

# MODULAR CONSTRUCTION TECHNIQUES: REVOLUTIONIZING THE FUTURE OF BUILDING

## Abstract

Modular construction is an innovative building method that utilizes three-dimensional units manufactured off-site and assembled on-site. It explores the stability of light steel walls, thermal-shielding effects of module floors, fire barriers, and heat transfer limitations that contribute to overall fire resistance. Internal module walls and ceilings are constructed with fire-resistant plasterboard and mineral wool for acoustic purposes. The study emphasizes the significance of these fire resistance and acoustic insulation measures in modular construction. The study highlights these measures' significance in ensuring modular buildings' safety and comfort. This book review contributes to the advancement of modular construction by offering practical approaches for streamlining the design, manufacturing, and assembly processes. The integration of BIM and lean principles provide valuable insights for professionals in the construction industry seeking to enhance efficiency and productivity. Overall, the research underscores the benefits of modular construction and highlights its potential for future development through the integration of innovative technologies.

**Keywords:** Modular construction, Building Information Modeling (BIM), Lean Construction, Prefabricated Prefinished Volumetric Construction (PPVC), Scenario-Based Analysis (SBA), Integrated Process Improvement (IPI), Value Stream Map (VSM)

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## I. INTRODUCTION

Modular construction, often known as modular building systems, is a novel construction technology that employs three-dimensional or modular units. These units are built in the factory and brought to the job site for assembly. This process involves careful procurement and coordination to ensure seamless integration of modular units. One distinguishing aspect of modular construction is that the components are fully constructed in the factory before being transported to the job site. This indicates that the unit has all of the required finishes, fittings, and services, such as power systems and plumbing. This level of preparation ensures that the on-site construction process is efficient and effective. [1]

After entering the construction site, the modular units are placed on the prepared foundations to form the desired building structure. These units can be configured to create complete rooms, room partitions or specialized units such as bathrooms and elevators. This flexibility allows for diverse design and efficient use of space.

Modular constructions are commonly employed in a variety of facilities, including student dorms, public housing, military dorms and hotels. This is especially efficient for projects that require many similar units, such as the multifamily building shown in Figure 1.



**Figure 1:** Modular Buildings

Modular units can be built with a variety of materials, including thick gauge steel, composites, timber frames, concrete. Additionally, modular construction can be combined with panel systems to create hybrid or composite structures, further expanding design possibilities.

Modular construction offers a cost-effective, time-efficient, and sustainable alternative to traditional construction methods. Its speed, quality control, and environmental impact advantages make it a compelling option for many construction projects.

Prefabricated Prefinished Volumetric Construction (PPVC) is a form of modular construction in which internal components such as ceilings, walls, and floors are finished before assembly. PPVC has advantages such as faster construction, increased output, and improved quality control. Over the last 20 years, it has been widely used in a variety of industries, including residential, hotel, and hospital building. [1]

PPVC modules are categorized into two types based on their load paths. In concrete constructions, load-bearing wall modules are often utilized to transfer gravity loads to the foundation while resisting lateral loads. Corner-supported modules, which are usually made of steel-concrete composite materials, transfer gravity loads to edge foundations, columns, and beams. Steel modules provide for greater design flexibility and speedier construction due to bolted connections, but they may necessitate additional steps to solve durability issues such as corrosion and fire. Because of their durability and simplicity of inspection, concrete modules are used for residential constructions. [2]

Despite its advantages, PPVC is still not widely used in high-rise buildings. Structural design, joint flexibility, manufacturing tolerances, and construction tolerances all have an impact on total building stability. For high-rise buildings, relying on lateral resisting systems and maintaining continuity in the beam-column frame become vital. Efforts are being made to solve these issues and promote modular building in high-rise developments.

Researchers have thoroughly investigated the usage of modular systems in multi-story and high-rise buildings, emphasizing their potential for design uniformity and repetition. Integration of innovative technologies, like Building Information Modeling (BIM), 3D laser scanners and robotic installations, has been discussed to enhance modular and industrial construction processes.

Comparative analyses have been conducted between different construction methods, such as panel and modular systems, to determine cost-effectiveness and implications for single-family homes. Other studies have focused on structural considerations, seismic influences, construction efficiency prediction, and alternative construction scenarios. [2]

In summary, modular construction offers numerous advantages over traditional methods, including speed, productivity, and quality control. Efforts are ongoing to overcome obstacles and encourage the use of modular construction, particularly in high-rise buildings. Technological advancements and research contribute to the continuous improvement and adoption of modular construction in the industry.

