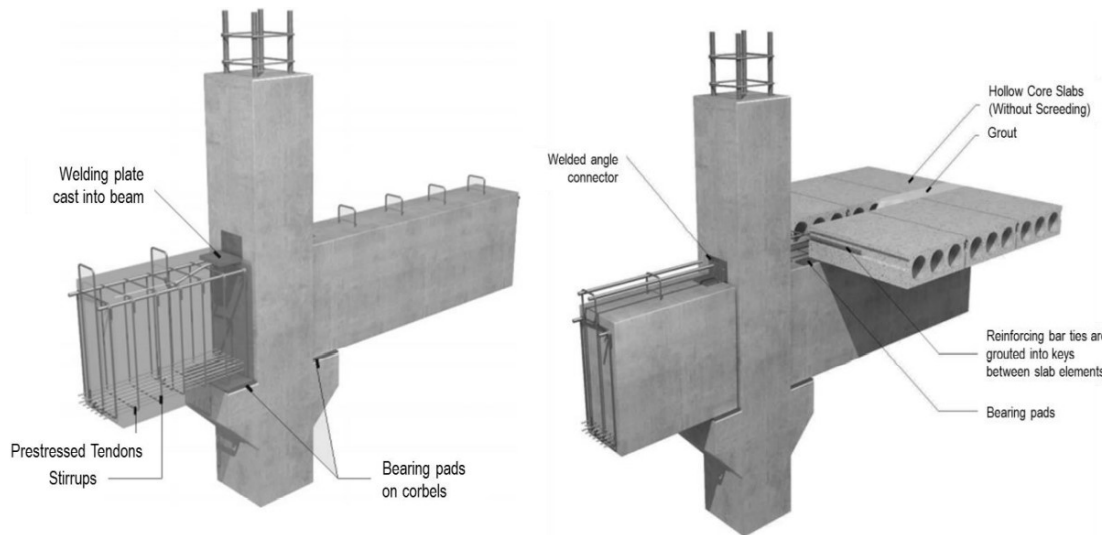


Figure 2.28 – Connection Detail

Estimated Cost of construction through Pre-fab

SL.NO	DESCRIPTION	COST
1.	Sub Structure - (Site cleaning, Earthwork, Foundation, Basement, Soil filling& Consolidation)	1.64cr
2.	Super Structure – (Wall panels framing and Roofing slabs.)	2.11cr
3.	Finishing Works – (Electrical, Plumbing Painting, Tiling, and Windows, Extra items)	0.94cr
	Total cost	4.7cr

Table 2.6 – Estimated Cost

Estimated Time of construction through Pre-fab

SL.NO	DESCRIPTION	COST
1.	Sub Structure - (Site cleaning, Earthwork, Foundation, Basement, Soil filling& Consolidation)	88days
2.	Super Structure – (Wall panels framing and Roofing slabs.)	208days
3.	Finishing Works – (Electrical, Plumbing Painting, Tiling, and Windows, Extra items)	154days
	Total cost	450days

Table 2.7 – Estimated Time

2.3.3.3 Hostel Block, VIT Vellore

There are 24 dormitories on the VIT Vellore campus, comprising 18 blocks for boys and 6 blocks for girls. Around 17000 students are housed in the men's hostel, while 4700 students are housed in the women's dormitory. A total of 1000 beds are available in the new hostel block. It has G+18 and G+10 floors, with a total built-up area of 20,786 square metres. The G+10 Hostel project is estimated to cost 5 crores and will take 605 days to complete.

Name	VIT hostel – R Block
Client	Vellore Institute of technology
EPC Contractor	B&B builders
Design firm	Murty and manyam architects
No. of floors	G+10
Total Built-up area	4200 sq.m
Total project cost	5 crores
Total project duration	605 days
Project status	On - going

Table 2.8 – VIT Hostel Project Detail



Figure 2.29 – VIT Hostel R Block



Figure 2.30 – VIT Hostel R Block (2)

2.3.3.3.1 Estimated Cost & Time for VIT Hostel Block

Estimated Cost of construction through Conventional Method

SL.NO	DESCRIPTION	COST
1.	Sub Structure - (Site cleaning, Earthwork, Foundation, Basement, Soil filling& Consolidation)	1.75cr
2.	Super Structure – (Wall panels framing and Roofing slabs.)	2.25cr
3.	Finishing Works – (Electrical, Plumbing Painting, Tiling, and Windows, Extra items)	1 r
	Total cost	5cr

Table 2.9 – Estimated Cost for Hostel Block

Estimated Time of construction through Conventional Method

SL.NO	DESCRIPTION	TIME
1.	Sub Structure - (Site cleaning, Earthwork, Foundation, Basement, Soil filling& Consolidation)	88days
2.	Super Structure – (Wall panels framing and Roofing slabs.)	477days
3.	Finishing Works – (Electrical, Plumbing Painting, Tiling, and Windows, Extra items)	240days
	Total cost	605 days

