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A Comprehensive Review on Installation Process and Challenges in Modular Construction

Divyesh Solanki [1], Shreya Singh[2], Prof. (Dr.) J. R. Pitroda[3], Er. Mukesh Macwan[4]

[1]Final Year, M.Tech (Civil) Construction Engineering and Management, BVM Engineering College, Vallabh Vidyanagar – Gujarat – India, Email- sdivyesh283@gmail.com
[2]Final Year, M.Tech (Civil) Construction Technology and Management, Department of Civil Engineering, School of Technology & Engineering, Nirma University– Gujarat – India, Email- shreyaa81415@gmail.com
[3] Professor, PG Coordinator Construction Engineering and Management, Civil Engineering Department, BVM Engineering College, Vallabh Vidyanagar– Gujarat – India, Email- jayesh.pitroda@bvmengineering.ac.in
[4] Project Manager, Civil Engineer, Synnove Atmosphere Project, Vadodara – Gujarat – India, Email-atmosphereengineers2022@gmail.com

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Abstract- This review paper examines the installation process in modular buildings, focusing on the challenges faced during their implementation. The global building industry is increasingly interested in modular construction due to its potential benefits such as shorter construction times, better quality control, and lower costs. The paper aims to provide a comprehensive understanding of the installation process and its challenges, such as off-site manufacturing, shipping, and on-site assembly, and how these factors affect project success. Modular buildings are increasingly being used in various sectors, including household, business, healthcare, and education. The review provides case studies and examples of successful modular building projects worldwide. The review aims to help individuals develop efficient plans for modular building projects. In conclusion, the assembly process in modular buildings presents several issues that need to be addressed to ensure project success. By being aware of these issues and using the best methods, the building industry can expand the use of modular building techniques and enjoy the benefits associated with them. The review's findings will be beneficial to researchers, builders, and lawmakers.

Key Words: Construction techniques; Construction industry; Challenges; Installation process; Modular construction (MC)

1. INTRODUCTION

Modular construction (MC), also known as prefabrication or off-site construction, is a method of building structures by manufacturing components in a factory and then assembling them on-site. This approach allows for greater precision and control, resulting in a higher-quality finished product(The American Institute of Architects, 2019).

The COVID-19 pandemic in India has significantly influenced the adoption of MC in the healthcare sector. Hospitals and healthcare centers in India quickly adopted this model to set up alternate care facilities for mass emergency response. MC offers advantages such as versatility, flexibility, reduced material wastage, improved precision, and better hygiene management. Key experts emphasize that MC in healthcare facilities can lead to shorter construction times, cost-effectiveness, energy efficiency, and improved indoor environments for patients. The scalability of MC allows for flexible and adaptable floor plans, enabling facilities to expand or modify easily based on evolving needs. Overall, MC has proven to be a valuable solution for the healthcare industry in India during the COVID-19 pandemic and beyond, offering efficient, cost-effective, and sustainable building options for healthcare infrastructure (Rani et al., 2022).

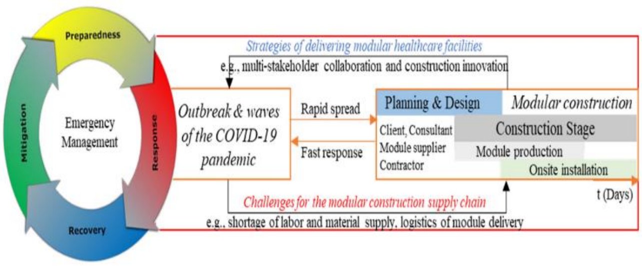

Figure-1: COVED-19 pandemic Emergency Management (Rani et al., 2022)

Building module manufacturing varies among manufacturers, with some employing a linear production process and others using a static process. Project teams must understand the specific methodology of the manufacturer they choose to work with (The American Institute of Architects, 2019).

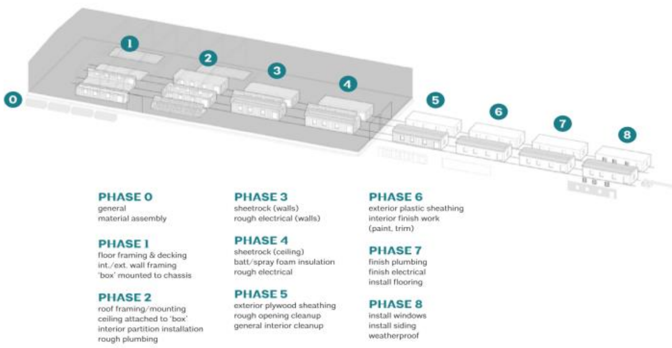

Figure-2: Different Phase of MC Manufacturing (The American Institute of Architects, 2019)

2. Scope of Study and Aims and Objectives

2.1 Scope of Study

Conduct a market analysis to identify trends, growth opportunities, key players, and market dynamics related to MC. Include case studies of successful MC projects to showcase best practices, lessons learned, and real-world examples of implementation. Explore the latest technologies, innovations, and advancements in MC that are shaping the industry. Provide insights into the future outlook of MC in the construction industry, including potential growth areas, challenges, and opportunities for innovation.

2.2 Aims and Objectives

Following are the objectives of conducting this study.