## 1. Characteristics of Modular Buildings

- Standardized 3-D Volumetric Units
  - Standardization of modules in modular construction.
  - Mass production of identical units in controlled factories.
  - Stricter quality control and inspection protocols for superior construction quality.
  - Reduction of waste through controlled factory production.
- Sustainability and Waste Reduction
  - Sustainable practices in modular construction.
  - Minimization of environmental impact and waste generation.
  - Reduction of on-site activity and disturbance.
  - Promotion of sustainability through factory production and waste reduction.
- Flexibility and Reuse of Volumetric Units

- Movable and flexible nature of modular buildings.
- Dismantling, refurbishment, and relocation of modules.
- Reduction in demand for raw materials and energy consumption.
- Consideration of transportation costs due to the size and weight of units.
- Efficient Construction Process
  - Construction phase shift away from the construction site.
  - Faster and more efficient manufacturing processes.
  - Simultaneous construction and site work.
  - Completion of projects in a shorter time compared to traditional methods.
- Importance of Planning and Coordination
  - Collaboration between stakeholders from early stages.
  - Involvement of clients, consultants, manufacturers, contractors, and suppliers.
  - Early consideration of logistics, design, and foundations.
  - Careful inspection and installation of modular units.
- Ease of Renovation
  - Simplification of renovation projects through modular construction.
  - Selection and installation of suitable modules.
  - Flexibility in modifying and updating existing buildings.
  - Reduction of disruption and cost compared to traditional methods.[1]

## 2. Benefits of Modular Construction

The following are the advantages of modular building:

- Modular construction allows for simultaneous construction with foundation work and site.
- When compared to traditional construction processes, projects can be completed in 30% to 50% less time.
- Weather delays are reduced because a substantial amount of construction (60-90%) is conducted within a facility.
- Modules are constructed with high-quality materials and are subjected to factory quality assurance/quality control management.
- Modular buildings must adhere to the same construction codes as traditional structures.
- Modular components can be manufactured in a factory and easily assembled on-site, enabling construction in inaccessible areas.
- Disassembling units is simple by removing joints and connections, enabling for relocation or reconfiguration.
- When compared to traditional methods, modular construction saves on repair costs, commissioning, and defect.
- Wastage reduction is achieved through controlled production environments, leading to cost savings.

- Modular buildings can be dismantled, relocated, or repurposed, reducing the demand for raw materials.
- Recycling of materials and inventory control in factory production reduces wastage.
- Enhanced safety on-site and in the factory result in fewer accidents.[1]

### 3. Challenges in Modular Construction

- **Modular Lightweight Unit:** The weight and size of each unit are affected by the logistics of transporting modular units from the factory to the building site. The maximum dimensions of modules to comply with regulatory standards are determined by local rules and transportation restrictions. Furthermore, the carrying of units during arranging and assembly limits the weight of each unit.