Table 2.9 – Estimated Time for Hostel Block

2.3.3.3.1 Comparison of Prefabricated & Conventional Structures

Comparison Graphs of Cost and Time for Conventional and Prefabricated Structures

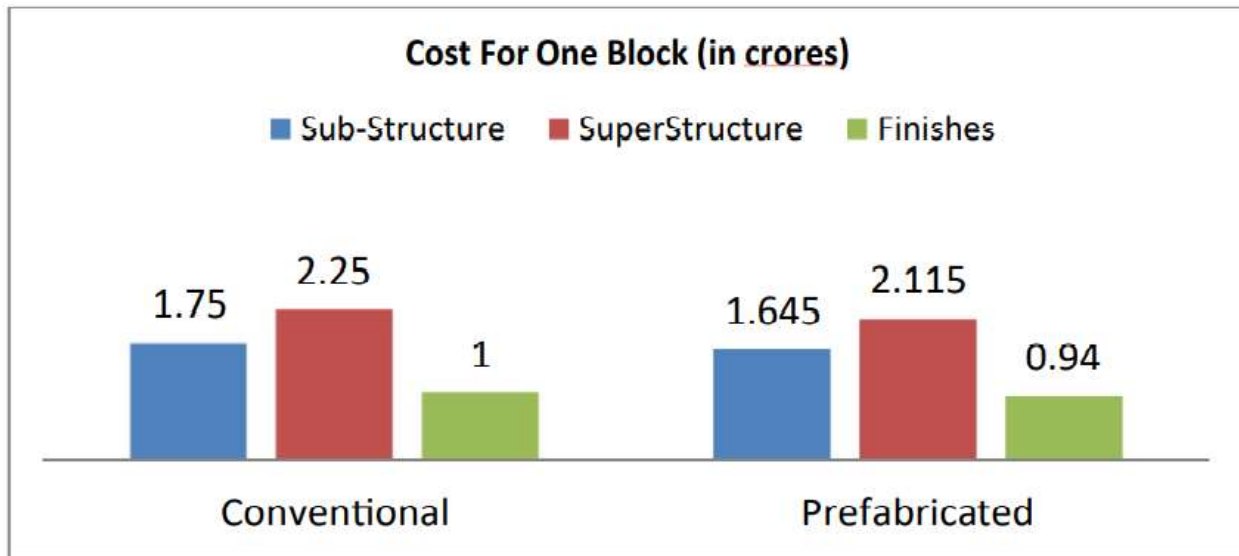


Table 2.10 – Cost for One Block

Prefabricated constructions have lower substructure costs. In both scenarios, the cost of the superstructure is nearly comparable. Prefabricated finishes show a difference of roughly 6 lakhs less.

