BIM-Driven Modular Steel Construction: Enhancing Prefabrication and On-Site Assembly

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Abstract - Building Information Modelling (BIM) has emerged as a transformative enabler for modular steel construction by providing parametric modelling, coordinated detailing, digital fabrication integration, and 4D construction sequencing. Modular steel systems require high accuracy in design, fabrication, logistics, and assembly, making BIM indispensable for reducing rework, improving coordination, and enabling just-in-time production. This paper examines the integration of BIM within modular steel construction, focusing on prefabrication accuracy, clash-free detailing, sequencing simulation, and digital manufacture. The study includes a comprehensive literature review, a methodology grounded in BIM-enabled workflows, and analysis of two major case studies Chennai International Airport Terminal T2 and Shanghai Tower. Findings indicate that BIM significantly improves productivity, reduces site conflicts, minimizes waste, and enhances assembly predictability, particularly in the Indian context where BIM adoption faces challenges such as limited skills, high costs, and low SME readiness. The paper concludes with strategic recommendations for India's modular steel industry and outlines future research directions.

Key Words: Building Information Modelling (BIM), Modular Steel Construction, Prefabrication, Digital Fabrication, 4D BIM, Clash Detection, SMEs, Coordination, Steel Structures

1. INTRODUCTION

Modular steel construction is rapidly transforming global building practices by shifting labour-intensive work from on-site conditions to controlled factory environments, thereby improving accuracy, quality, and speed. Building Information Modelling (BIM) enhances this shift through parametric modelling, clash detection, and fabrication-ready detailing, creating a unified digital workflow essential for modular steel systems [1], [2]. Countries like China, Singapore, and the UK have already leveraged BIM to industrialise construction, demonstrating its effectiveness in managing complex steel geometries and large-scale prefabrication [3].

In India, BIM adoption is growing due to infrastructure megaprojects, but implementation remains inconsistent because of skill shortages, interoperability issues, and the absence of national BIM standards [4], [5]. Fabricators especially SMEs often rely on manual processes, creating disconnects between design intent and on-site assembly, which BIM could otherwise prevent [6]. As rapid urbanisation increases demand for faster and more precise construction systems, integrating BIM with modular steel construction becomes essential for improving prefabrication accuracy, logistics planning, and project predictability [7].

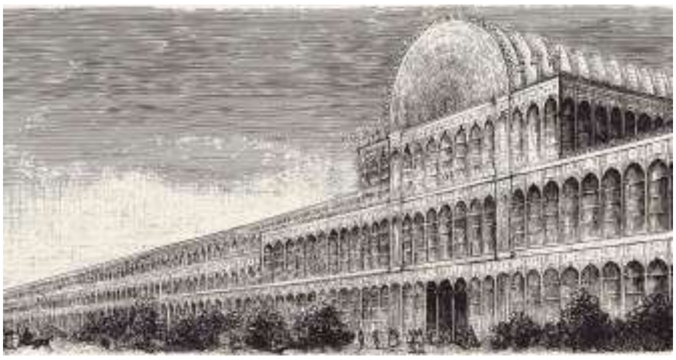

Fig -1: Crystal Palace, a massive structure built in Hyde Park, London, to house the Great Exhibition of 1851
Source: Medium

2. BACKGROUND

The global construction industry is shifting toward industrialised and technology-driven methods due to rising demands for speed, precision, and reduced on-site labour. Modular steel construction plays a key role in this transition as prefabricated steel components manufactured in controlled factory settings ensure higher quality and faster project delivery [1]. BIM strengthens this system by providing parametric modelling, coordinated detailing, and digital fabrication workflows that minimise rework and enable predictable assembly [2].

Countries such as China and Singapore have adopted BIM-supported modular construction at scale, using detailed 3D models, CNC-linked fabrication, and digital twins to streamline entire project lifecycles [3]. In India, BIM implementation is increasing in large infrastructure projects like airports and metros, but industry-wide adoption remains uneven due to fragmented workflows, skill gaps, and limited SME digitalisation [4]. These gaps highlight the need for research on how BIM can optimise modular steel construction in the Indian context [5].