1. To examine the current trends and practices related to the installation of MC in the construction industry.
2. To identify the benefits and challenges associated with the installation of MC compared to traditional construction methods.
3. To explore the technological advancements and innovations in MC that are influencing installation processes.
4. To assess the future outlook of MC installation in the construction industry and potential growth areas for innovation and development.

Concrete is now everywhere used in construction industry that is prone to cracking and damage due to various environmental factors, such as temperature fluctuations, humidity, and chemical attacks. Traditional repair methods can be time-consuming, costly, and may not fully enough for the structural designing of the concrete. To overcome this issue, researchers have been exploring the concept of SHC, which incorporates bacteria that can repair cracks and damages autonomously (Rajczakowska et al., 2019).

3. Different types of MC

3.1 Panelized Construction(Egege, 2018)

Figure-3: Panelized MC

In panelized construction, building components such as walls, floors, and roofs are prefabricated in panels off-site and then transported to the construction site for assembly. Panelized construction allows for faster installation and can help reduce on-site labor costs.

3.2 Volumetric Construction(The American Institute of Architects, 2019)

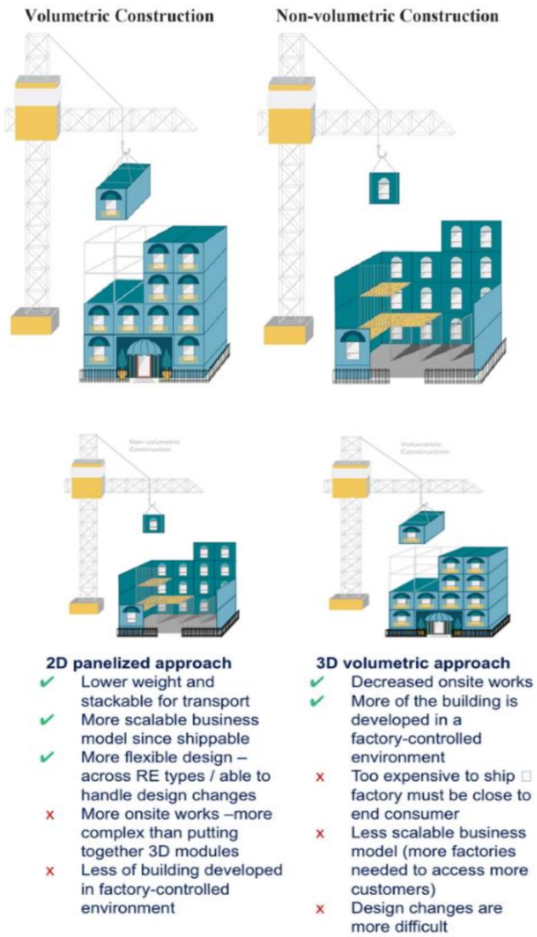

Figure-4: 2D Panelized Approach, 3D Volumetric Approach

Volumetric construction involves the prefabrication of entire modules or "volumetric units" off-site, including complete rooms or sections of buildings. These modules are then transported to the site and assembled into the final structure. Volumetric construction is known for its speed and efficiency in installation.

3.3 Hybrid Construction(Di Pasquale et al., 2020)


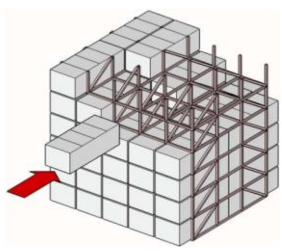

Figure-5: Hybrid MC , Figure 6. 3D view of Hybrid MC

Hybrid construction combines traditional on-site construction methods with pre-fabricated modular components. This approach allows for greater flexibility in design and customization while still benefiting from the speed and efficiency of MC.

3.4 Bathroom Pods

Figure-7: Bathroom Modular Pods

Bathroom pods are prefabricated units that contain all the necessary fixtures and fittings for a bathroom, including plumbing, electrical, and finishes. Bathroom pods are commonly used in hotels, student housing, and other multi-unit residential projects to streamline installation and improve quality control.

3.5 Pre-fabricated Facades (Egege, 2018)(Chourasia et al., 2023)

Figure-8: Pre-fabricated Facades Modular Structure

Prefabricated facades are modular components that make up the exterior envelope of a building, including cladding, windows, and insulation. Prefab facades can be manufactured off-site and installed quickly, helping to accelerate the construction schedule and improve energy efficiency. This is the most common type of MC, where individual modules or sections are built in a factory and then transported to the site for assembly. These modules can be single or multi-story and can be used for residential, commercial, or industrial purposes.

3.6 Modular Roofing Systems (Egege, 2018)

Figure-9: Modular Roofing System

Modular roofing systems consist of prefabricated roof components that are assembled on-site to create a complete roofing system. These systems can help reduce installation time, improve weather resistance, and enhance energy performance.

3.7 Modular MEP Systems

Figure-10: Modular MEP Systems

Modular mechanical, electrical, and plumbing (MEP) systems involve the prefabrication of building services components such as HVAC units, electrical panels, and plumbing fixtures off-site. Modular MEP systems can be installed more efficiently than traditional on-site installations, reducing project timelines and costs.

