Integrating BIM with Modular Construction: Challenges and Strategies to Enhance Industry Efficiency

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Abstract- The combination of Building Information Modeling (BIM) with modular construction, is transforming the construction industry by offering advantages like sustainability, quality, and efficiency. Compared to conventional procedures, this integration results in wastage reduction by up to 90%, construction time saving up to 50%, & expenses decline by 20%, along with the reduction in budgeting error by 40%. Consequently, at least 75% of businesses see a favourable return on investment. There are still issues in completely integrating BIM with modular building. Existing BIM programs struggle to offer a single platform for smooth cross-disciplinary modifications and lack the detail and flexibility required for modular projects. The creation of thorough BIM models that can efficiently assist decision-making during modular building projects is hampered by these constraints. To solve these problems, a complete methodology is provided, with an emphasis on developing industry standards, implementing collaborative design techniques, adopting lifecycle-oriented design strategies, and developing specialized BIM tools. Key efforts include developing parametric modelling, automating design optimization procedures, incorporating manufacturing concerns into the design phase, and improving interoperability between platforms. Stakeholders must upskill the workforce and provide supporting regulatory frameworks to fully exploit the promise of BIM in modular construction. Future studies should concentrate on digital twins in lifetime management, standardized data-sharing protocols, and AI-driven design optimization. The construction industry may create a more inventive, sustainable, and efficient future by adopting these technologies and research avenues, tackling global issues and establishing a new paradigm for building.

Keywords: **Building Information Modeling (BIM); Modular Construction; Design Efficiency; Innovation; Integration;**

I.. INTRODUCTION

It is well known that building boosts the global economy. Environmental violations are common in the sector. Construction is one of seven major greenhouse gas emitters, according to the IPCC. Many construction businesses now include economic, social, and environmental factors into their design and building processes as awareness of sustainable construction grows. A project's economic and environmental effectiveness depends on its construction approach. The budgetary advantages of modular building over conventional construction are widely known. Modular construction produces volumetric building components off-site and brings them to the construction site for assembly. Complete buildings are built off-site in the most modern prefabrication test. Semiprefabrication reduces greenhouse gas emissions and embodied carbon more than typical construction methods, according to study. No systematic study has compared volumetric construction methods like modular to conventional methods, even though research has examined their environmental and economic impacts. Thus, there is no quantitative study comparing modular and conventional architecture across several factors. Modular construction has been established since the 1960s, although it took longer to become popular. Modifying tried-and-true construction methods may be difficult. Numerous studies suggest that modular construction approaches, where pieces are created off-site in a continuous flow process, have several benefits. These advantages may include safety, productivity, and environmental performance.

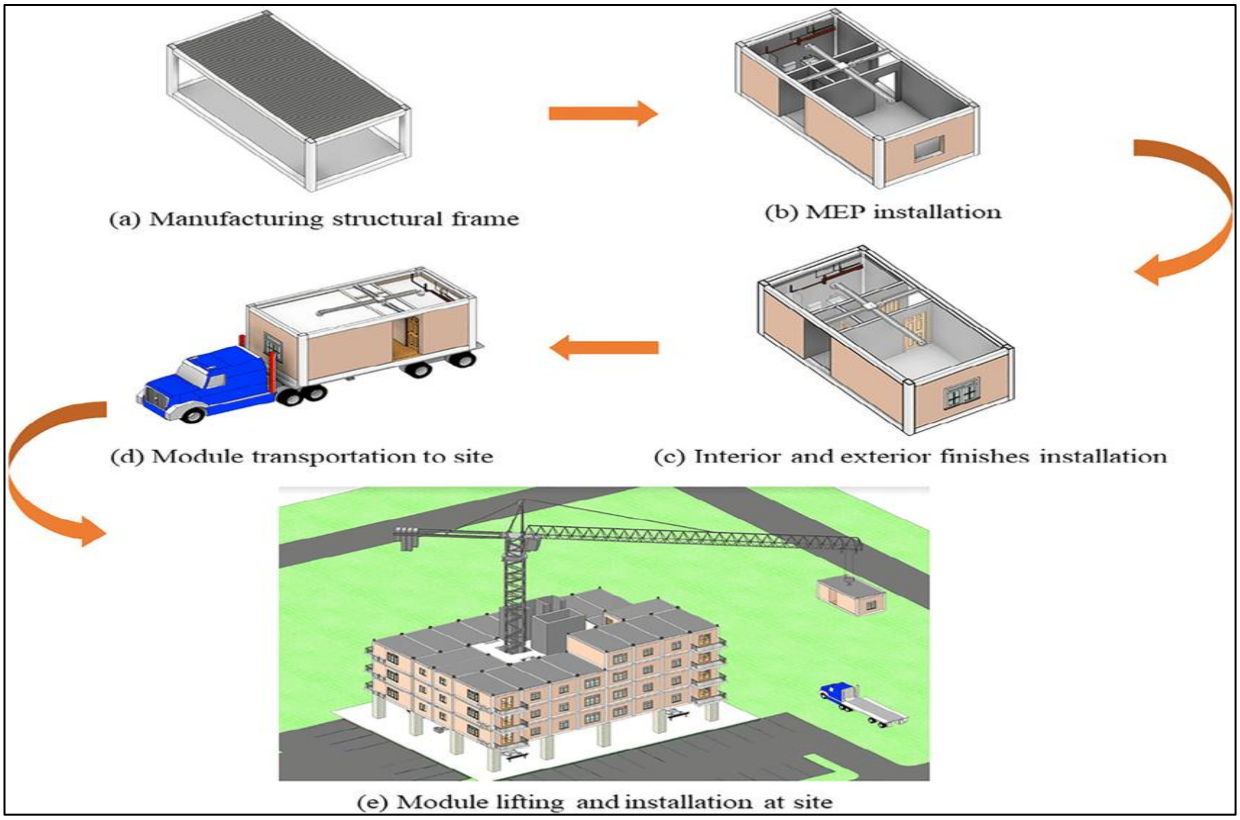

Figure 1. Modular construction-from manufacturing to site installation

Modular construction is an innovative building method where structures are built off-site in a controlled industrial environment using the same materials and standards as traditional construction but in about half the time. The process ensures greater flexibility and reuse, as modules can be disassembled, transported, or repurposed with less energy and material waste. Factory-controlled conditions reduce waste through material recycling, inventory management, and supply protection while also improving air quality by eliminating excess moisture. Since modular construction occurs alongside site preparation, project timelines are shortened by 30-50%, with minimal weather-related delays, leading to faster occupancy and a quicker return on investment. These buildings are designed to meet or exceed the same codes and quality standards as site-built structures, using high-quality materials like wood, steel, and concrete. Additionally, modular construction enhances safety for workers, integrates advanced BIM technology for energy efficiency, and offers limitless design options that seamlessly blend with existing architecture.

1.1 Challenges of Modular Construction

Modular structure seems forward-thinking and really beneficial. However, there are several significant obstacles that might make your modular project successful or unsuccessful, just as with other building techniques.

1. Mass Production / Limited Variety

First, when the locations and products are more repeatable and consistent, a modular (think mass manufacturing) approach works better on a large scale. Hotels and apartment buildings are obvious options if each unit can be standardized and stacked. The time and cost benefits for both the supplier and the customer are diminished, if not eliminated, at this stage of technology when attempts are made to develop unique or non-repetitive modules.

2. Higher Amount of Complex Decisions / Front Loaded Design

Second, a modular approach requires upfront engineering and design effort as well as more possibilities. Architects, engineers, and contractors must comprehend the principles of modular construction and manufacturing. For example, the bigger the structure (the higher the modules stacked), the more attention must be given in how the modules are connected to guarantee alignment and how the modules and outer shell allow compression. (The weight of the stacked modules may crush the wood underneath.) Buyers and owners have to make decisions about appliances and finishes long before construction begins because of this front-loaded design process. Those of you who have worked in the construction industry before may see this as advantageous since you understand how challenging last-minute alterations may be.