3. LITERATURE REVIEW

Research shows that BIM significantly enhances modular and prefabricated construction by enabling accurate 3D modelling, early clash detection, and coordinated multidisciplinary workflows that reduce rework and improve predictability [1]. Studies highlight that BIM's parametric modelling and LOD400 detailing ensure fabrication-ready steel components, which is crucial

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because modular systems demand millimetre-level precision during off-site manufacturing [2]. Digital mock-ups further help validate fit-up before production, minimising on-site adjustments in steel assembly [3].

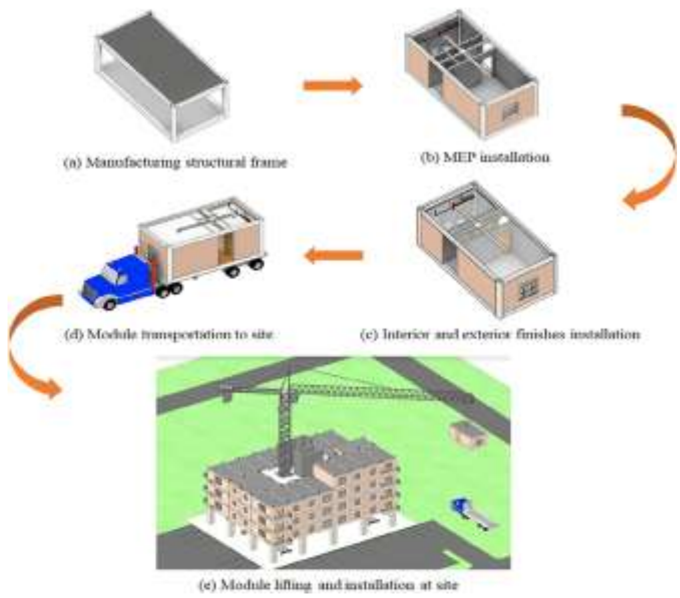

Fig -2: Modular Construction from manufacturing to Site Installation
Source: Research Gate

Global literature indicates that BIM-enabled sequencing (4D BIM) greatly improves logistics planning, crane routing, and installation sequencing in modular steel projects [4]. In digitally mature countries such as China and Singapore, BIM is directly linked to CNC fabrication, robotic welding, RFID tracking, and digital twin-based monitoring, enabling fully industrialised steel module production and rapid installation cycles [5]. These advancements demonstrate the potential of BIM to optimise the entire modular steel lifecycle from design to operation.

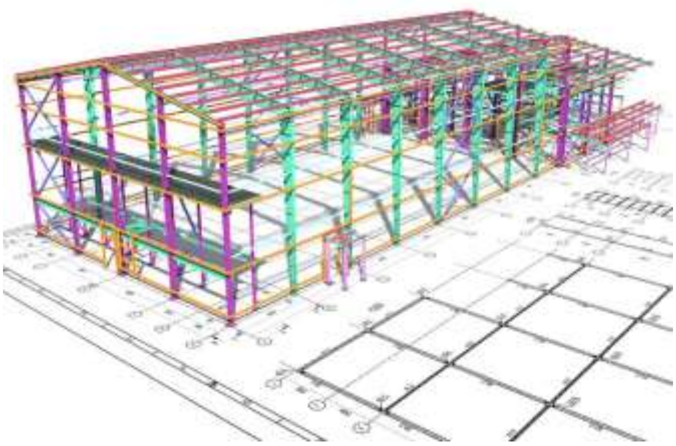

Fig -3: BIM modelling for detailed steel structures.
Source: PMA Consultants

Indian literature, however, emphasises persistent challenges such as inconsistent BIM adoption across contractors, limited interoperability between software platforms like Tekla, Revit, and Navisworks, and major skill shortages in BIM-based steel detailing [6]. SMEs who constitute most of India's fabrication ecosystem struggle with costs, training gaps, and outdated workshop practices, leading to disconnects between BIM models and physical fabrication output [7]. Comparative studies show that while India uses BIM effectively for coordination in large airport and metro projects, the lack of national BIM standards restricts widespread integration with modular steel construction [8].