3.8 Modular Steel Construction

Figure-11: Modular Steel Construction

In this method, Steel is a popular material for MC due to its durability, fire resistance, and ability to create larger spaces. It is also a recyclable material, making it reusable after the building is no longer needed. Prefabricated steel structures have tight fittings, leak-free doors, and windows, making them ideal for heat insulation and air conditioning. This method reduces utility bills, costs, and time, making it a cost-effective and efficient choice for construction.

4. Application, Benefits of MC and Comparison Between Traditional Construction Method vs MC Method

Table-1: Application of Modular Construction

1. Container-Based Modular Construction 	2. Modular Housing 
3. Modular Education Building 	4. Modular Healthcare Facilities 
5. Modular Industrial Buildings 	6. Modular Commercial Building 
7. Multi-Story Buildings 	8. Interim Offices and Administrative Building 

4.1. Benefits of MC:

1. MC leads to a significantly reduced construction time compared to traditional on-site construction methods.
2. In MC takes place in a factory setting, the quality of materials and workmanship can be better controlled and monitored. This results in fewer defects and a more durable final product.
3. Modular buildings are often designed with energy efficiency in mind, incorporating features like better insulation, energy-efficient HVAC systems, and advanced lighting systems.
4. MC generates less waste and pollution compared to traditional construction methods.
5. Modular buildings can be easily expanded, reconfigured, or relocated as needs change.
6. MC takes place in a controlled indoor environment, which reduces the risk of accidents and injuries associated with traditional on-site construction.
7. In MC building components can be designed and built according to specific requirements and preferences.
8. MC is less susceptible to weather delays and labor shortages, project timelines can be more accurately predicted and maintained.
9. Modular buildings often come with reduced noise and dust during construction, leading to a more pleasant experience for nearby residents or businesses.

Table-2: Comparison Between Traditional Construction Method vs MC Method

Key Points	Traditional Construction	Modular Construction Method
Speed and Time Savings	Traditional construction is more linear, with steps completed sequentially, and is subject to delays from weather and other factors.	Modular construction can be up to 50% faster than traditional methods, as the building is constructed simultaneously off-site while the foundation is prepared on-site. This allows for quicker occupancy.
Cost Predictability	Traditional construction costs are less predictable, with change orders and damaged materials being common issues that increase costs.	Modular construction costs are more predictable, as standardized processes allow for quality control and fewer unexpected changes or material losses.
Sustainability and Efficiency	Traditional construction sustainability varies based on the contractor and materials used, but the large volume of construction waste is a growing problem.	Modular construction is more sustainable, with fewer material deliveries, less transportation, reduced waste, and better control of materials and processes in a factory setting.
Design Flexibility	Traditional construction provides greater design flexibility and ability to adapt to site conditions.	Modular construction may limit some architectural design choices, but allows for customization of layout, appearance and operations.

5. Installation Process of MC:

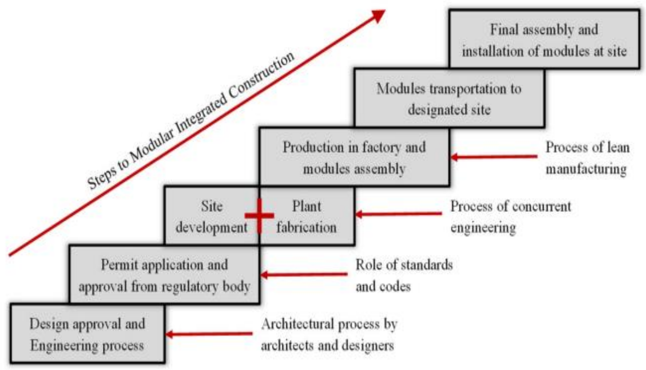

Figure -12: Modular Installation Process(A. Khan et al., 2022)

The MC process involves four stages: design development, assembly in a factory, transportation to the project site, and erection of units. The process begins with comprehensive planning and design, where architects and engineers collaborate to create detailed blueprints. Skilled workers in a controlled environment construct the modules, ensuring high-quality and consistent results. Once ready, they are carefully transported to the construction site for assembly, where precision is required to create the final structure. This process requires expertise and strict quality control measures to ensure seamless integration, meeting safety and building code standards (Sri Velamati, 2012).

5.1. Design approval by the regulating authorities and end users

Using BIM systems, architects and engineers draft exterior and interior plans to start the modular building process. These

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plans are approved and then submitted for building permit applications to the local government or outside services. After the design is complete, component manufacturing starts (Chi et al., 2015)(Hough & Lawson, 2019).

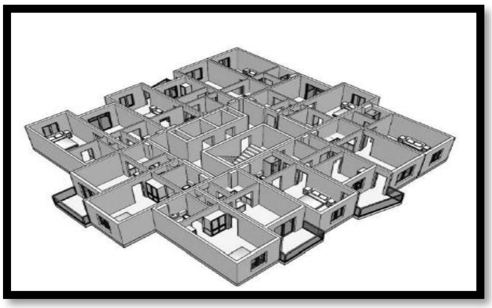

Figure-13: BIM Design Modular Structure (Hough & Lawson, 2019)

5.2. Factory

Figure-14: Modular Assembly Line in Factory (Sri Velamati, 2012), Steel Frame installed(Sri Velamati, 2012), Wood Frame Installation(Sri Velamati, 2012)

The process of production in a factory and modules assembly involves several steps to convert raw materials into finished products. Here is a brief description of the typical production process: (Sri Velamati, 2012).