3. Approval Process Can Be Complicated

Third, the approval process might be intricate. Every project must abide by local, state, and federal rules and regulations, regardless of how it is built. Nevertheless, the appropriate codes vary based on the approach. In certain jurisdictions and areas, modular manufacturing is more accepted than in others. Local inspection is only applicable to connections and work done on-site; ideally, the modules are built in accordance with state regulations (such the Pennsylvania Industrialized Housing Act) and may be examined and finished within the factory. However, certain states, like as Maryland, mandate local inspections of systems that restrict wall closures and finish application until on-site. In settings where unions have substantial influence, the way contractors negotiate trade relations may complicate the approval and implementation processes.

4. Risk is on Few Suppliers

Furthermore, you are focusing the project's execution risk on one or a small group of vendors. Single-family houses have been the primary product of modular producers. Although the number of businesses creating commercial and multi-family items is increasing, few are willing, able, and financially able to meet demand. Before making a deal that puts all of their eggs in one basket, buyers—whether general contractors or owners—should thoroughly investigate businesses. They must continue to pay close attention to the follow-up throughout their task. Changing manufacturers in the midst of a project must be a major catastrophe, even with bonding.

5. Transportation Costs & Risk

Then there's the transportation danger. Modules must be carried straight to the building site or staged close by before being installed since they are constructed at a facility a mile from the project site. Because a single transport fault might need extensive repairs or module replacement, the riggers and transporters must be very careful with each module. This might potentially make the whole installation procedure more difficult. With the exception of some minor inside drywall cracking from putting the modules into position, shipping, staging, and set went rather well on our Philadelphia project. There was nothing to be concerned about since this harm was easily fixed.

For the transportation and rigging businesses, tracking down the roadways and planning the logistics of moving the modules for the length of their trip are essential jobs. They are unable to get stuck in bridges, tight curves, traffic jams, crane setup, or temporary road closure permits. The road's permissible dimensions, which may be 10 feet wide by 70 feet long, and the crane's ability to lift up to 25 tons over the depth of a project site are often the initial restrictions on module sizes. Make sure your insurance consultant's broker and insurer are aware of the various hazards associated with off-site construction.

6. Difficult Financing Process

The financial aspect is an additional challenge. Bills are frequently much higher early in the development process than investors and lenders are used to seeing and paying since modular construction requires acquiring and constructing on a faster timeline. Together with the manufacturer and contractor, ascertain the amounts and schedule of anticipated financial outlays (create a monthly estimate and revise it as the project develops). This will assist prevent mechanic's liens and ensure that there is sufficient money to complete the project. To ensure that money is invested in your product and not someone else's, a bank, owner, and contractor representative should arrange to visit the factory at different points throughout the manufacturing process.

Modular construction has drawbacks and isn't always the ideal option, even if it could be useful in certain circumstances. On the other hand, we think modular and off-site building will gain a lot of traction in the future.

II. LITERATURE REVIEW

2.1 Modular Construction

Khaled Elsayed et al. (2024) examine the seismic response of modular steel construction (MSC), proposing a stiffness coupling spring matrix approach for better seismic analysis. Their study finds MSC1 and MSC2 vulnerable to displacement, while MSC3 shows superior integrity, emphasizing the need for improved external inter-module connection stiffness. Mehrdad Arashpour et al. (2017) investigate uncertainties in hybrid infrastructure projects combining on-site and off-site modular construction. By analyzing seven projects, they identify risks like cost overruns and quality deficiencies. Their research advocates a triadic risk analysis approach to enhance coordination and mitigate project deviations, improving overall efficiency in modular construction. Sriskanthan Srisangeerthanan et al. (2020) review inter-module connection systems in multi-story modular buildings, addressing challenges in structural integrity and lateral load transfer. They highlight the need for high-performance connections to ensure stress dissipation and load distribution, concluding that optimized connection strategies significantly enhance seismic resilience and durability. Timothy O. Olawumi et al. (2022) explore digitalization in modular integrated construction (MiC), focusing on blockchain, RFID, and BIM. Their findings highlight digital tools' benefits in prefabrication and assembly but identify inefficiencies in transportation. The study suggests blockchain can improve efficiency, security, and interoperability in modular construction processes. Diana Lopez and Thomas M. Froese (2016) analyze cost-effectiveness in panelized versus modular prefabricated homes. Their study finds that while panelized construction offers flexibility, modular construction ensures better quality control and lower on-site labor needs. Cost analysis shows modular construction is slightly more economical, but site-specific factors influence the best prefabrication choice.

2.2 Reviews on Building Information Modeling (BIM)

Abdullah Mohammed Alshehri et al. (2024) explore BIM's role in sustainable building development, emphasizing its impact on energy efficiency and environmental risk reduction. Using mixed methods, they demonstrate BIM's effectiveness in climate adaptation and integrating eco-friendly materials, significantly enhancing structural sustainability. Vito Getuli et al. (2025) address the lack of standardized BIM object libraries for construction site modeling. They propose a six-step vendor-neutral approach using parametric geometries and hierarchical structuring, improving spatial planning, cost estimation, and risk assessment for more efficient BIM-based workflows. Peter Smith (2014) examines global BIM adoption strategies, highlighting government mandates and industry leadership in driving implementation. He underscores the need for national and international standards, regulatory frameworks, and product databases to enhance BIM's effectiveness in project delivery and cost reduction. F.H. Abanda et al. (2017) investigate BIM's integration with off-site manufacturing, demonstrating its advantages over traditional on-site methods. Their analysis reveals how BIM enhances productivity, optimizes manufacturing, and reduces inefficiencies, making it a crucial tool for factory-based construction. Qunzhou Yu et al. (2016) introduce a BIM-based dynamic model for site material supply management. By integrating 4D modeling with real-time data, their approach improves material delivery, minimizes waste, and enhances supply chain efficiency, particularly in urban construction projects.

2.3 Reviews on Design Challenges in Construction

Fulin Jiang et al. (2023) tackle facility layout optimization in logistics, addressing inefficiencies in transport lines and material handling. They propose a multi-objective simulated annealing algorithm combined with a force-directed method to improve material flow, balancing transport efficiency, cost, and spatial constraints. Shubham Jadhav et al. (2022) examine design and cost challenges in precast and modular construction, focusing on quality control, material standardization, and regulatory compliance. Their cost-benefit analysis highlights the need for improved frameworks to facilitate modular construction adoption while ensuring structural integrity. Nazanin Kordestani Ghalehnoei et al. (2022) explore BIM integration in offsite construction, identifying policy, training, and documentation gaps. They propose a structured framework involving government support and stakeholder collaboration to overcome these challenges and improve BIM's efficiency in modular manufacturing. Wenying Ji et al.

(2022) introduce a Bayesian-based approach to quantify complexity in prefabricated construction. Their hierarchical clustering model integrates design data and quality metrics to assess risk and variability, offering a data-driven method to enhance quality control and efficiency in prefabrication. Kaveesha Gihani Dewagoda et al. (2024) investigate circular economy principles in modular construction, proposing the Design for Circular Manufacturing and Assembly (DfCMA) framework. Their study emphasizes standardized modular components, material reuse, and lifecycle assessments to enhance sustainability and resource efficiency in modular building design.

2.4 Leveraging BIM for Prefabrication and Modular Construction

Shengxi Zhang et al. (2021) analyze BIM's role in prefabricated construction (PC), emphasizing its ability to streamline workflows, reduce lifecycle costs, and improve stakeholder communication. The study highlights challenges like fragmented supply chains and interoperability issues while advocating for a fully integrated BIM-PC ecosystem to enhance efficiency. Issa Jafar Ramaji (2016) develops a BIM-based framework for multi-story modular buildings, introducing the Product Architecture Model (PAM) to improve modular integration and interoperability. The study highlights BIM's role in automating design, enhancing coordination, and standardizing information exchange while addressing assembly scheduling challenges. Lukman O. Saliu et al. (2024) investigate BIM adoption barriers in modular construction within Sub-Saharan Africa, identifying high costs, expertise shortages, and stakeholder collaboration issues. They recommend improved training, governmental support, and early stakeholder involvement to enhance BIM's effectiveness in design accuracy, prefabrication, and supply chain management. A. Alwisy et al. (2012) explore BIM automation in modular construction manufacturing, introducing an intelligent system for automated drafting, shop drawing generation, and assembly planning. Their research underscores BIM's role in minimizing design errors, improving fabrication efficiency, and optimizing modular workflows. Amin Jamshidzadeh and Mohammad Jamshidzadeh (2022) examine BIM's impact on off-site modular construction, highlighting its benefits in cost control, project timelines, and interdisciplinary coordination, particularly in MEP systems. They emphasize BIM's role in material management and sustainability but note challenges like high software costs and extensive training needs.