4. METHODOLOGY

4.1 Need of the Study

The need for this study arises from India's growing requirement for faster, precision-driven construction systems, where traditional site-based methods often result in rework, delays, and coordination failures. Modular steel construction can address these challenges, but its success depends on BIM-enabled accuracy, digital fabrication, and 4D sequencing, which remain underutilized in India due to fragmented workflows and limited BIM maturity [1]. This study is therefore essential to understand how BIM can optimize prefabrication, detailing, logistics, and on-site assembly for the Indian modular steel sector [2].

4.2 Structure of the Research Process

The research follows a structured three-stage process beginning with a comprehensive literature review on BIM-enabled modular and prefabricated construction to establish theoretical foundations. This is followed by a comparative case study analysis of Chennai International Airport and Shanghai Tower to evaluate differences in BIM maturity, digital fabrication, and sequencing practices [3]. Finally, insights from literature and case analysis are synthesized into a BIM–Modular Steel Interface Framework that outlines how India can advance toward industrialized construction workflows supported by BIM [4].

5. BIM'S ROLE IN PREFABRICATION, DETAILING & SEQUENCIN

BIM plays a crucial role in enhancing prefabrication accuracy for modular steel systems by enabling parametric modelling, LOD 350-400 detailing, and digital mock-ups that validate fit-up before fabrication begins. These high-precision models eliminate inconsistencies that often arise in 2D workflows and ensure CNC machines receive fabrication-ready data for cutting, drilling, and welding [1]. Through this digital workflow, BIM significantly reduces dimensional errors and improves off-site manufacturing efficiency [2].

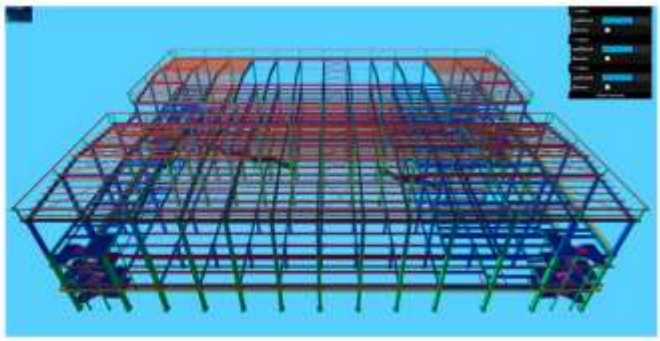

Fig -4: BIM digital mock-ups validating steel module fit-up.
Source: MDPI

In modular steel projects, coordinated detailing is essential because structural members, MEP services, and façade systems must integrate seamlessly during assembly. BIM-based clash detection tools such as Navisworks allow teams to identify and resolve conflicts between steel components and building services before manufacturing starts, preventing costly rework on-site [3]. Automated extraction of shop drawings, bolt schedules, and connection details further strengthens accuracy, ensuring modules are produced with exact tolerances required for rapid installation [4].