Comparison Graphs of Cost and Time for Conventional and Prefabricated Structures

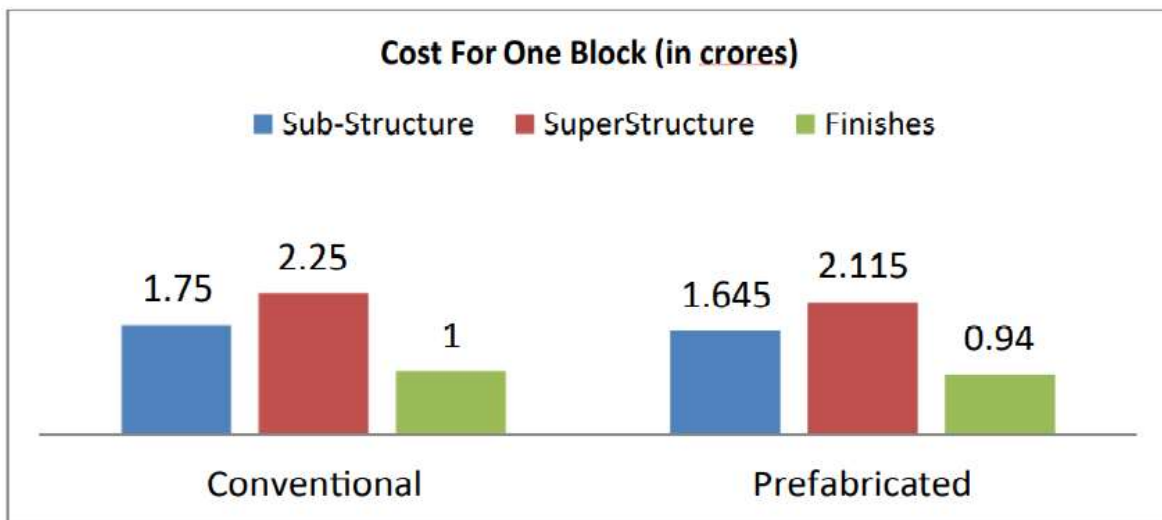


Table 2.11 – Comparison of Costs

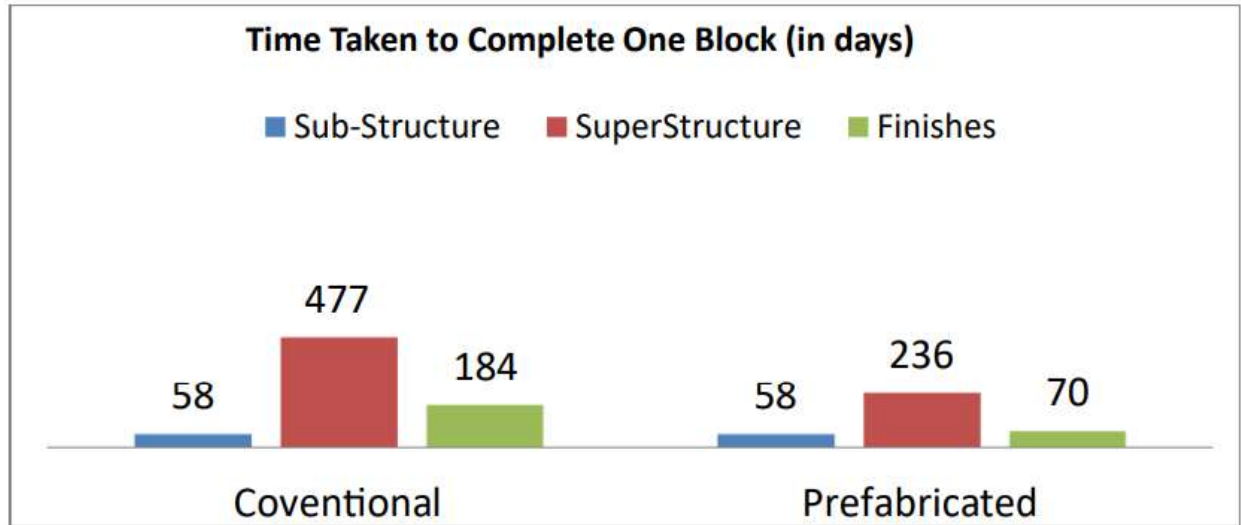


Table 2.12 – Comparison of Time taken

Prefabricated constructions have lower substructure costs. In both scenarios, the cost of the superstructure is nearly comparable. Prefabricated finishes show a difference of roughly 6 lakhs less.

Both prefab and conventional building take nearly the same amount of time to complete the substructure. The superstructure in traditional methods takes 241 days longer than the prefabricated structure, allowing for a significant reduction in total prefabrication time. Finishes in a traditional structure take 114 days longer than in a prefabricated construction.

	Prefabricated construction	Traditional methods of construction
Cost	Significantly lower than traditional methods	High cost
Speed	Faster method of construction	Slow as compared to prefabricated construction.
Wastage	Less wastage of materials due to green practices and controlled environment in prefabrication construction	High waste due to in-situ construction practices
Flexibility	Less flexibility due to standardisation of units	More flexible
Quality	Higher quality control due to production under controlled environment	In-situ construction practices are subject to weather changes. They may lead to poor quality construction.
Labour	Less labour intensive due to Computer Integrated Manufacture (CIM)	Skilled personnel and labour required.

Table 2.13 – Comparison of Prefabricated Construction & Traditional methods of Construction

2.3.3.3.2 Conclusion

The cost of the project differs by about 6% when prefabrication is used instead of traditional construction. This indicates that the prefabricated structure was cost effective. The overall project duration for both construction and completion was computed and displayed in the graph. It denotes that the prefabrication construction takes less time than traditional construction. The difference in project duration between prefabrication and conventional construction is 355 days. In comparison to the traditional procedure for the structure, this has a relatively short time length.

Chapter 3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

To carry out my thesis I have followed two phases of data collection.

- Qualitative Analysis
- Quantitative Analysis

The first phase of the research includes interviews to identify the barriers to implement modular construction technologies in India. This discussion was recorded along with written notes to review the discussion. After the interview, a written summary of the data collected was shared with the interviews to confirm their accuracy after transcription. After full understanding of recordings and responses from multiple participants, similar responses were grouped together.

3.2 IDENTIFICATION OF CHALLENGES/BARRIERS TO IMPLEMENT MODULAR CONSTRUCTION

PHASE-1: The first phase of research was a qualitative method carried out through interviews with designers and contractors to understand the barriers they were facing to implement the modular construction technology in India. Interviews started with a brief background of the modular construction technology familiarize the participants with the research topic. This was followed by a quick introduction to advantages of modular construction in the construction industry. Later, it was followed by the questionnaire prepared to understand their strategies. The questionnaire was semi-structured but consisted of some open-ended questions that helped in deriving direct questions for the survey in Phase 2. Valid perceptions from member experience were be recorded after discussion. A copy of the questionnaire is included in the Appendix 1.

A nonrandom, convenience sampling of designers and contractors was identified based on availability and approachability for the interviews. All the participants were requested to share their experience and suggest some strategies to implement modular construction in India. After the discussion, each participant validated the data gathered through member checking of interview transcripts.

PHASE-2: To generalize the findings and to find the feasibility options to implement modular construction in India, a statistical analysis of a larger group of population is required. An electronic survey was developed to collect the data from a larger population.

The survey consisted of a structured questionnaire to reduce the variance. The survey was distributed electronically, as it allows distributing a survey to a larger group of people. Questions in the questionnaire were framed using the barriers identified in the phase one of the research. The instrument was pilot tested to understand the reliability of the questions. One of the questions was repeated with a restructured sentence for identifying the quality of each response. Those responses were eliminated from the results to avoid unwanted measurement error. Respondents were requested to participate voluntarily to share their perspective on each question. Typical questions were in the following format with the impact and a strategy changing among each question.

Example:

What do you think about standardizing design in construction industry?

1. Very Ineffective
2. Ineffective
3. Somewhat Ineffective
4. Neutral
5. Somewhat Effective
6. Effective
7. Very effective

3.3 MEASUREMENT ANALYSIS

The first phase of the research included interviews to explore the barriers/challenges to implement the modular construction technology in India. After the interview, a written summary of the data collected was shared with the interviewees to confirm their accuracy after transcription. The recordings were processed multiple times to take notes of the data missed in the hand notes recorded during the interview. Microsoft Excel was used to do the pattern analysis and each participant was given an identification number to avoid reporting personal identity. Strategies suggested by each interviewee for each strategy were grouped along with the participant number. After full understanding of recordings and responses from multiple participants, similar responses were grouped together. A sufficient number of patterns were identified in the grouped responses. The data was condensed into a tabular matrix according to the repetitive themes. This matrix was shared with another researcher to come to a reasonable acceptance of the responses and grouping. All the Challenges/Barriers mentioned by the participants with at least three repetitions were chosen to create the survey for phase 2. This process helped in identifying the barriers/challenges mentioned by the participants with reasonable repetition and acceptance among researchers.