2.5 Manufacturing Challenges in Modular Construction

Enaam Ouda and Mahmoud Haggag (2024) investigate automation in modular construction, emphasizing human-robot collaboration, digitalization, and lean production. They highlight challenges such as high automation costs, workforce training gaps, and data interoperability issues, advocating for integrated robotic assembly to enhance precision, reduce labor costs, and optimize material usage. Matthew W. Meehleis (2023) presents a case study on manufacturing challenges in modular construction, focusing on pre-construction planning, constructability issues, and production bottlenecks. The study underscores the need for effective risk management and process standardization to maintain quality control and ensure seamless integration of prefabricated modules on-site. Kennedy Araújo et al. (2024) explore production planning complexities in modular construction, particularly scheduling and curing times for prestressed precast beams. Their study proposes optimization models to improve mold utilization, reduce idle capacity, and enhance demand forecasting, ultimately increasing efficiency and minimizing material waste.

Ahmed M. Abd El Fattah et al. (2023) assess factors affecting precast concrete adoption in Saudi Arabia, identifying transportation constraints, skilled labor shortages, and design standardization issues as key barriers. The study highlights logistical challenges and stakeholder resistance as major obstacles to efficient precast production and implementation. Guo Zhanglin et al. (2017) examine BIM's role in prefabricated buildings, showcasing its benefits in production accuracy, error reduction, and streamlined assembly. However, challenges such as fragmented data systems, interoperability issues, and a lack of skilled personnel hinder its full potential. The study calls for improved digital collaboration and industry-wide standardization.

III. METHODOLOGY

The framework for conducting the study is described in the research methodology. It outlines the procedures for gathering, evaluating, and interpreting data in order to respond to the research questions and accomplish the goals of the study. This section describes the kind of study, the methodology to be used, and the many techniques and instruments that will be used to collect and examine the data.

Type of Research: Descriptive and Comparative Research

Building Information Modeling (BIM) integration in modular construction is investigated in this study using a descriptive and comparative research strategy, with an emphasis on contrasting it with traditional building techniques.

Primary Data: This study collects primary data through industry surveys, expert interviews, and BIM model creation. Surveys gather quantitative insights from professionals on BIM integration, cost savings, and coordination issues. Expert interviews provide qualitative perspectives on implementation challenges and productivity impacts. Additionally, BIM models in Revit and Navisworks facilitate cost, time, and performance analysis.

Secondary Data: Secondary data is obtained from literature reviews and historical project records. Scholarly articles and reports offer context on BIM adoption, benefits, and challenges in modular construction. Historical project data is analyzed to compare traditional and modular methods, highlighting BIM-driven improvements and identifying areas for further optimization in construction practices.

A stratified random sampling approach ensures diverse representation of construction professionals, including architects, project managers, engineers, BIM consultants, and contractors. The target population includes individuals experienced in BIM and modular construction. A sample size of 100-150 survey participants and 10-12 expert interviews ensures statistical significance and qualitative depth. Inclusion criteria focus on professionals with hands-on BIM experience, while those lacking BIM knowledge are excluded. Stratified sampling guarantees key industry subgroup representation.