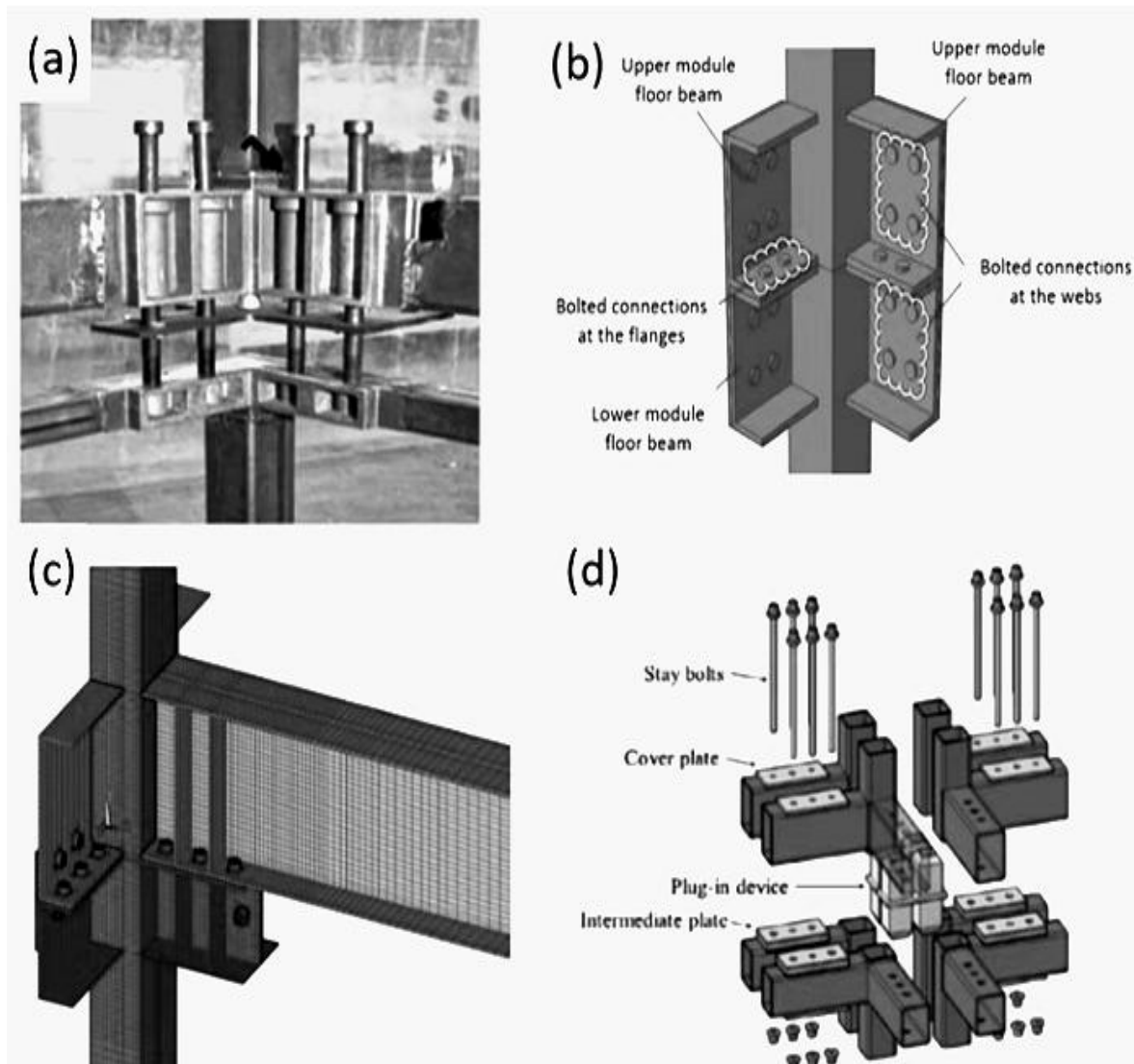
Composite design principles may be used in modular building to minimize weight while increasing performance. Composite slab and beam designs can replace traditional steel structures, resulting in lighter floors and improved structural stiffness. This design approach not only reduces weight but also allows for larger headroom, which is important in modular construction due to the double slab system.

Lightweight materials, such as lightweight concrete, can be used in thin floor systems to further reduce module weight. Lighter partition walls can also be used for non-structural functions while still providing acoustic and fire safety. The weight of the hoisting system can be decreased even further by adopting composite designs in columns that separate the weight of the concrete fillings from the weight of the steel components.

Overall, optimizing the size and weight of modular units is crucial for efficient transportation and assembly. By utilizing composite design and lightweight materials, modular construction can achieve lighter modules, improved performance, and increased efficiency without compromising structural integrity. [2]

- **Joining Approaches for Quick Installation:** In modular construction, the way the different parts of the building are connected is important. Welded connections are commonly used for steel modules, and they need to be strong and rigid. The joints between the modules can be classified into different types, each with its own details and performance.

When using steel modules in high-rise buildings, it is more efficient to have the modules connected to a central core. This allows for faster construction compared to traditional methods. However, using only steel modules can make the columns larger and more expensive. To solve this, a combination of steel and concrete can be used to keep the column sizes manageable while still providing strength. The joining techniques for different building elements have been shown in Figure 2.