Table-3: Process of Production in a factory and modules assembly

No.	Process	Description
1.	Planning	This stage involves determining the production requirements, including the quantity of products to be produced, the materials needed, and the schedule for production.
2.	Sourcing raw materials	Raw materials such as metal, plastic, electronic components, etc., are sourced from suppliers and brought to the factory for processing.
3.	Manufacturing	The raw materials are then processed and assembled into modules or sub-assemblies according to the product design. This may involve cutting, shaping, welding, molding, and other manufacturing processes.
4.	Quality control	Throughout the manufacturing process, quality control checks are carried out to ensure that the products meet the required standards and specifications.
5.	Assembly	Once the modules are produced, they are assembled together to form the final product. This may involve integrating electronic components, connecting parts, and testing the functionality of the product.
6.	Packaging	The finished products are then packaged and prepared for shipment to customers or distributors.

5.3. Transportation and installation

Figure-15: Transportation Modular Component(Sri Velamati, 2012)

Modular building modules are shipped over highways due to road size and load restrictions. The approval process is complex and often involves dealing with multiple government agencies. Issues include potential delays due to oversized loads, customs issues along the Canadian border, and dimensional restrictions on the modules being transported. The transportation of modules depends on factors such as cost, method of transport, travel distance, and weight. The maximum width, height, and length of individual modules depend on local Department of Transportation restrictions, bridges, overpasses, utility lines, and the actual route from the factory to the final destination(Sri Velamati, 2012)(Meehleis, 2009).

5.4. On-site Erection of modules to form a finished building

Figure-16: On-Site Erection and Installation of MC (Sri Velamati, 2012)

When the modules are prepared, they are transported to the location and assembled. The matte finish line connections for MEP, exterior finishes, and interior finishes are included in module installation, where applicable (Sri Velamati, 2012).

At the jobsite, tasks include bolting and stacking modules together, connecting them, weatherproofing them, installing exterior siding and roofing, and completing site work. The last phase entails installing stairs and elevators, caulking, sealing, and competing interior features like painting, trim, cabinets, countertops, and the installation of appliances that weren't included in the factory (Sri Velamati, 2012)(Meehleis, 2009).

5.5. Quality control and Safety in MC During Installation Process

Quality control during the MC installation process involves creating quality control checklists, stress testing modules before shipping, performing pre-installation quality checks, using qualified equipment operators, and implementing a formal Quality Audit Plan with Factory Accepted Testing (FAT) where possible(Chi et al., 2015).

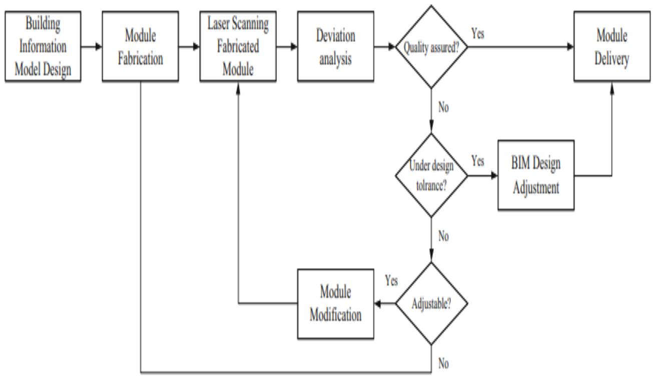

Figure-17: Quality-Assured Fabrication Process for Identifying Modular Inconsistency among Design and Implementation Stages (BIM)(Chi et al., 2015)

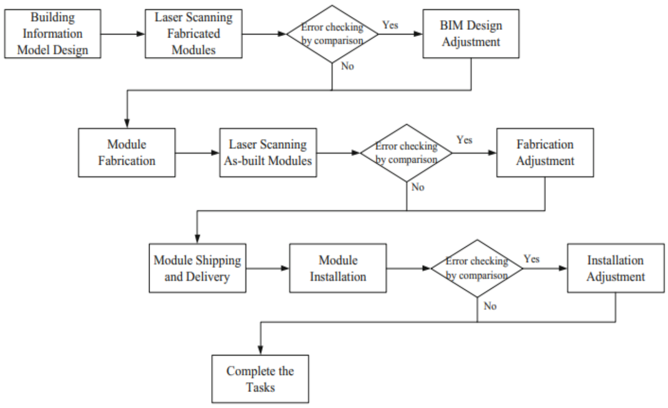

Figure-18: Recursively Quality Control Processes for MC (BIM) (Chi et al., 2015)

Safety in MC during the installation process is crucial due to unique risks like falls, defects, and transportation hazards. It's vital to focus on intensive safety management during unit installations, ensuring personal safety equipment and stable workspaces. Preplanning installation processes, securing loads during transportation, and stabilizing temporary connections are key safety measures. Addressing manufacturing hazards, managing crane operations, rigging, and ensuring proper site clearance during component movement are essential for safe MC (Jeong et al., 2022).