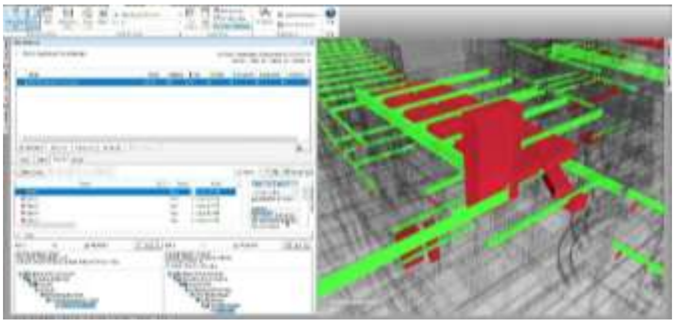

Fig -5: BIM resolving steel-MEP clashes using Navisworks
Source: Autodesk

BIM also transforms construction sequencing through 4D simulation, linking time schedules with 3D models to optimise crane operations, delivery timing, and on-site assembly workflows. These simulations allow stakeholders to visualise installation sequences, predict site congestion, and plan just-in-time delivery for modular steel components [5]. Advanced global projects extend these capabilities with digital twins, RFID tracking, and robotic assembly simulation, demonstrating the full potential of BIM-driven sequencing in industrialised construction environments [6].

Fig -6: 4D BIM showing steel assembly sequencing
Source: United BIM

6. BARRIERS TO BIM ADOPTION & STRATEGIC RECOMMENDATIONS

BIM adoption in India's modular steel construction sector faces several barriers, including high initial costs, lack of skilled professionals, and fragmented project delivery systems. Many SMEs struggle to invest in BIM software, hardware, and specialised training, leading to limited digital readiness across the fabrication ecosystem [1]. Interoperability issues between platforms such as Revit, Tekla, Navisworks, and CNC file formats further slow adoption and reduce model consistency [2].

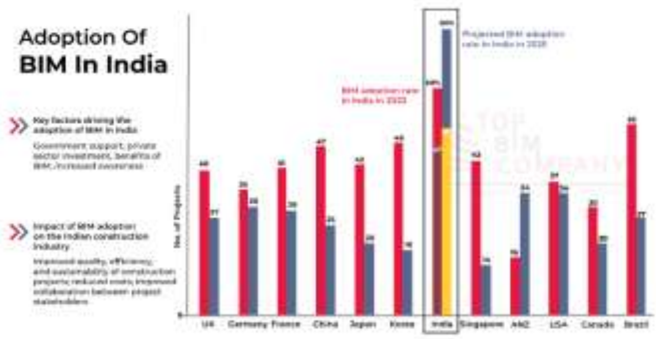

Fig -7: Growth and challenges of BIM adoption in India
Source: Top BIM Company

Another major barrier is the absence of national BIM standards, resulting in inconsistent workflows, variable modelling quality, and limited data exchange across organisations. Traditional Design Bid Build approaches also limit collaboration between architects, engineers, and fabricators, causing information silos and frequent rework during modular steel assembly [3]. Resistance to digital transformation, especially among small contractors, contributes to the slow transition toward BIM-enabled industrialised construction processes [4].

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Fig -8: Shift from traditional construction processes to BIM-enabled modular workflows.
Source: Linarc

Strategic recommendations include establishing national BIM mandates, standardising LOD definitions and data formats, and promoting Integrated Project Delivery (IPD) for early collaboration between stakeholders.

Strengthening workforce capacity through structured BIM training programs and supporting SMEs with financial incentives and shared cloud platforms can accelerate adoption [5]. Finally, encouraging open BIM, cloud-based collaboration tools, and CNC-linked digital fabrication workflows will significantly enhance the efficiency and accuracy of modular steel construction in India [6].