**Figure 2:** Typical Beam-Beam Connection (A) Vectorbloc System (Bowron, 2016), (B) Corner Joint (Mao, 2017), (C) Perimeter Joint (Lee Et.Al, 2017), and (D) Interior Joint (Chen Et.Al, 2017)

There are different methods for joining the modules together. One approach is using bolted connections, but this can be challenging and may require modifications to the modules. Another method involves connecting the columns outside the modules using threaded bars. However, this approach can also have its difficulties and may not provide enough strength for tall buildings. The design of these joints is important for the overall stability of the building. Engineers need to carefully consider the best way to connect the modules to ensure the building is safe and structurally sound. [2]

- **Automation Technologies:** Currently, manual labor tasks are still engaged in the fabrication of modular components and on the construction site, limiting the efficiency and productivity of Prefabricated Prefinished Volumetric Construction (PPVC). This is due to the high initial cost of technological advancements in automation, as well as a lack of support from local governments. Manual techniques used in module manufacture might result in inaccuracies in verticality, horizontality, and water leakage, causing complications during on-site assembly. The lack of automated technology on the construction site results in longer adjustment times for lifting chains and manual module positioning.

However, the construction industry is gradually embracing automation. Figure 3 depicts how manufacturers use automated technologies to create building components faster and with greater quality control. Construction on-site is becoming more automated as well, such as the use of machines for interior fit-outs. The future goal is to achieve 3D printing of entire modular units and utilize 3D laser scanners for quick and accurate measurements of module alignment.



**Figure 3:** Automated Types of Equipment used to Build the Module, (J. Y. R. Liewa Et.Al, 2018)

RFID technologies and Building Information Modeling (BIM) are being deployed to improve asset and inventory management, expedite communication between project stakeholders, and enable virtual walkthroughs of buildings prior to construction. Virtual reality (VR) and Augmented reality (AR) and can improve BIM

models by enabling for improved problem identification and resolution. Cloud-connected mobile devices enable on-site real-time sharing of BIM models, allowing for more efficient decision-making. Furthermore, BIM models can be utilized to compute each module's center of gravity, assisting with module stabilization during lifting and limiting damage.

Overall, advancements in technology are transforming the modular construction industry, increasing productivity, and improving the quality of construction processes. [2]

## II. FIRE RESISTANCE AND ACOUSTIC INSULATION

Modular construction relies heavily on fire resistance and acoustic insulation. Several aspects contribute to modular construction's fire resistance:

1. **Light Steel Wall Stability:** The force applied to the walls, as well as the fire protection on the modules' internal faces, contribute to overall stability during a fire.
2. **Thermal Insulation Effect:** Because of the ceiling beneath, the module floors provide a thermal-shielding effect, increasing load capacity and fire resistance.
3. **Fire Barriers:** Fire barriers are put between modules to prevent smoke and flames from spreading in the gap between them, hence restricting fire propagation.
4. **Transfer of Heat Limitation:** The modules' floor-ceiling structures and double-leaf walls minimize heat flow during a fire.

Internal faces of module ceilings and walls are typically built with two layers of 15 mm plasterboard, at least one of which is fire-resistant plasterboard. Mineral wool is sandwiched between C-sections to provide acoustic and fire resistance. The combination of the floor, ceiling, and load-bearing light steel walls guarantees a fire-resistance rating of 120 minutes, relying on the sheathing board used on the exterior of the modules. The double-leaf floor-ceiling and walls construction also provide exceptional airborne resistance and impact sound protection, particularly when combined with an exterior sheathing board. In addition, using a thin concrete flooring slab on a light steel floor between beams or walls can increase sound insulation and floor stiffness while minimizing vibration. [3]