Safety in MC during the installation process is crucial to prevent accidents and ensure the well-being of workers. Here are some key safety measures that should be implemented(Jeong et al., 2022):

Table-4: Safety in MC during the installation process

No.	Safety measures	Description
1.	Adequate training	Ensure that all workers involved in the installation process are properly trained in modular construction techniques and safety procedures.
2.	Personal protective equipment (PPE)	Require all workers to wear appropriate PPE, such as hard hats, gloves, safety glasses, and steel-toed boots.
3.	Fall protection	Install guardrails, safety nets, or personal fall arrest systems to prevent falls from elevated surfaces.
4.	Secure transportation	Ensure that modules are securely transported to the construction site and lifted into place using proper equipment and techniques.
5.	Communication	Maintain clear communication between workers during the installation process to prevent accidents caused by miscommunication.
6.	Site organization	Keep the work area clean and organized to prevent tripping hazards and other safety risks.
7.	Regular inspections	Conduct regular inspections of the construction site and equipment to identify and address potential safety hazards.
8.	Emergency response plan	Develop an emergency response plan that outlines procedures for dealing with accidents or injuries that may occur during the installation process.

By implementing these safety measures, MC companies can create a safe work environment for their workers and minimize the risk of accidents during the installation process.

6. Challenges and Limitations

MC faces challenges like logistical issues, labor shortages, design constraints, initial capital costs, communication hurdles, and regulatory complexities. These challenges can impact project efficiency, safety, and cost-effectiveness. Despite these obstacles, MC offers benefits such as improved safety, design flexibility, and time savings, making it a promising solution for various construction needs.

6.1. Financing and investment(Ready, 2023)

Financing and investment challenges in MC include high initial capital costs for specialized factories and equipment, increased project costs due to logistical challenges and labor shortages, and communication issues among stakeholders. Regulatory complexities, such as compliance with building codes and inspections, can also lead to project delays and increased costs. Despite these challenges, MC offers benefits like improved safety, design flexibility, and time savings, making it a promising solution for various construction needs.

6.2. Limited design flexibility(Ready, 2023)

MC, while offering numerous benefits such as speed, efficiency, quality control, cost savings, and sustainability, also presents certain challenges and limitations. These include design limitations due to the need for a design that can be divided into discrete modules, logistical challenges in transporting large modules to the construction site, the need for proper site preparation, coordination and planning between the factory and the construction site, strict adherence to quality standards in the factory, compliance with specific building codes, permitting requirements, and zoning regulations, and a significant initial investment for setting up a MC facility. Additionally, MC may have limited design flexibility and customization options due to the use of standardized modules, and there may be increased transportation costs and emissions associated with transporting large modules. Overcoming these challenges requires careful planning, coordination, and management of the entire supply chain, as well as the adoption of a collaborative and integrated approach involving various stakeholders such as architects, engineers, contractors and regulators.

6.3. Regulatory and legal aspects(Sri Velamati, 2012)

MC offers numerous benefits, including improved safety, flexibility, enhanced mobility, and cost savings. However, it also faces regulatory and legal challenges. The lack of proper design codes and standards in different countries can increase risks, as implementing a novel approach without regulatory guidance can result in problems. A research study identified 'High initial investment' as one of the top five risks influencing MC cost and schedule performance (Sri Velamati, 2012).

Regulatory and legal issues can create difficulties in obtaining permits, approvals, and certifications for MC projects, and may lead to legal uncertainties regarding ownership, liability, and warranty of modules and final buildings. In the UK, for example, there is a lack of clarity on whether the modules are considered as goods or buildings, and who is responsible for their defects or damages (Sri Velamati, 2012).

6.4. Public perception and acceptance

Public perception and acceptance challenges and limitations in MC are influenced by misconceptions. Some believe MC is low-quality, limiting design options, and cheaper. Overcoming these perceptions involves showcasing sustainability, aesthetics, and high-end designs. Educating the public on the benefits, like shorter schedules and superior quality, can shift perceptions positively.

7. Role of Technology:

7.1. Advancements in materials and construction techniques(Zhang et al., 2023)

MC has significantly improved with the development of technologies like Building Information Modeling (BIM), 3D printing, and robotics. These advancements enable better project management, precision in fabrication, and application to complex projects. MC can reduce construction time and waste, improve quality control, and enhance structural integrity. However, challenges remain, such as low automation and robotic usage in module fabrication and assembly. Increasing automation and robotic usage can improve productivity and the effective use of modularization. Advanced construction techniques, such as prefabrication, 3D printing, green building practices, advanced materials, BIM, drones, and UAVs, offer a pathway to greater efficiency, sustainability, and competitiveness in a rapidly changing world (Meehleis, 2009) (Zhang et al., 2023).

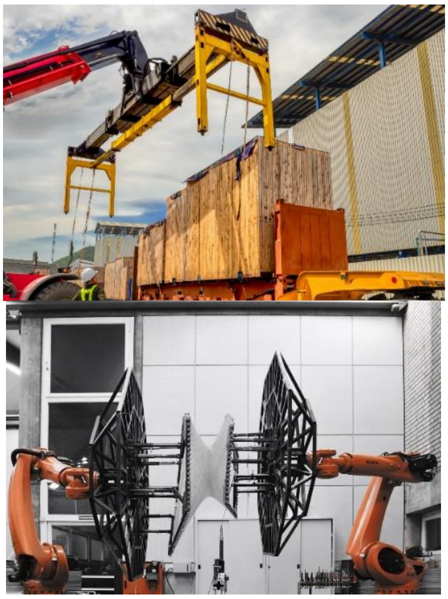

Figure-19: Robotic and Automation used in MC Sector

7.2. Integration of digital tools and automation(Lee & Lee, 2021)

Digital tools and automation are revolutionizing modular construction, offering faster, more efficient, and sustainable building processes. These technologies improve precision manufacturing, quality control, cost savings, and sustainability by reducing waste and energy consumption. However, challenges such as limited design flexibility and initial investment in digital technologies need careful consideration. Despite these, the integration of digital tools and automation in MC holds immense potential for a more sustainable built environment. Building Information Modeling (BIM) enhances design precision and planning, while automation, including robotics, improves construction speed, quality, and safety. These advancements enable faster project completion, cost savings, and sustainability through efficient resource management and reduced waste. Overall, technology in MC drives efficiency, quality, and sustainability in building processes.