The second phase of the research includes an electronic survey to mitigate those challenges. To understand the feasibility of implementing modular construction technology from a larger group of people. An experienced researcher evaluated survey instrument for the ease of understanding. All the responses were recorded on a Likert scale of seven points from agreement to disagreement.

All the data received through the survey was exported into Microsoft Excel to analyze. Exported data contained unintended data like the time it took for each participant and the time opened. All unwanted details collected by the survey website were deleted. Arithmetic mean aided the analysis of the responses to each question.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the findings from both the phases of data collection along with the discussion. As mentioned in Chapter 3, the data required to answer this question was obtained from two phases of data collection as presented in the following sections.

4.1.1 Phase 1 Interviews

The first phase of the research includes interviews to identify the barriers to implement modular construction technologies in India. This discussion was recorded along with written notes to review the discussion. After the interview, a written summary of the data collected was shared with the interviews to confirm their accuracy after transcription. After full understanding of recordings and responses from multiple participants, similar responses were grouped together.

Inadequate training and the lack of awareness are the major issues which are holding the adoption of modular construction	The organization is not ready to provide training to their employees to adopt to the new system.	Even if willing to adopt the technique the inadequacy of the resources makes it difficult in adopting the technique
There is no adequate promotions available to advertise the current construction trends to educate people	Unaware of the structure's lifespan and stability which creates fear in adopting a new technique	There is no acceptance from the people in managerial level adopt to the changes.
There are no sufficient Government initiatives to promote the technology	There are difficulties in transportation of materials and modules from the unit to the site	The organization is not ready to changeover from the traditional practice
The organization is not ready to invest money on implementation of the system	The fear of losing the role and importance in the industry if the technology changes	Site plays a major role for modular construction. Specially when comes to installing a larger crane for lifting.
It was difficult to counter the typical mind-set of people to adapt to change in construction technology, patience & willingness to experiment with a new technology.	Although, European and other standards were available for ready reference but unavailability of IS codes was deemed important. The designers from India had only few Indian Standard to refer.	It requires intensive pre-project planning and engineering. Also, along with the complexity of modules design, further considerations and planning are needed when incorporating different components within a module

Table 4.1 – Random Interview Responses

All participant responses were matched constantly among other responses, with the objective of consolidating data into repetitive themes.

PROJECT PLANNING	• Inadequate training and the lack of awareness are the major issues which are holding the adoption of modular construction • Lack of skilled manpower with the knowledge of precast industry • It requires intensive pre-project planning and engineering. Also, along with the complexity of modules design, further considerations and planning are needed when incorporating different components within a module • Although, European and other standards were available for ready reference but unavailability of IS codes was deemed important. The designers from India had only few Indian Standard to refer.
RESISTANCE TO CHANGE	• There is no acceptance from the people in managerial level adopt to the changes. • The organization is not ready to changeover from the traditional practice • The organization is not ready to invest money on implementation of the system • The fear of losing the role and importance in the industry if the technology changes • It was difficult to counter the typical mind-set of people to adapt to change in construction technology, patience & willingness to experiment with a new technology.
TRANSPORTATION CONSTRAINTS	• Transportation cost of materials and modules from the unit to the site is high. • Site plays a major role for modular construction. Specially when comes to installing a larger crane for lifting.

Table 4.2 – Responses under Theme

4.1.2 Barriers/Challenges

1. **Project Planning:** It necessitates extensive planning and engineering prior to the start of the project. Additionally, because of the intricacy of module design, more thought and preparation is required when incorporating diverse components within a module, as well as when modules are lifted, transported to the final project site, set on the foundation, and linked to form the building.
2. **High Initial Cost and Site Constraints:** Setting up sufficient machinery to run a modular manufacturing plant necessitates a significant amount of upfront money. New construction processes may be challenging in locations where labour is cheap. A drawback is the scarcity of competent and experienced individuals, such as designers and engineers, who have sufficient experience with modular systems. Another big challenge is locating off-site construction experts, suppliers, and contractors.
3. **Reduced Adaptability to Design Changes:** Other interdependent actions are carried out simultaneously after the design has been accepted, therefore the design cannot be changed.
4. **Transportation Constraints:** Transporting modules across long distances can be difficult. Late transmission permits for large components can cause time delays.

- 5. Resistance to Change:** It was tough to overcome people's natural resistance to change in construction technique, as well as their patience and desire to try out new ideas.

4.2.1 Phase 2 – Survey

Thirty-six responses were received from the on-line survey. Data received was analyzed to identify any incomplete surveys and were excluded from the data reported in this document. Three out of thirty-six responses were incomplete and excluded from the analysis. Two of the participants had experience that did not match the experience criteria chosen for participation and were excluded from reporting. Thirty one responses were complete and usable for the analysis.