## III. FUTURE SCOPE USING BIM

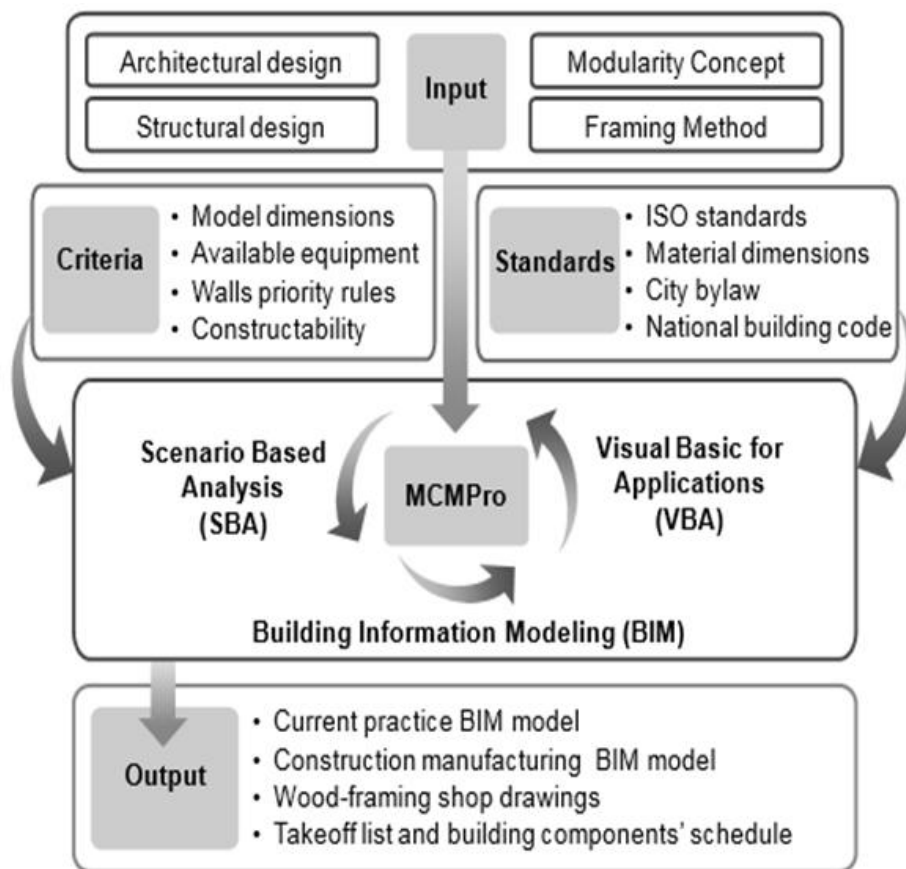
### BIM Application in Modular Construction

BIM (Building Information Modeling) is an innovative digital technology that has transformed the construction sector. It entails the generation and administration of detailed 3D models, as well as necessary data, to aid in the effective planning, design, construction, and operation of buildings and infrastructure projects. BIM goes beyond traditional 2D drawings by allowing stakeholders to participate virtually, boosting communication,



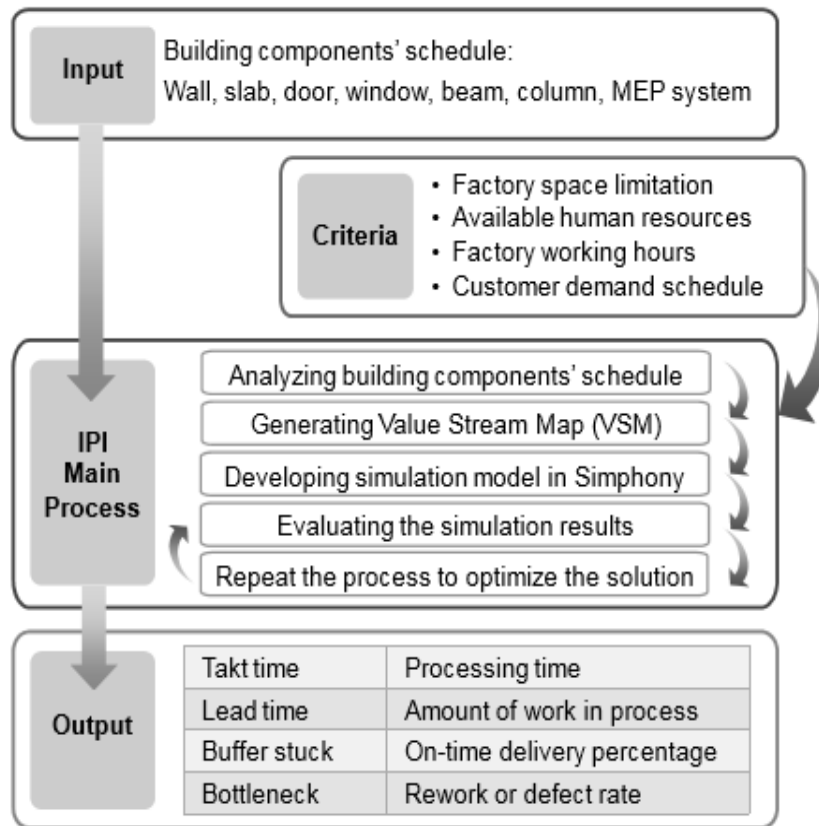
decreasing errors, and improving overall project outcomes. BIM has become a vital tool in modern construction, affecting the way projects are designed and implemented due to its capacity to expedite procedures and deliver significant insights.