IV. EXPERIMENTAL ANALYSIS

4.1 Develop model in REVIT

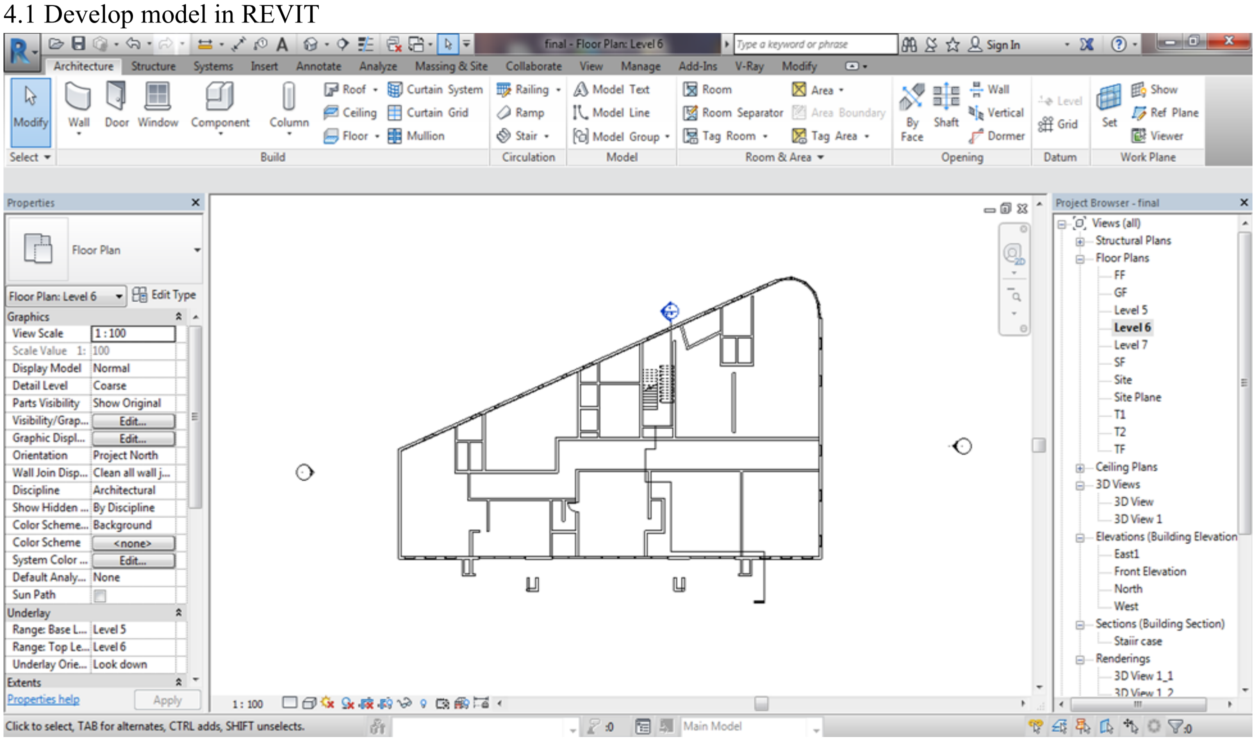

Figure 1. architectural floor plan created in Revit for Level 1

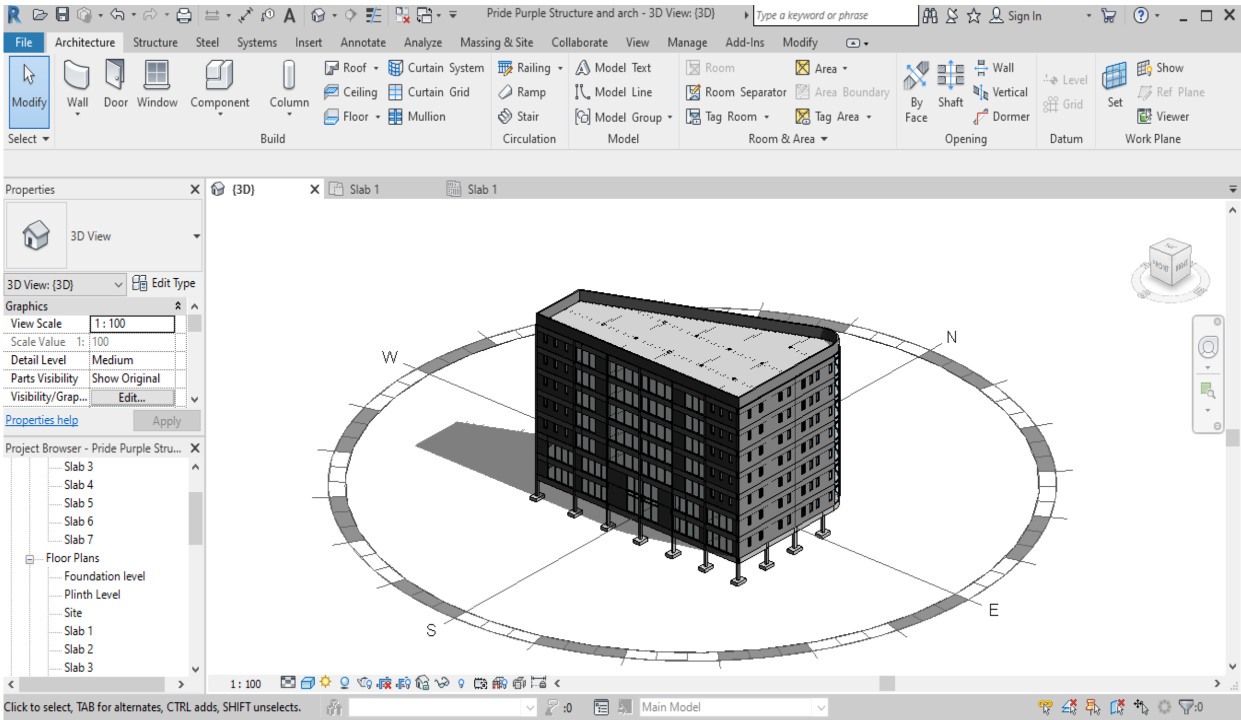

Figure 2. The plan is created in Revit Architecture at level 2, showcasing the column layout in the 3D view.