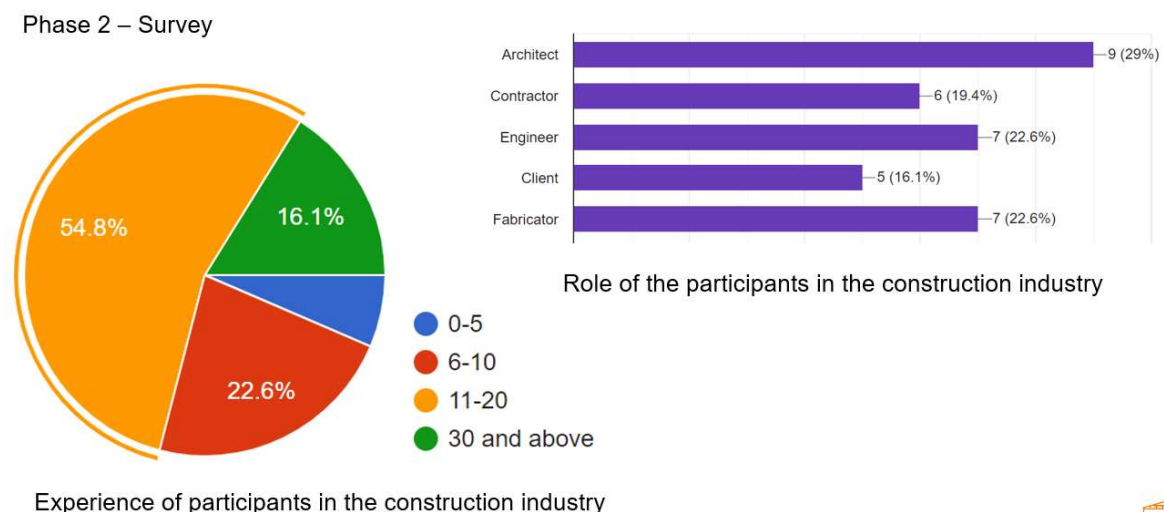


Figure 4.1 – Role of Participants & their Experience

The question was structured as “What do you think about standardizing designs in construction? Is it a good idea?” to understand the perception of the respondent. A majority of participants (58.1%) stated that Standardizing would be a good idea.

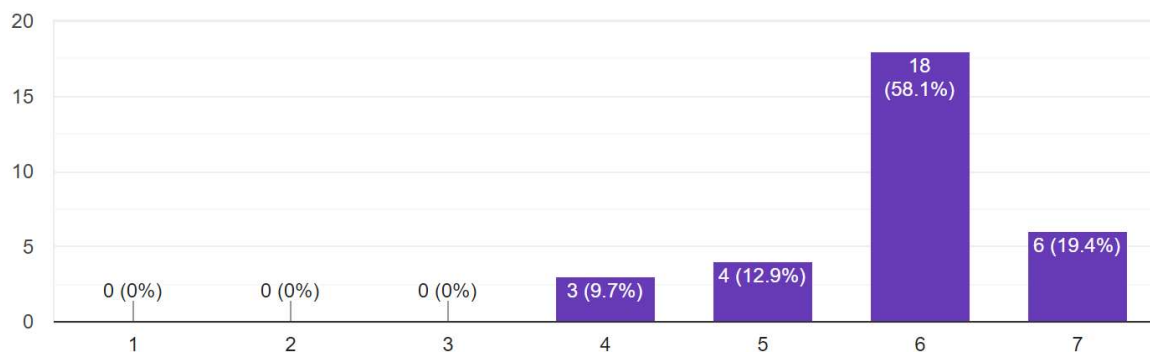


Figure 4.2 – Responses on Standardizing Designs in Construction

Then the second question was “According to you what building type designs can be standardized?”

A majority of participants (58.1%) stated that Healthcare Buildings can be a standardized, then 54.8% stated that Commercial building can be standardized, then 35.5% of participants stated that Educational Institutional can be standardized, and very few participant 12.9% stated that Residential Buildings can be standardized since residents looking for the customization.

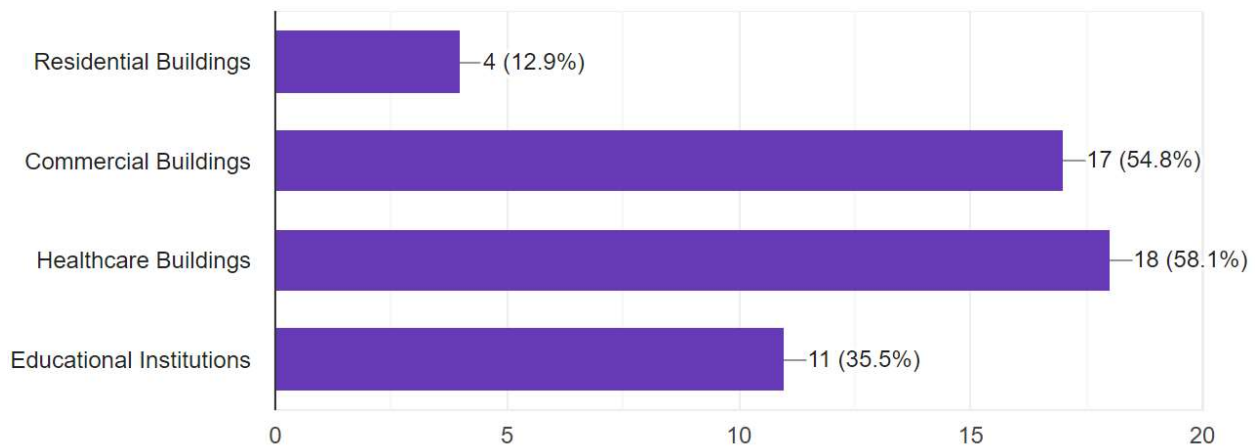


Figure 4.3 –

Then the Third question was “If designs are standardized, do you think modular constructions shall be a viable option?”