The modular construction method is based on the principles of combining Building Information Systems (BIM) with Lean. A computer program called MCMPro is used to generate diagrams and work charts based on a design. To eliminate waste in production processes, Value Stream Mapping (VSM) was developed utilizing Lean principles. Figure.4 shows how MCMPro uses AutoCAD Visual Basic for Applications (VBA) and scene-based analysis (SBA) to generate design drawings.



**Figure 4:** Scenario-Based Analysis (SBA) Process, Mansooreh Moghadam Et.Al, (2012)

Lean design concepts are then used and a VSM is created to optimize production lines based on the prevention plan. VSM graphically displays the flow of data and information, identifying opportunities for improvement and disposal. Integrated process improvement (IPI) aims to increase efficiency, standardize processes, reduce delays and solve problems as shown in Figure 5. The simulation model is used to test the VSM and refine it until a good result is obtained. This study demonstrates the usefulness of the BIM/LEAN model in decreasing time, waste and resource utilization in modular building construction. [4]



**Figure 5:** Integrated Process Improvement (IPI) Process, Mansooreh Moghadam Et.Al, (2012)

Despite the multiple benefits it provides, including as reduced labor requirements, onsite greenhouse gas emissions, improved scheduling, and product quality, its mainstream implementation has been hampered by the significant pre-project planning and interdisciplinary collaboration necessary. [5]

The emergence of Building Information Modeling (BIM) provides a solution to these challenges and facilitates the integration of modular construction. The benefits and limitations of applying BIM in modular construction can be readily understood by leveraging its capabilities. BIM models increase cooperation by recognizing collisions and allocating access space. Resolving interferences involve determining system priority based on functionality to ensure optimal performance.

MEP coordination is a critical aspect of modular construction, given the lack of detailed design for building systems. BIM technology offers an opportunity to enhance this process by fostering collaboration between design engineers and construction contractors. It enables early consideration of constructability issues and facilitates dialogue between specialists and designers.

However, due to the substantial design and MEP coordination required, the existing construction delivery model falls short of supporting modular construction. Integrating BIM into construction projects increases the effectiveness and desirability of modular building

technologies. It simplifies the entire process, from planning and design through manufacturing and construction, by recognizing and resolving issues early on. BIM eliminates the need for conventional paper plans and requirements. Further research should concentrate on the organizational and legal difficulties associated with using BIM into building projects to improve modular construction. [5]

#### **IV. DISCUSSION**

Modular construction and traditional building are two separate approaches to structure construction, each with its own set of benefits and drawbacks. Building elements are manufactured off-site in a controlled factory setting and then integrated on-site in the same way as building blocks are in modular construction. This method saves time since off-site production can take place concurrently with on-site preparation, resulting in faster project completion. The speed and efficiency of modular construction make it a preferred choice for projects with tight timelines or urgent needs. Another key benefit of modular construction lies in its enhanced quality control. The standardized processes and factory-controlled conditions ensure a higher level of precision and consistency in the final product. This leads to a reduction in defects and rework, ultimately resulting in cost savings for the project. Moreover, the controlled environment of the factory also allows for better optimization of resources, leading to less material wastage. Sustainability is another noteworthy advantage of modular construction. With less on-site construction activity and reduced transportation of materials, there is a smaller carbon footprint associated with modular projects. The minimized disruption to the surrounding environment during construction further adds to its eco-friendliness. However, modular construction does come with certain limitations. The design flexibility is somewhat limited to the available modular configurations, making it less suitable for intricate or highly customized architectural designs. While some customization is possible within the modular framework, it may not cater to the specific needs of every project. On the other hand, conventional building involves constructing the entire structure on-site using traditional construction materials and techniques. This approach provides greater design flexibility, as architects and builders can adapt the structure to specific site conditions and tailor it to meet the owner's specific requirements. This makes conventional building an excellent choice for projects where unique architectural designs or complex layouts are essential. Despite its flexibility, conventional building methods tend to have longer construction timelines compared to modular construction. Sequential on-site construction processes and potential weather-related delays can extend project schedules, impacting overall project costs and timelines.

#### **V. CONCLUSION**

Both modular construction and conventional building have their merits and drawbacks. Modular construction excels in terms of speed, efficiency, quality control, and sustainability, making it a viable option for projects with standardized designs and time-sensitive requirements. On the other hand, conventional building provides greater design flexibility, allowing for customized structures and adaptations to unique site conditions. The choice between the two methods ultimately depends on the project's specific requirements, budget constraints, and desired outcomes.

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