7.3. Remote monitoring and control systems(Lee & Lee, 2021)

Remote monitoring and control systems in MC involve innovative technologies like IoT and cloud connectivity. These systems, as seen in research and industry solutions, enable real-time data collection, sensor integration, and energy management in smart buildings. They enhance building efficiency, occupant comfort, and safety by monitoring indoor conditions, energy consumption, and even user behavior. Such systems utilize smart controllers, IoT communication, and sensor data to optimize operations, reduce energy costs, and ensure sustainable building performance. Overall, remote monitoring and control play a crucial role in modern MC for efficient building management and risk mitigation(Lee & Lee, 2021).

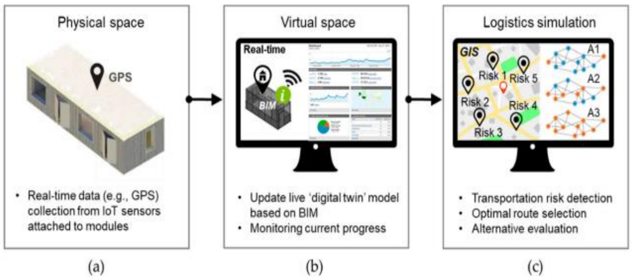

Figure-20: Digital twin framework for real-time logistics simulation in MC (a) Data collection; (b) Virtual asset update (c) What-if analysis ;(Remote monitoring and control systems) (Lee & Lee, 2021)

8. Critical Literature Review

`**(X. Zhang & Qian, 2020)** study explores the use of microbial SHC in ship lock engineering. They developed self-healing agents containing microbial spores and calcium sources, which were tested in a spray drying method. The concrete, applied to the ship lock side wall, showed complete crack healing after 60 days. The study also introduced a commercial SHC production system for mass production.

(Meehleis, 2009) explore the challenges faced by MC delivery methods face numerous challenges, including design, pre-construction, fabrication, shipping, and assembly onsite. These obstacles often discourage adoption. To understand the modular sector, qualitative interviews with experienced builders were conducted. Familiarity with the modular sector is crucial for all aspects of project delivery, including design, pre-construction, fabrication, inspection, structural engineering, and shipping or placing problems. Approaching challenges with confidence and careful calculation is necessary for success in the construction industry, particularly modular delivery. Successful modular companies, like Meehleis Modular, act as General Contractors (GCs) for most projects, allowing them to control all aspects and deal directly with the owner. To stay alive, companies must adapt to technology such as robotics, plasma cutters, and 3D-printers.

(Boyd et al., 2013) to finding the increasing population in major Australian cities is leading to a housing shortage, which can be addressed by adopting factory-based or off-site-constructed (OSC) multi-story apartment buildings. The adoption of OSC by Unitized Building (UB) has led to significant advances in project delivery and is expected to be sustainable. However, for OSC to be successfully adopted in residential construction, the industry and stakeholders must accept the change and understand its benefits. These concerns may become more significant than time and money as the world grows greener, and their benefits should be recognized when thinking about off-site products rather than conventional building techniques.

The study by **(Jellen & Memari, 2018)** explores factors affecting the feasibility of modular vertical expansion in residential construction projects. It suggests using a coarse finite-element modeling approach to identify these factors and generalize them to other modular applications. Professionals can use resources from the Construction Industry Institute (CII) to help with front-end planning tasks and the application of cutting-edge technologies like virtual design and construction (VDC) and Building Information Modeling (BIM).

The study by **(Kayastha, 2019)** explores the MC technique in Nepal, focusing on its opportunities and challenges. It identifies five main opportunities: reduced construction time, improved productivity, and reduced rework; challenges include competition with traditional methods, lack of information, and skilled workers. The findings aim to help stakeholders understand these opportunities and challenges, leading to solutions and wider adaptation in developing countries like Nepal. The study also aims to familiarize people with MC.

The UK construction industry has seen an increase in housing demand and concerns over performance, but traditional offsite technologies are often resisted. A study by **(Young et al., 2020)** discovered that when compared to conventional methods, MC offers better quality, significant cost savings, enhanced health and safety, and higher end-user satisfaction. The authors forecast that rising awareness, better design, and shifting client perceptions will make modular home construction the new standard in home building. Poor perception, transportation issues, a lack of coordination, information, regulatory guidance, industry awareness, and a shortage of skilled workers are some of the barriers.