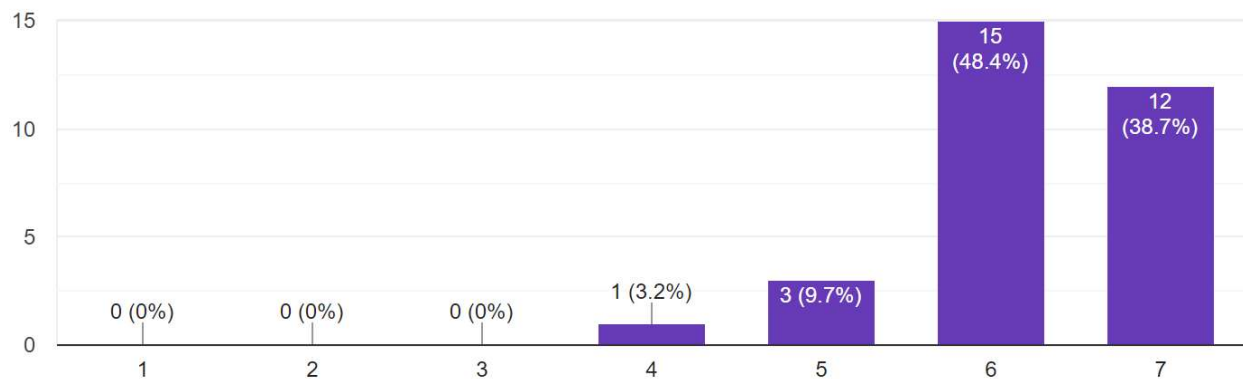


Figure 4.4 –

Then the Fifth question was “Is providing "warranty" an effective strategy to reduce the impact on resistance to change?”

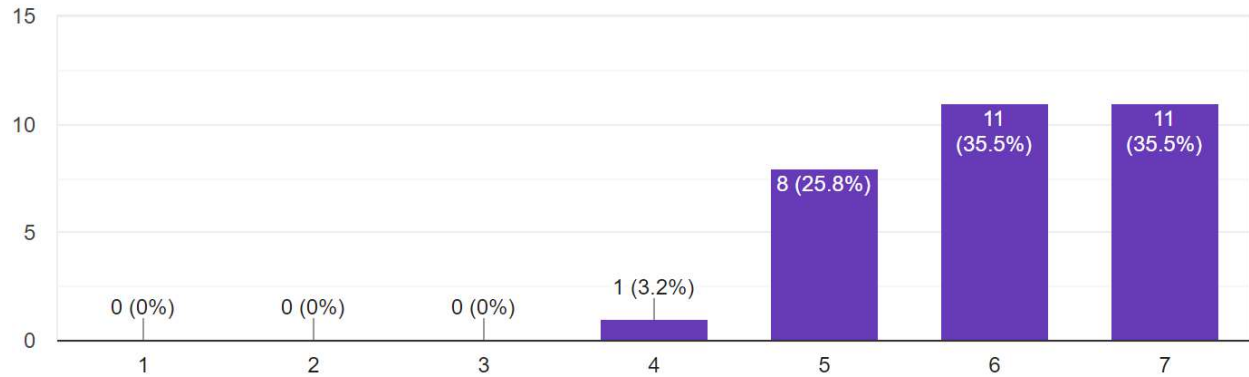


Figure 4.5 –

Then the Sixth question was “If Tax exemptions / subsidies are provided by the Government for pre-cast modular construction, how effective will it be in reducing the resistance to change?”

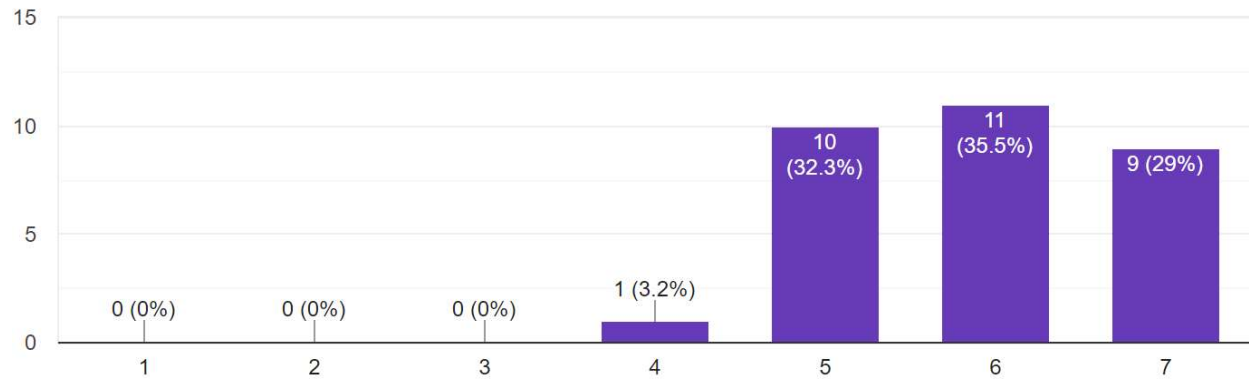


Figure 4.6 –

Then the question was “Is installing a manufacturing plant near the site, a viable solution for solving transportation issues?”