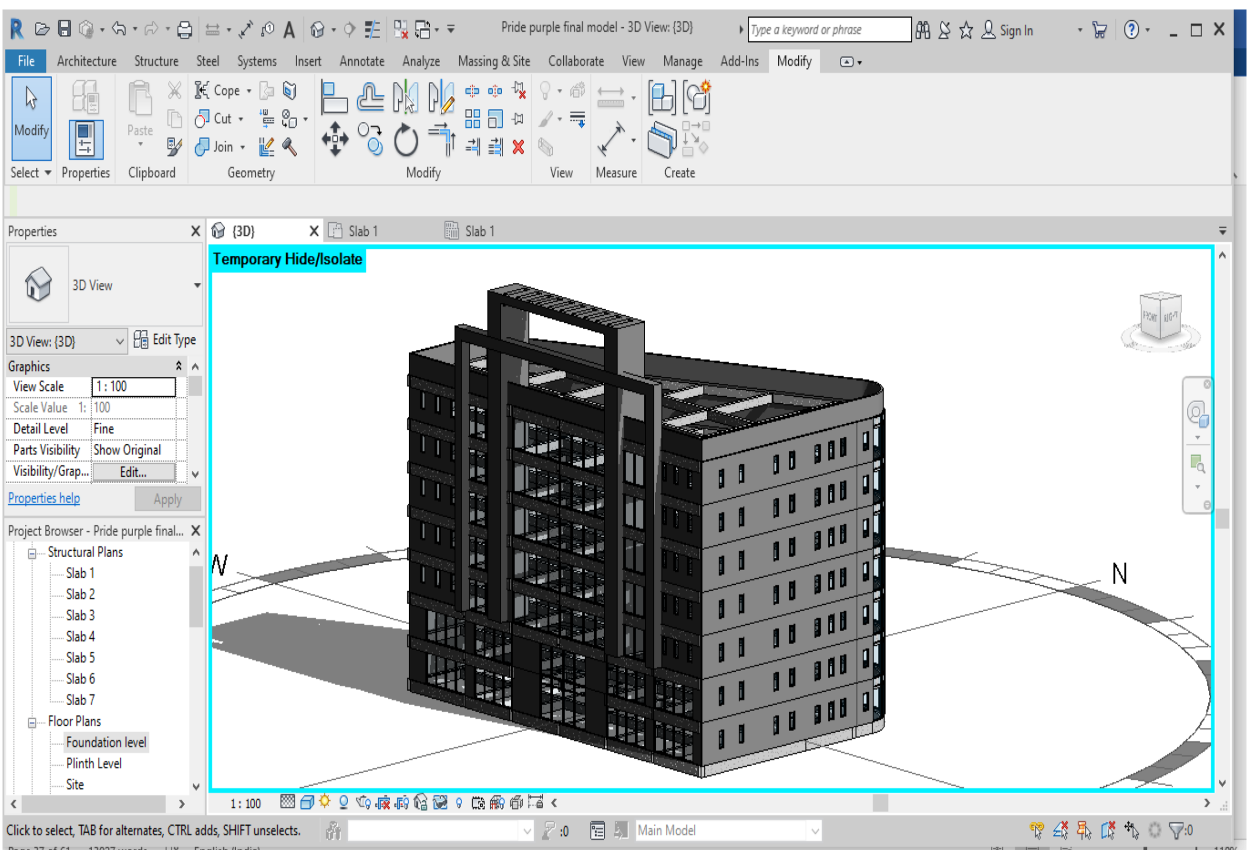

Figure 3. Final Elevation

4.2 Method For 5D Modeling in Navisworks

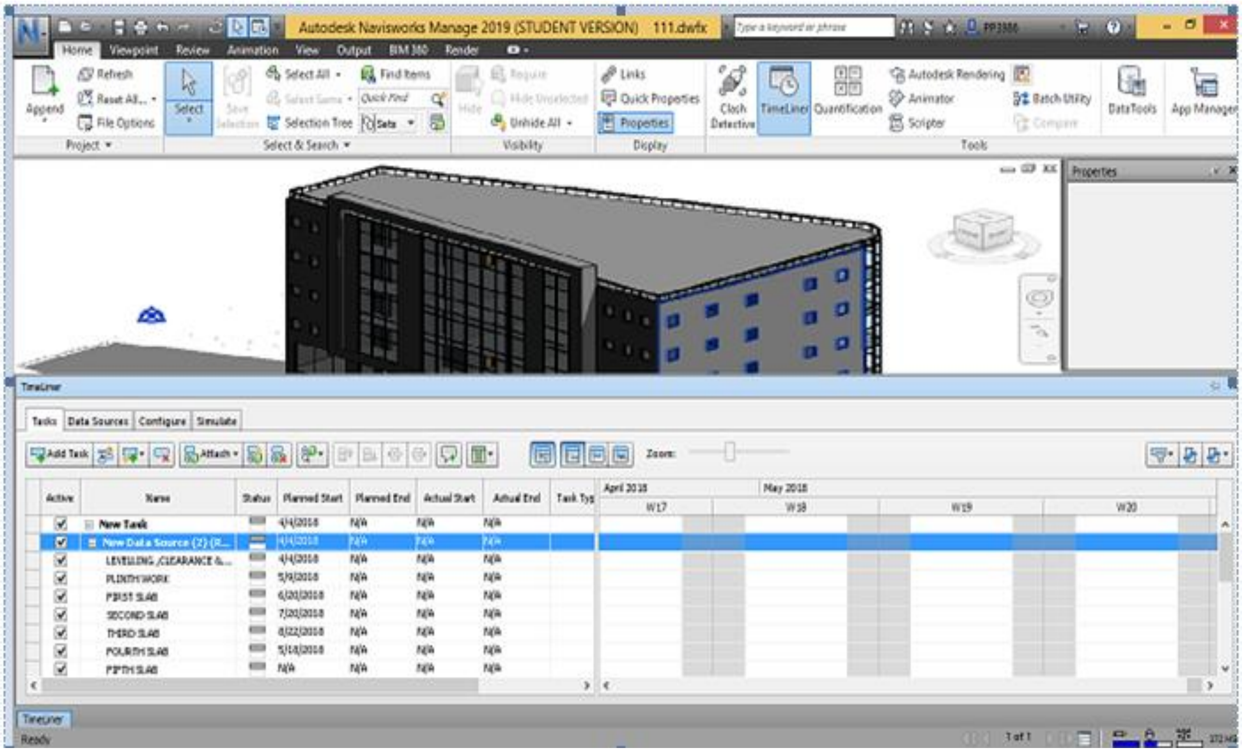

Figure 4. Naviswork Time liner

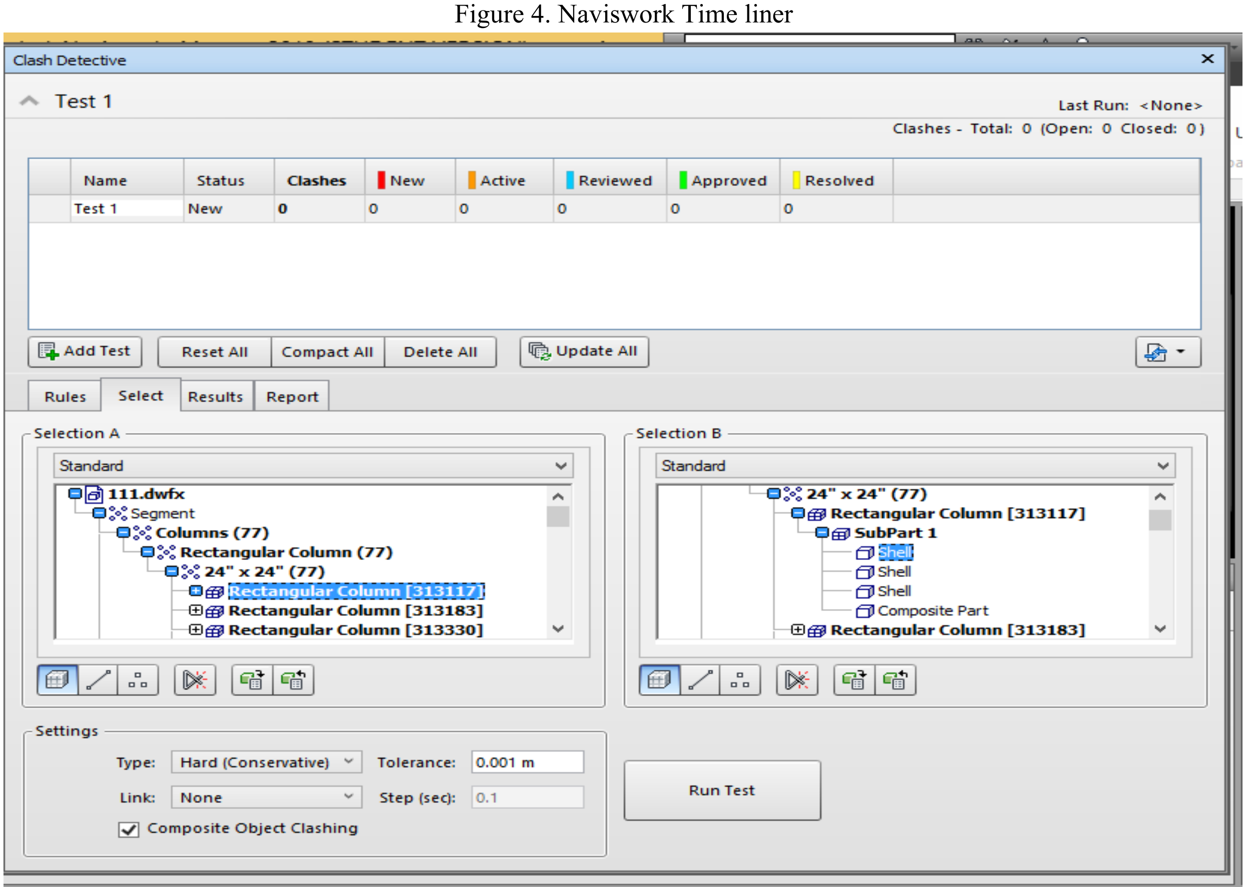

Figure 5. Navisworks clash detection

V. DATA ANALSYS

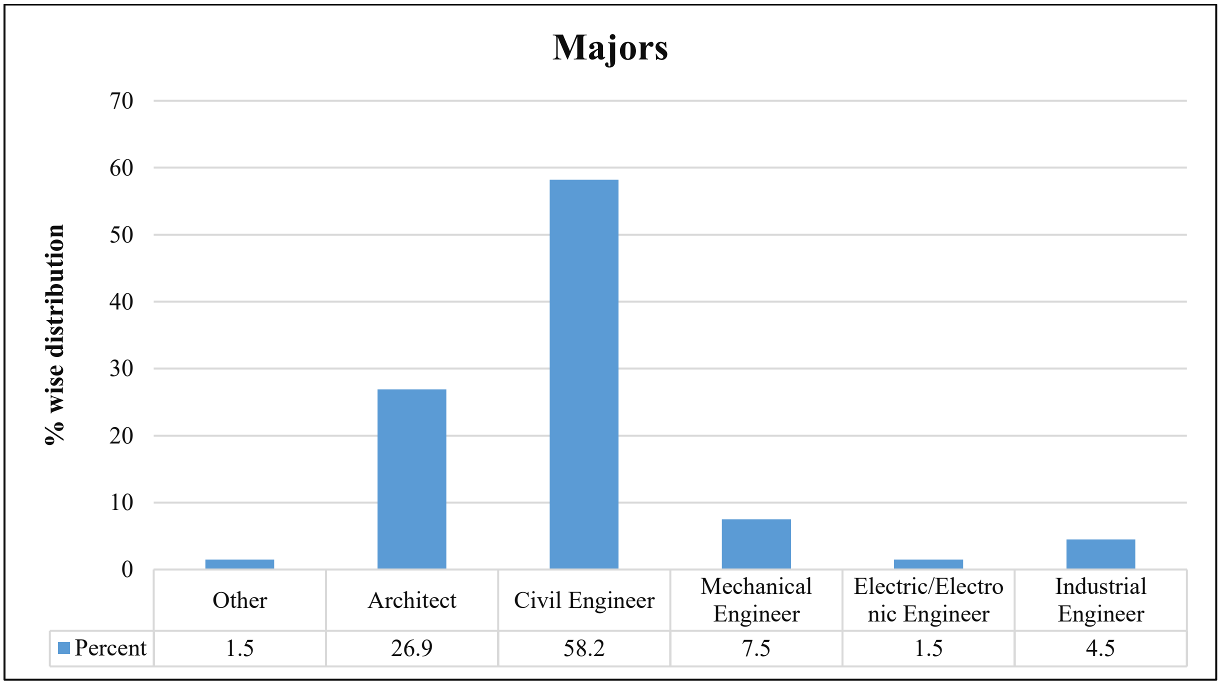

Figure 6. Majors

The data shows the distribution of majors among 67 respondents. The majority (58.2%) are Civil Engineers, followed by Architects (26.9%). Mechanical Engineers make up 7.5%, while Industrial Engineers account for 4.5%. A small percentage (1.5%) are either Electrical/Electronic Engineers or from other fields. This indicates a strong representation of Civil Engineering and Architecture in the sample, with fewer participants from other engineering disciplines.