Fig -9: BIM for cost Estimation
Source: Kaarwan

7. CASE STUDIES

7.1. CHENNAI INTERNATIONAL AIRPORT (NEW INTEGRATED TERMINAL T2)

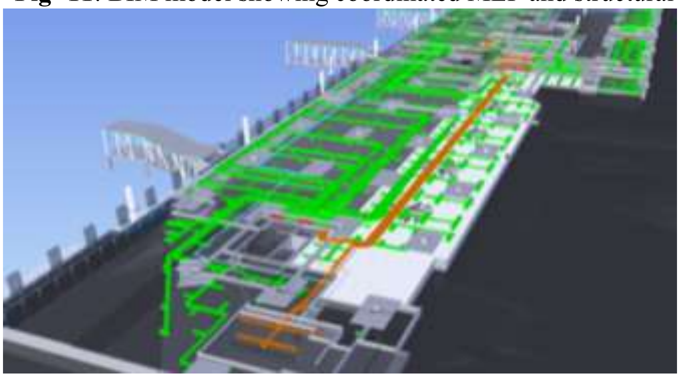
The New Integrated Terminal Building (T2) at Chennai International Airport is one of India's most advanced BIM-enabled steel megastructures. The project features a large-span modular steel roof, composite trusses, and geometrically complex façade systems requiring high coordination between structural and MEP disciplines [1]. Due to its scale and precision requirements, BIM became central to ensuring clash-free design, accurate prefabrication, and optimized installation sequences [2].

Fig -10: Chennai Airport Terminal 2
Source: Zee News

7.1.1 How BIM Is Used in Modular Steel Construction

BIM was utilized extensively from conceptual design to installation, enabling federated models that integrated architectural, structural, and MEP systems. The steel roof trusses and modular components were modelled at high LOD, allowing fabricators to produce CNC-ready components with precise connection details [3]. BIM based clash detection using Navisworks helped eliminate conflicts between steel members and services, ensuring the prefabricated trusses could be assembled without on-site modifications [4]. 4D BIM simulations supported crane planning, delivery sequences, and just-in-time installation of large steel modules.

Fig -11: BIM model showing coordinated MEP and structural



systems
Source: The BIM Engineers

7.1.2 Role in this study

This case study provides an Indian benchmark demonstrating how BIM can enhance modular steel accuracy, reduce rework, and improve sequencing in large infrastructure projects. It reveals India's strengths in BIM-based coordination but also highlights gaps such as limited fabrication automation and varying digital maturity among contractors [5]. Insights from this project help contextualize BIM readiness within India and allow comparison with digitally advanced countries such as China.

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7.2. SHANGHAI TOWER, SHANGHAI, CHINA

The Shanghai Tower is a 632-meter supertall skyscraper and one of the world's most digitally advanced steel-and-concrete hybrid structures. Featuring a twisting façade, mega-frame steel system, and complex vertical zones, the project demanded rigorous accuracy, multi-disciplinary coordination, and advanced modelling workflows [6]. BIM was mandated from the outset, making the tower an exemplary global reference for integrated digital construction.

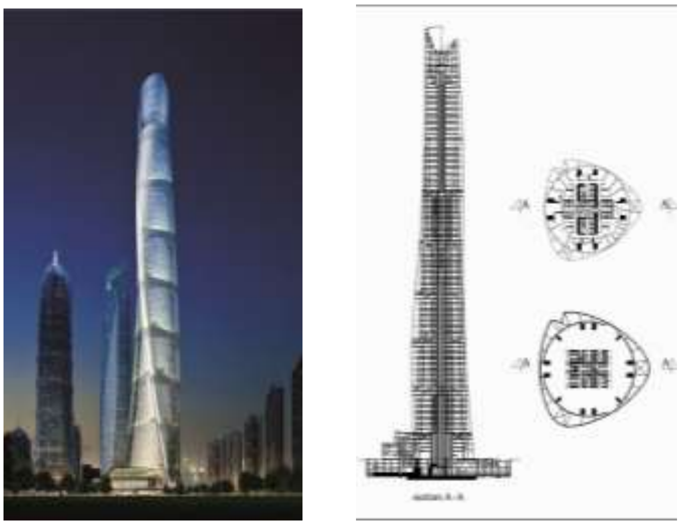

Fig -12,13: Shanghai Tower, Plan and Cross Section
Source: Arch20, Research Gate

7.2.1 How BIM Is Used in Modular Steel Construction

BIM was employed across architecture, structure, MEP, façade engineering, and steel fabrication, integrating all disciplines within a single digital environment. High-LOD structural steel models supported automated CNC fabrication, robotic welding, and QR/RFID-enabled component tracking during logistics and installation [7]. Navisworks-based clash detection and Autodesk Revit models ensured precise alignment of complex steel elements, while 4D simulations guided multi-level construction sequencing and crane coordination [8]. The project also used digital twins for real-time progress tracking and lifecycle monitoring.