(Di Pasquale et al., 2020) suggest hybrid modular architecture with permanent structural systems and detachable living systems. This concept provides dynamic and adaptable housing for the global professional working class's expanding mobility needs. The article recommends random module interchangeability and rapid plug-in and plug-out structural connections between the host structure and dwelling modules for hybrid modular buildings. This simplifies detachable module installation, disconnection, and relocation. The hybrid MC system optimizes housing services throughout the building's lifecycle, making modifications, retrofits, and module replacements straightforward.

(Lee & Lee, 2021) MC used a digital twin architecture to replicate real-time logistics. A virtual copy of the actual module, the digital twin refreshes its asset using BIM and IoT sensors. The virtual asset is then transported to a GIS-based logistics simulation routing program. In a case study, the methodology identified logistical risks and accurately predicted module delivery times. This may improve supply chain collaboration, cut costs and timetables, and increase sector MC usage.

Using a game engine-based digital platform, **(Ezzeddine & Soto, 2021)** improved MC project management and communication, notably with PPVC construction. The software lets design, manufacturing, transportation, and construction teams visualize projects and examine BIM data. A virtual factory, discrete-event simulation model, 3D city maps, and module alignment on-site assembly process are included. The platform might improve cooperation, according to industrial and construction specialists. Integration of factory and site schedules, automation of manual activities, and optimization of factory architecture, production, assembly sequences, transportation, and logistics need further study.

(Jeong et al., 2022) examines US MC accident cases from 2000 to 2018 and compares safety risk elements to general structures. The study identifies significant MC accident causes and kinds, enhancing safety management and decision-making. The report advises collecting additional accident cases to investigate causes and construct safety management measures, identifying accident variables, estimating probabilities, and implementing MC project accident prevention techniques.

A thorough literature study by **(A. A. Khan et al., 2023)** discovered 31 major risk variables in the Volumetric MC building sector during the COVID-19 pandemic. These risks were divided into design and planning, offshore manufacturing, transportation and logistics, and onsite assembly. The report advised using circular solutions based on emerging and disruptive technologies to mitigate digital technology's consequences. However, its universality of risk variables versus geographical sensitivity and lack of empirical data are drawbacks.

(Chourasia et al., 2023) highlight the lack of design principles, joint connections, and experimental outcomes in prefabricated volumetric modular component systems (PVMC) compared to conventional construction methods. They want to offer structural designers and engineers’ confidence to recreate PVMC using standard building techniques despite its numerous benefits.

8.1. Major Finding from Literature Review

The outcomes of literature Review for the installation of MC used in the construction industry include various benefits and challenges. Here are some key points based on the provided sources:

- Benefits

1. It can accelerate project timelines by 20 to 50% and reduce costs by up to 20%.
2. MC allows for monitoring and controlling quality, ensuring projects meet requirements.
3. Provides a way to ensure high interior completion levels, improving building quality.
4. Modular buildings are sustainable, reducing waste and promoting environmental friendliness.
5. They can be expanded, changed, disassembled, or moved to accommodate changing needs, reducing the need for raw materials.

- Challenges:
    1. MC limits design choices as building modules are prefabricated in factories, focusing on safe transportation and assembly.
    2. Initial material and labor costs for MC can be higher, making it necessary for project owners to be prepared for increased upfront expenses.
    3. Traditional construction experts may be hesitant to adopt MC due to unfamiliarity with the process.

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In conclusion, the outcomes of installing MC in the construction industry offer significant advantages in terms of cost savings, quality control, flexibility, and sustainability. However, challenges such as design restrictions, upfront costs, and resistance to adopting new technology need to be addressed for wider adoption and success in the industry.

9. Case study

9.1 Case Study -1 (Factory Shed Site)

Name of Client: - M.D Motors Factory Shed Site Address: - Western Carbon and Chemicals, Sakarda, Vadodara, Gujarat
Consultancy Name: - Vishvakarma Consultancy Services Pvt. Ltd
Site Types: - M.D Motors Factory Shed, Industrial prefabricating Construction Work

Figure-21: Industrial Factory Shed Transportation, Erection and Installation

Vishvakarma Consultancy Services Pvt. Ltd Construction Company was tasked with installing a new industrial shed for a manufacturing plant within a tight timeframe. The client required a large, durable structure that could accommodate their production needs while adhering to strict budget constraints. To meet these requirements, Vishvakarma Consultancy Construction decided to utilize MC methods for the project.

The first step in the process was to design the industrial shed using modular components that could be prefabricated off-site. This approach allowed for greater precision in construction and reduced the risk of errors during installation. The modular components were manufactured in a controlled factory environment, ensuring consistent quality and minimizing waste.

Once the modular components were ready, the installation process began on-site. The MC approach also allowed for greater flexibility in design, enabling Vishvakarma Consultancy Construction to customize the facility to meet the client's specific requirements.

Vishvakarma Consultancy Construction Company successfully completed a high-quality industrial shed on time and within budget, showcasing the efficiency and cost-effectiveness of MC. The company's innovative approach to shed installation, which involved prefabricating components off-site and assembling them on-site, saved time and reduced costs, resulting in high-quality facilities. This project exemplifies the potential of MC in the construction industry, highlighting its advantages for industrial applications and its potential to revolutionize the industry.