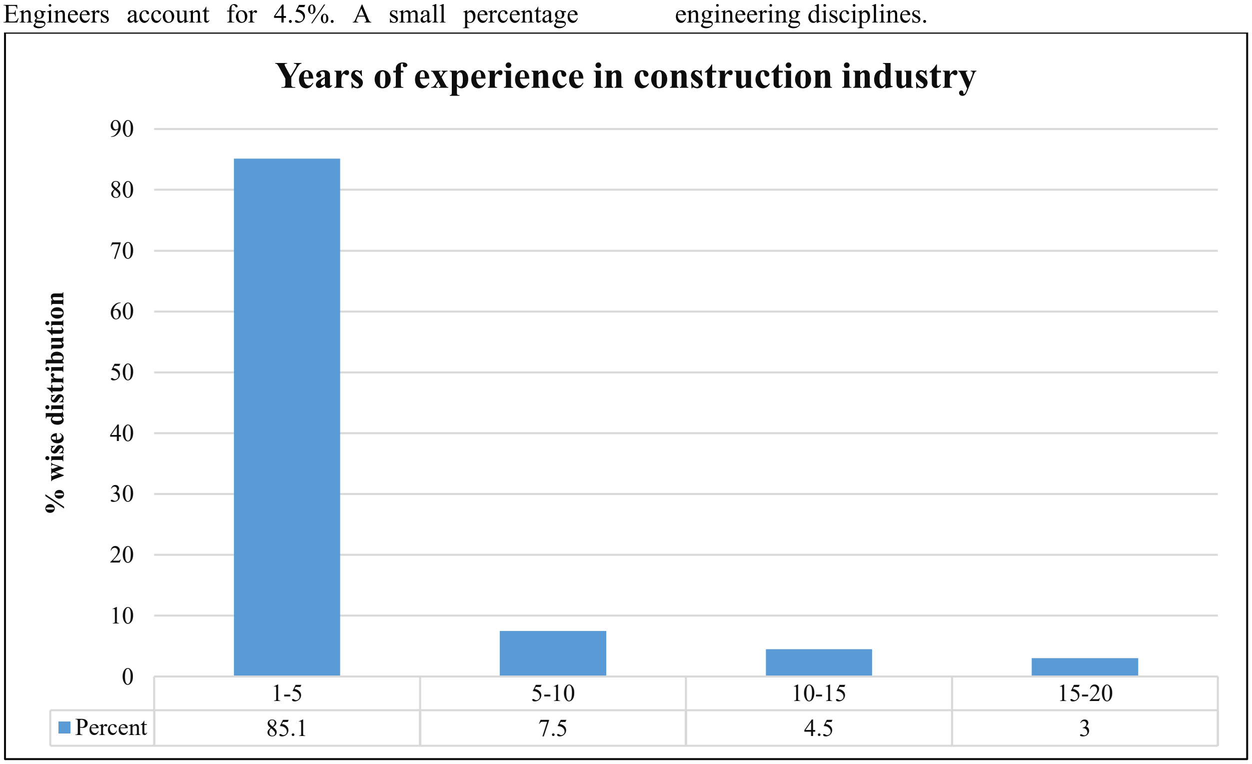

Figure 7. Years of experience in construction industry

The data reveals that the majority of respondents (85.1%) have between 1 to 5 years of experience in the construction sector, indicating that the sample primarily consists of professionals in the early stages of their careers. A smaller proportion, 7.5%, have between 5 to 10 years of experience, while only 4.5% have been in the industry for 10 to 15 years. Additionally, 3.0% of respondents have 15 to 20 years of experience, representing a minimal presence of highly seasoned professionals. These findings suggest that the construction sector workforce in this sample is predominantly composed of individuals with limited experience, with relatively fewer professionals having long-term tenure in the field.

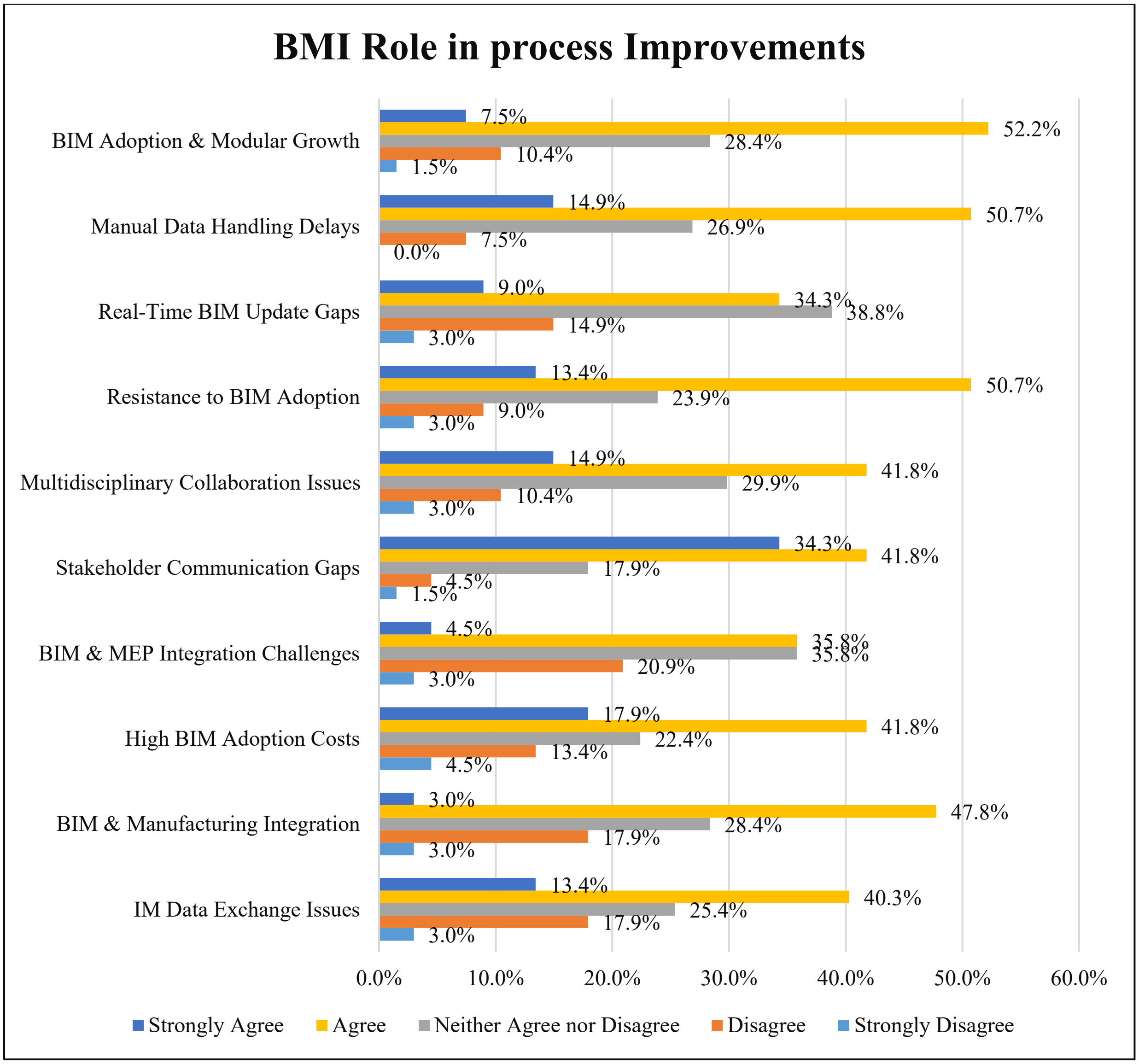

Figure 8. BMI Role in process Improvements

The analysis highlights key challenges in BIM adoption for modular construction, particularly in data exchange, integration, cost, communication, and collaboration. Interoperability issues between BIM platforms were a major concern, with 53.7% of respondents acknowledging difficulties in data exchange. Similarly, 50.8% reported challenges integrating BIM with modular manufacturing. High initial costs were also a significant barrier, with 41.8% agreeing, while 35.8% recognized difficulties in MEP integration. Communication issues emerged as a major challenge, with 76.1% citing poor stakeholder coordination. Resistance to new technology among traditional teams complicated BIM adoption (50.7%), while 56.7% noted collaboration challenges across disciplines. Additionally, 43.3% felt that the lack of

real-time updates hindered workflow efficiency, and 65.6% cited manual data handling as a bottleneck.
Overall, 59.7% of respondents highlighted inconsistent BIM adoption as a limitation to modular construction scalability. Addressing these barriers through streamlined processes, better collaboration, and enhanced technology integration is crucial for maximizing BIM's potential.