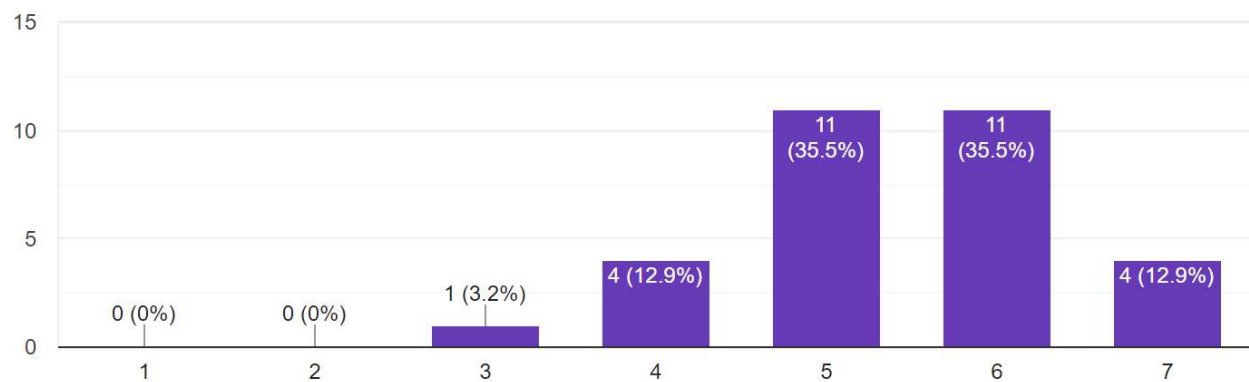


Figure 4.7 –

Then the question was “Will standardizing module size have an impact on transportation challenge?”

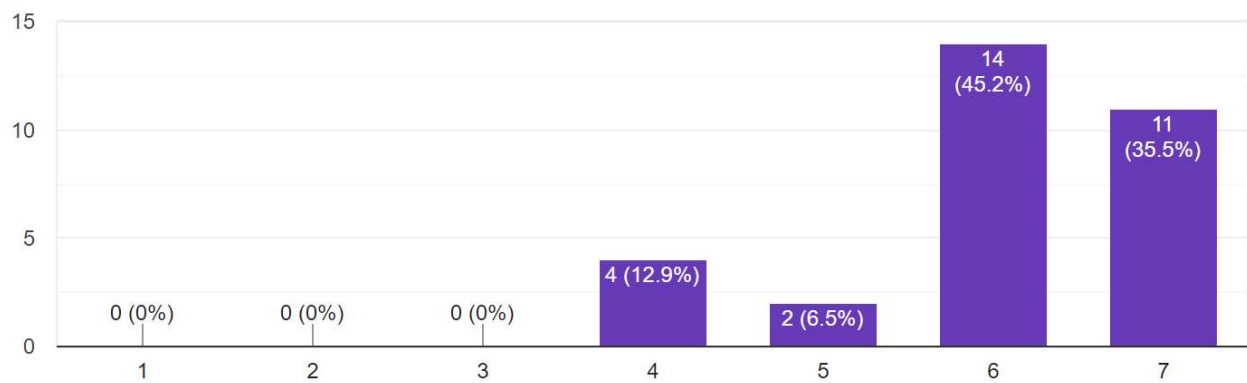
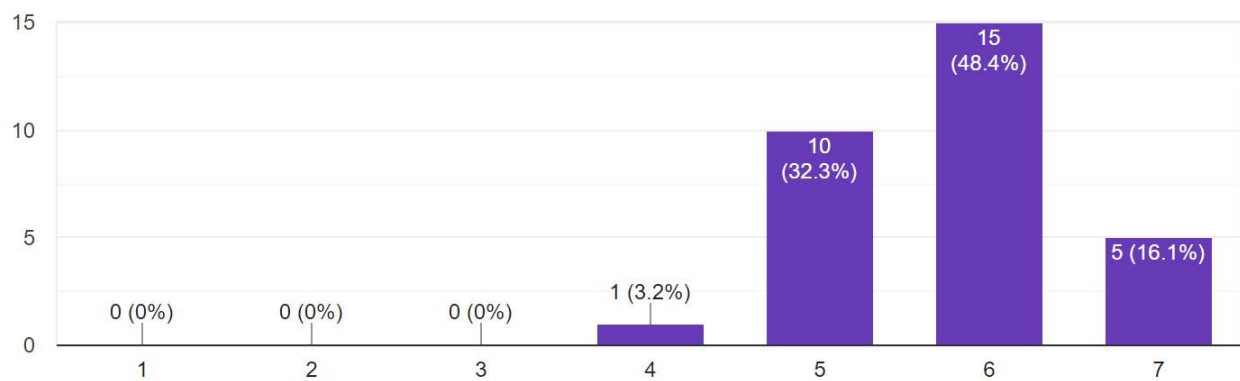


Figure 4.8 –

Then the Fourth question was “Is “Design standardizing” an effective strategy to reduce the bottle necks in Project Planning?”



4.3 Results of Surveys

To identify the confirmations, data from eight interview participants (qualitative) and thirty one survey participants (quantitative) were evaluated. The highest number of occurrence during interviews happened for

- **Standardization** is the main core to implement the Modular construction In India.
- **Incentives for adopting Modular Construction**

The Government of India intends to give clients incentives by reducing the current Stamp Duty of 7% to a subsidy for precast solid dwelling ventures for LIG and EWS groupings.

This would contribute to a greater interest in precast solid products. The central and state governments can implement more of these programmers.

- **Proper cost analysis and planning** can aid in achieving a cost-effective prefab construction estimate. Educating students, trainers, and even laborers about prefabrication in greater depth would aid in the development of a better trained and educated prefabrication workforce.