Fig -14: BIM and structural models of Shanghai Tower
Source: Viktor

7.2.2 Role in this study

The Shanghai Tower serves as a global benchmark illustrating full BIM lifecycle integration, CNC-linked digital fabrication, and real-time coordination across disciplines. By comparing this digitally mature approach to India's developing ecosystem, the study identifies technological gaps, capacity needs, and opportunities for India to adopt global best practices [9]. This case highlights how BIM can enable industrialized modular steel construction when fully supported by policy, training, and digital infrastructure.

8. COMPARATIVE ANALYSIS & INFERENCES

The comparison between Chennai Airport and Shanghai Tower shows clear differences in BIM maturity, fabrication automation, and digital integration. Chennai Airport demonstrates effective use of BIM for modular steel coordination, clash detection, and prefabrication, but its fabrication ecosystem still relies largely on manual welding and limited CNC workflows, reducing overall precision and efficiency [1]. In contrast, Shanghai Tower illustrates a highly industrialised BIM environment, supported by national BIM mandates, robotic fabrication, RFID-based tracking, and unified multidisciplinary collaboration, enabling advanced modular steel construction accuracy [2].

Parameter	Chennai Airport (India)	Shanghai Tower (China)
BIM Maturity	Moderate to High	Very High
Prefabrication Level	High (modular trusses)	Extremely High (CNC + unitized steel)
Digital Fabrication	Limited CNC + manual welding	CNC + Robotics + Automated QA
BIM Integration	Coordination + sequencing	Full lifecycle integration
Government Mandate	Limited	Strong BIM-driven national policies
Data Exchange	Mixed (Revit, Tekla, Navisworks)	Unified open BIM + CNC fabrication data
Labour Dependency	Medium–High	Low (automation-intensive)
Logistics	Traditional + 4D planning	Smart logistics (QR + GPS + digital twin)
Industrialisation Level	Evolving	Fully industrialised digital ecosystem

Table -1: Comparative Table of Chennai Airport and Shanghai Tower
Source: Author

These contrasts are essential to the study as they reveal India's strengths in BIM-based design coordination while highlighting gaps in automation, digital standardisation, and supply-chain integration. The Chennai case proves BIM's value in reducing rework and improving modular assembly, whereas the Shanghai Tower represents the global benchmark for fully digitised industrial construction [3]. Insights from this comparison shape the BIM–Modular Steel Interface Framework, emphasising SME digitalisation, fabrication-linked BIM workflows, and policy-driven adoption to help India transition toward global modular steel construction standards [4].

9. CONCLUSION AND FUTURE SCOPE

This study concludes that BIM plays a transformative role in modular steel construction by significantly improving prefabrication accuracy, clash-free detailing, and construction sequencing. The Chennai Airport case demonstrates India's growing ability to use BIM for large-scale steel coordination, while the Shanghai Tower highlights the potential of fully integrated digital ecosystems supported by automation, robotics, and national BIM standards [1]. The findings reveal that India's progress is promising but still limited by fragmented workflows, skill shortages, and low SME digital readiness [2].

Future work should focus on establishing national BIM guidelines, advancing SME-level digital fabrication, and integrating open BIM standards to improve interoperability across the construction supply chain. Increased investment in CNC automation, QR/RFID tracking, cloud collaboration, and workforce training will be essential for India to transition toward global modular steel practices [3]. Expanding BIM into digital twin integration and lifecycle asset management offers additional opportunities to enhance operational efficiency and push India toward a fully industrialised construction environment [4].

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