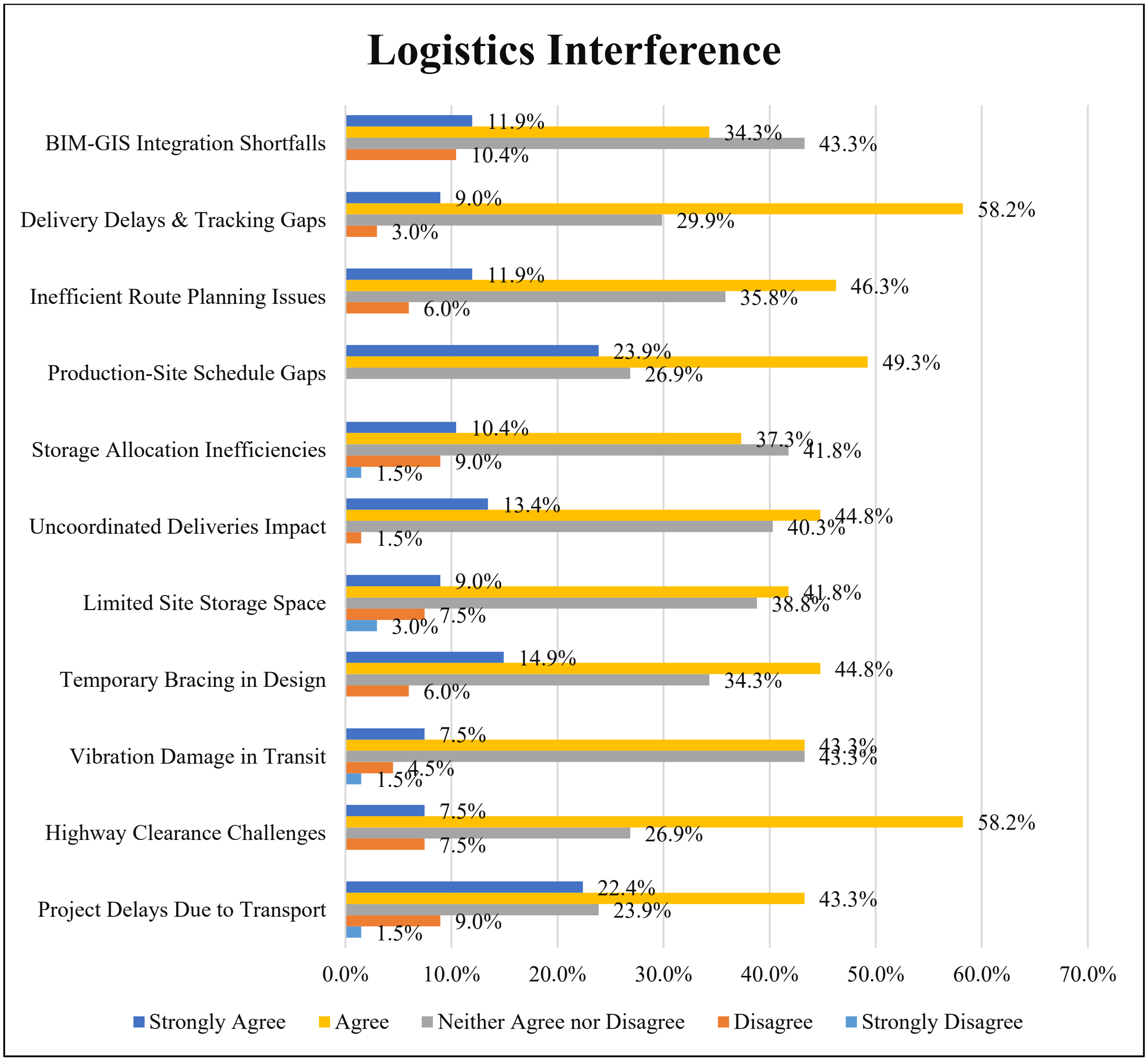

Figure 9. Logistics Interference

Graph shows precast construction component transport and management challenges.The replies show regular and occasional logistical challenges, underscoring large-scale operations' complexity. 43.3% and 22.4% strongly believe transportation interruptions might delay projects. Transport affects project timelines. According to 58.2% of respondents, highway clearances make transporting precast parts problematic, hence logistics planning should emphasize road infrastructure.Vibration damages 43.3% of precast modules during transportation. Prioritize shipping and handling to avoid damage. Another issue is temporary bracing during transport, with 59.7% agreeing or strongly agreeing that it should be included in the design scope, underlining the need to address transportation considerations early in project preparation. Other concerns include construction site storage and coordination. 41.8% say precast module storage is inadequate, and 44.8% think uncoordinated deliveries cause site-level logistical issues. Site management needs improvement as 37.3% think storage allocation is inefficient. 49.3% think factory-site scheduling missynchronization hinders projects. Route planning inefficiencies (46.3%) highlight the logistical challenge of delivering precast components on schedule and accurately. 58.2% say poor real-time tracking systems cause delivery scheduling issues Visibility and cooperation need current tracking techniques. Finally, 34.3% believe GIS and BIM for logistics tracking is inadequate, showing a need for technical alignment to enhance logistics operations. Construction's logistical issues and how planning, technology, and cooperation may boost efficiency are discussed.