4.4 Discussion

- There are several project advantages to modular construction, but the most common are time savings, cost savings, and more environmentally friendly construction.
- As shown in the case study, adoption of modular construction saved at least 6% on project costs. The same study discovered that respondents saved a significant amount of time on their projects.
- When thinking about modular high-rise building, think about the product type and how each volume of space can be built. Hotels, apartments, and condominiums are the most advantageous product kinds, whereas speculative office, which requires interior fit out after the basic building is completed, is the least advantageous. It's also worth noting that a structure doesn't have to be entirely modular or constructed on-site. Most modular projects use a combination of these two strategies, but the combination is critical for time and cost savings.
- Through the early conceptual design process it's possible to quickly determine what elements of the building can or should be modular and which should be site built.

Chapter 5

SUMMARY AND FUTURE RESEARCH

5.1 Conclusion

In terms of economics, social issues, and the environment, the modular construction technology has the potential to make a difference in the Indian building industry. It is critical that the potential benefits of this breakthrough are realised in order for necessary development to occur. The work's primary objectives have been met. For both prefab and conventional development, the total cost and length have been determined. In addition, the overview urged us to consider the benefits and drawbacks of both building and conventional development. The analysis reveals that there isn't a significant cost difference between the procedures (6 percent), with prefab being more temperate in tall constructions than normal. Meanwhile, the prefabricated construction shortens the project duration by 335 days as compared to the standard. More research is needed, however, to assure that these prefabricated building technologies and construction provide significant economic and environmental benefits. Here are some ideas for increasing market demand and contributing to India's development of prefabricated building systems.

The major variables to consider in transportation planning are transportation limits, regulation, and special traffic control in the construction area. As a result, additional case studies are required to assess project planning, scheduling, and costing for both small and large-scale projects.

To develop and include design requirements and recommendations for modular construction according to Indian design standards, more research and case studies are required.

A fundamental difficulty for the marketing of modular building in India is a lack of information about the performance, benefits, and cost design and techniques supplied by prefabricated systems. Through sociological and economic study, this may have been accomplished. The following activities should be prioritised in this study: questionnaires, workshops, conferences, and media interviews.

In India, necessary educational courses, workshops, conferences, and vocational training are needed to acquire and reinforce the skills and knowledge required for modular construction techniques. Universities and educational institutions should also explore incorporating modular design and construction into their curriculum. This will improve the design and construction practices' professional abilities and knowledge while also enhancing their productivity.

5.2 Limitations

The major variables to consider in transportation planning are transportation limits, laws, and special traffic control in the construction area. As a result, additional case studies are required to assess project planning, scheduling, and costing for both small and large-scale projects. To develop and integrate design requirements and recommendations for prefabricated structures according to Indian design standards, more research and case studies are required.

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APPENDICES

Appendix 1

Thesis Questionnaire

My name is Princely K and I am doing Masters in Architecture in Sathyabama Institute of Science & Technology. I am doing a thesis on "Feasibility Study on Implementing Modular construction Techniques in High-rise buildings in India."

I would like you to take an online survey. Participation will take approximately fifteen minutes. Your participation in this research is voluntary.

We will be collecting information on your experience and area of expertise. When we report and share the data with others, we will combine the data from all participants. We will keep your data confidential; your name and data will be kept separately accessible only to the research team.

* Required

1. What is your current title?

2. How many years of experience do you have in the design and construction industry?

Mark only one oval.

- ☐ 0-5
- ☐ 6-10
- ☐ 11-20
- ☐ 30 and above
- ☐ None

3. What is your primary role in the design and construction industry?

Check all that apply.

- ☐ Architect
☐ Contractor
☐ Engineer
☐ Client
☐ Fabricator

Other: ☐ _____

4. What do you think about standardizing designs in construction? Is it a good idea? *

Mark only one oval.

	1	2	3	4	5	6	7	
Least Ineffective	☐	☐	☐	☐	☐	☐	☐	Highly Effective

5. According to you what building type designs can be standardized? *

Check all that apply.

- ☐ Residential Buildings
☐ Commercial Buildings
☐ Healthcare Buildings
☐ Educational Institutions

6. If designs are standardized, do you think modular constructions shall be a viable option? *

Mark only one oval.

	1	2	3	4	5	6	7	
Least Effective	☐	☐	☐	☐	☐	☐	☐	Highly Effective

7. Is "Design standardizing" an effective strategy to reduce the bottle necks in Project Planning? *

Mark only one oval.

	1	2	3	4	5	6	7	
Least Effective	☐	☐	☐	☐	☐	☐	☐	Highly Effective

8. Is providing "warranty" an effective strategy to reduce the impact on resistance to change? *

Mark only one oval.

	1	2	3	4	5	6	7	
Least Effective	☐	☐	☐	☐	☐	☐	☐	Highly Effective

9. If Tax exemptions / subsidies are provided by the Government for pre-cast modular construction, how effective will it be in reducing the resistance to change? *

Mark only one oval.

	1	2	3	4	5	6	7	
Least Effective	☐	☐	☐	☐	☐	☐	☐	Highly Effective

10. Is installing a manufacturing plant near the site, a viable solution for solving transportation issues? *

Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Poor Idea	☐	☐	☐	☐	☐	☐	☐	Great Idea

11. Will standardizing module size have an impact on transportation challenge? *

Mark only one oval.

	1	2	3	4	5	6	7	
Least Impact	☐	☐	☐	☐	☐	☐	☐	Greatest Impact

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