9.2 Case Study-2 (Office and Class Room Construction Work)

Name of Client: Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar
Consultancy Name: - Jay Maharaj Consultancy Pvt. Ltd
Site Types: - Panelized MC

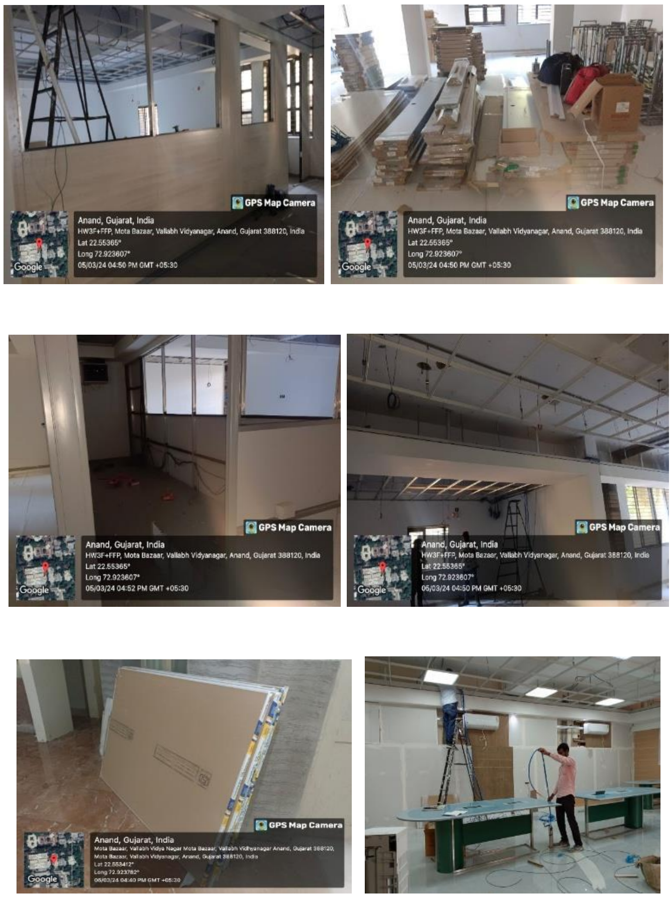

Figure-22: Panelized MC Installation

Jay Maharaj Consultancy Pvt. Ltd Construction Company was tasked with building a modern, energy-efficient office, Computer Lab, and Class room using panelized construction methods. The company opted to use MC techniques in conjunction with panelized construction, allowing for precise measurements and consistent quality. The office complex was designed using prefabricated off-site panelized components, manufactured in a controlled factory environment.

The combination of panelized construction and modular techniques allowed Jay Maharaj Consultancy Pvt. Ltd Construction to complete the office complex ahead of schedule and within budget. The client was impressed with the speed and efficiency of the installation work, as well as the high-quality finish of the building.

The integration of MC techniques with panelized construction can significantly improve efficiency in installation work for building projects. By prefabricating components off-site and assembling them on-site, construction companies can save time, reduce costs, and improve quality control. The success of Jay Maharaj Consultancy Pvt. Ltd Construction Company's project exemplifies the advantages of combining MC with panelized construction methods and the potential for this approach to revolutionize the construction industry.

10 CONCLUSIONS

In conclusion, MC installation offers numerous benefits, including faster construction times, cost savings, and reduced environmental impact. However, it also presents unique challenges, such as transportation risks, quality control, and installation issues. Addressing these challenges requires robust quality assurance programs, stress testing of modules, pre-installation quality checks, and skilled teams familiar with MC. Despite these challenges, the MC industry is poised for growth, driven by the advantages of a controlled building environment, significant cost savings, and shorter build times. To overcome construction challenges, modular building methods can be employed in remote locations, multiple locations, and areas with extreme weather, offering solutions for tight timelines, short-term needs, and weather delays.

10.1 Implications for the construction industry

The future of MC installation holds significant implications for the construction industry. As MC gains traction, it brings new risk management landscapes, cost savings, speed advantages, and enhanced construction quality. The shift towards modular methods is driven by factors like rising materials prices, demand, and the need for efficient construction. With the potential to reduce costs, accelerate project timelines, and improve quality control, MC is poised to revolutionize the industry by offering faster, more cost-effective, and safer building solutions.

The rise of MC brings significant implications for the industry, including increased efficiency and speed, enhanced quality control, cost efficiency, sustainability, design flexibility, and technological integration. This method accelerates project completion by up to 50%, ensures consistent quality, reduces costs, aligns with sustainability goals, offers design adaptability, and integrates advanced technologies for smart buildings. As the industry embraces MC, it promises a more efficient, sustainable, and adaptable built environment with greater design innovation and improved construction techniques.

10.2 Suggestions for further research and development

Further research and development in MC should focus on enhancing automation and robotic usage in module fabrication and assembly, akin to automakers like Tesla. Innovations to allow robotic arms to execute these tasks could significantly boost productivity and efficiency in the industry. Additionally, exploring ways to shift practitioners from traditional stick-build methods to modularization can accelerate advancements in MC. Emphasizing collaboration with designers early on and fostering repeat partnerships can ensure building plans align with modular techniques and enhance project outcome.

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AUTHOR PROFILE

Name of Author- Divyesh Solanki
Email Address- sdivyesh283@gmail.com
Final Year, M.Tech (Civil) Construction Engineering and Management, BVM Engineering College, Vallabh Vidyanagar – Gujarat – India,