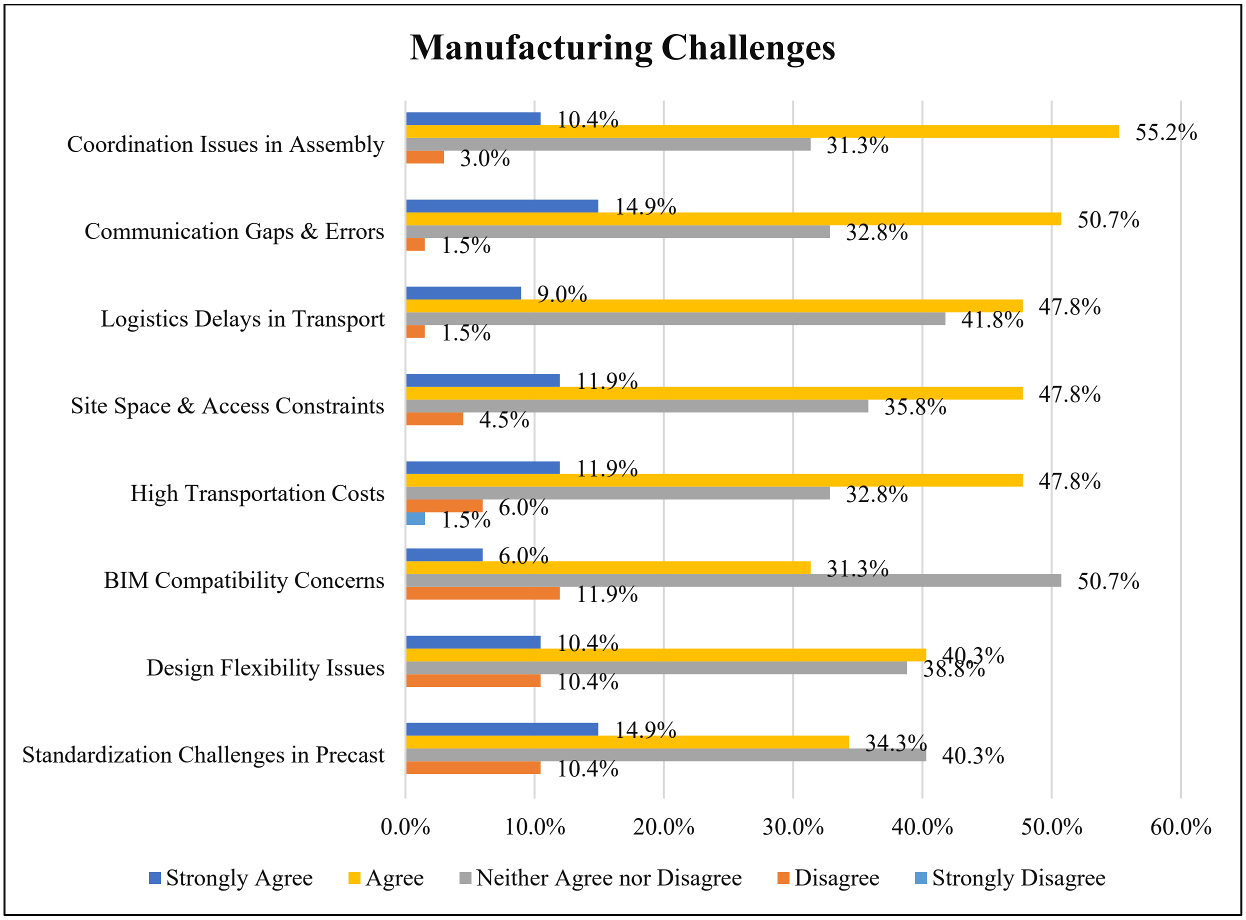

Figure 10. Manufacturing Challenges

The analysis of manufacturing challenges in precast concrete highlights key concerns, including standardization, design flexibility, BIM compatibility, transportation, and stakeholder coordination. 48.6% of respondents struggle with standardizing precast components, while 50.7% face challenges in design flexibility, limiting customization. 37.3% report difficulties integrating BIM tools, though 50.7% remain neutral, indicating room for improvement in BIM adoption. Transportation costs are a major concern for 59.7%, with 56.8% also citing logistical delays. Limited space at construction sites is a persistent issue for 59.7%, affecting material handling and installation. Coordination gaps between off-site manufacturing and on-site assembly create inefficiencies, with 65.6% agreeing on this challenge. Similarly, miscommunication between architects, engineers, and manufacturers leads to errors, affecting project execution.

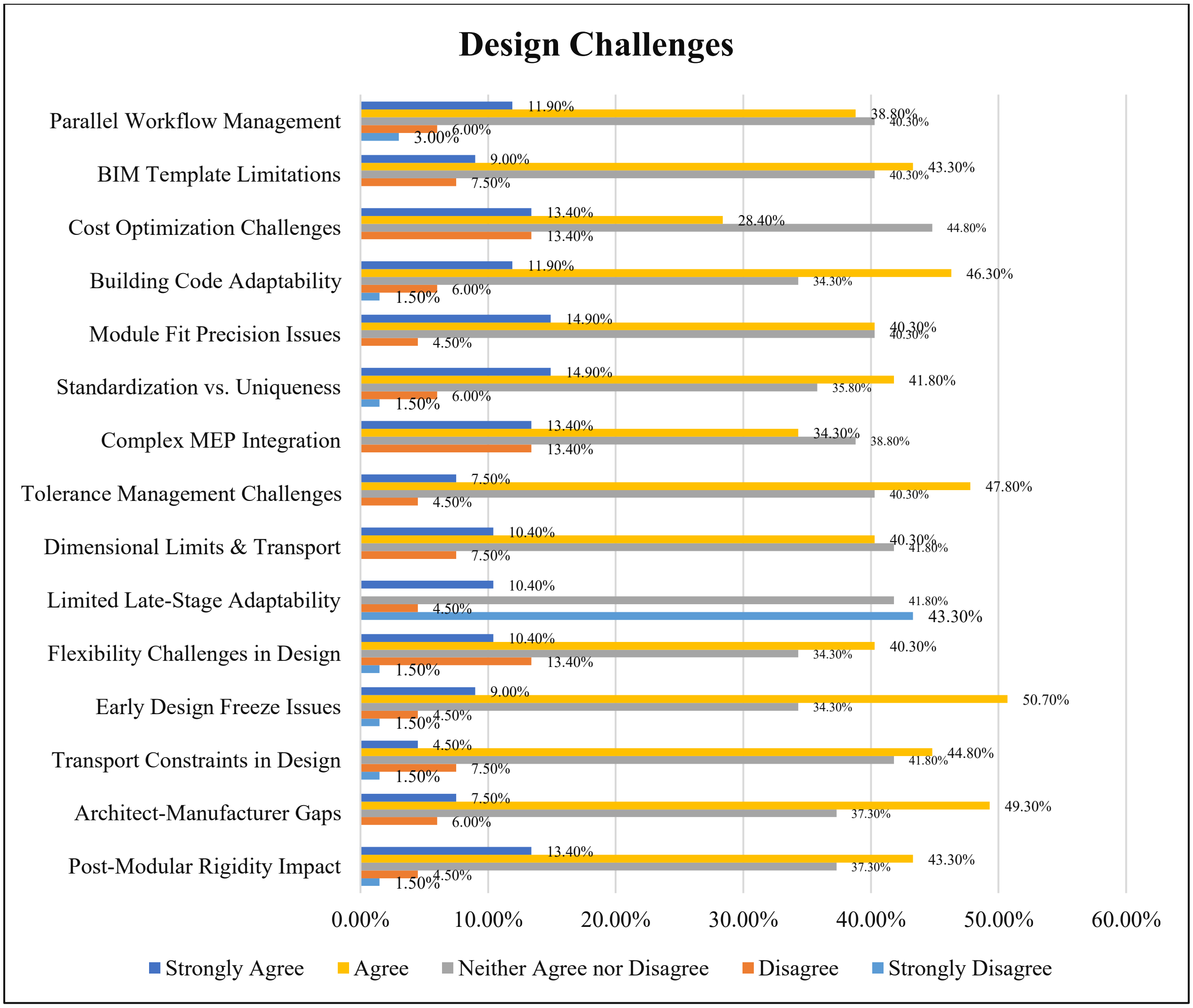

Figure 11. Design Challenges

The analysis highlights key design challenges in modular construction, particularly in coordination, flexibility, and technical integration. 56.7% of respondents report design rigidity post-modularization, while 59.7% identify the early design freeze as a major limitation to project adaptability. Additionally, 43.3% strongly disagree that modular designs accommodate late-stage client changes, reinforcing concerns about flexibility. Coordination gaps between architects and manufacturers are a persistent issue (56.8%), and 49.3% of respondents recognize structural constraints due to transportation. Managing tolerances in high-rise and seismic applications is a challenge for 55.3%, while 47.7% struggle with MEP system integration in modular designs. Conflicts between standardization and architectural uniqueness are also noted by 56.7%. Local building codes remain outdated for modular construction (58.2%), and parallel design-manufacturing workflows pose difficulties (50.7%). Cost optimization (41.8%) and the lack of BIM templates (52.3%) further complicate modular construction. Addressing these coordination and flexibility challenges is essential for improving modular construction efficiency.

VI.CONCLUSION

The study's conclusions demonstrate how BIM may revolutionize modular construction. Industry cooperation, cost reduction, and efficiency may all be greatly increased by incorporating digital processes.

The study emphasizes how important BIM is for maximizing prefabrication, simplifying logistics, and reducing typical project hazards. However, several challenges must be addressed to ensure the widespread adoption and success of BIM-driven modular construction. Interoperability between different BIM software platforms remains a pressing issue, as does the need for industry-wide standardization. Moreover, the high initial cost of BIM implementation continues to deter smaller firms from leveraging its full benefits. Training and capacity building are crucial for improving BIM adoption rates. The study recommends that industry stakeholders invest in structured training programs to enhance professionals' proficiency in BIM applications. Furthermore, policymakers should consider providing incentives for BIM adoption to encourage broader industry participation. From a project management perspective, BIM has demonstrated its effectiveness in minimizing delays and improving cost efficiency. The ability to create accurate 4D and 5D simulations allows for better planning, forecasting, and decision-making, which ultimately enhances project outcomes. The findings suggest that, with the right investment in training, standardization, and technological infrastructure, BIM can become a foundational tool in the evolution of modular construction. The long-term effects of BIM integration, especially in major infrastructure projects, should be the main focus of future studies. Furthermore, merging BIM with cutting-edge technologies like as AI and IoT has the potential to radically alter the construction business. In conclusion, while challenges persist, the benefits of BIM in modular construction far outweigh its drawbacks. The industry must now focus on overcoming barriers to adoption and fully leveraging BIM's potential to create more efficient, cost-effective, and sustainable construction solutions.

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