Optimizing Modular Construction Processes Through BIM Integration: Comparative Analysis of CAD and BIM Workflows

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Abstract

The architecture, engineering, and construction (AEC) industry is increasingly adopting modular construction to accelerate delivery, improve efficiency, and reduce environmental impact. However, workflows reliant on traditional CAD often suffer from fragmented coordination, design errors, and costly rework. This study evaluates the impact of Building Information Modelling (BIM) on modular construction using three complementary methods: a literature review, a survey of industry professionals, and a comparative case study of two high-rise projects in Dubai. Results demonstrate that BIM reduces design hours, revisions, RFIs, and factory rework while increasing installation efficiency, cost effectiveness, and standardization of modular components. Survey findings on benefits such as time savings, improved coordination, and reduced rework are directly reflected in the case study KPIs. Furthermore, the case study evidence indicates that many of the barriers reported in the survey can be mitigated through appropriate strategies, and that certain obstacles—most notably implementation costs—may be substantially offset by the accrued benefits, thereby diminishing their constraining effect. The study represents the first quantified comparison of CAD and BIM workflows on high-rise modular bathroom pods, combining survey evidence with KPI and cost analysis to triangulate results. It concludes with actionable recommendations for practice and a framework for broader BIM adoption in modular construction.

Keywords

Modular Construction, Building Information Modelling (BIM), Prefabrication, CAD vs BIM, Bathroom Pods, High-Rise Projects, Cost Optimization, Clash Detection, Standardization

1. Introduction

The construction industry faces increasing pressure to deliver projects faster, more cost-effectively, and with improved quality. As global demand intensifies, modular construction is increasingly recognized as a transformative approach. It involves off-site prefabrication of standardized components—such as volumetric modules, (as shown in Fig. 1) bathroom pods, and structural panels—later assembled on-site. Factory-controlled environments enable precision, repeatability, and reduced dependence on site conditions, resulting in faster timelines, higher quality, and improved safety.

Fig. 1. On-site assembly of prefabricated modular components demonstrating modular construction workflow.

Yet, workflows relying on traditional 2D CAD often encounter fragmented coordination, inconsistent documentation, and manual clash checking, leading to rework, delays, and added costs. Building Information Modelling (BIM) addresses these inefficiencies by enabling a multi-dimensional digital environment for collaboration among architects, engineers, fabricators, and contractors (see Fig. 2). Its capabilities—from 3D visualization to 5D cost estimation—support parametric design reuse, automated clash detection, and integration with manufacturing. When combined with modular methods, BIM transforms fragmented processes into coordinated, scalable workflows aligned with digital construction trends.

Fig. 2. BIM integration: Left – visualization of BIM dimensions (3D–10D) covering geometry, scheduling, cost, sustainability, and facility management; Right – practical application in a modular construction project demonstrating coordinated digital workflows.

1.1 Unique Contributions of This Study

Despite its potential, significant gaps remain. Few studies directly compare CAD and BIM in modular projects, and no structured framework exists for systematically integrating BIM across design, manufacturing, and installation. In practice, BIM is still often limited to visualization rather than lifecycle management. This highlights the need for empirical evidence demonstrating BIM's impact and for strategies that overcome persistent barriers.

This study provides one of the first quantified comparisons of CAD versus BIM workflows in high-rise modular bathroom pods. By triangulating evidence from a professional survey, case study KPIs, and cost analysis, it demonstrates measurable improvements in design efficiency, coordination, and rework reduction. The findings culminate in actionable recommendations to guide BIM integration in modular projects, offering a replicable framework for industry and academia.

2. Methodology

This study evaluates BIM's impact on modular construction, focusing on prefabricated bathroom pods in high-rise projects. A mixed-method approach was employed:

1) **Literature Review** – Examined current research on modular construction and BIM applications.
2) **Professional Survey** – Conducted with professionals, including architects, engineers, contractors, and fabricators, exploring BIM adoption, benefits, challenges, and trends.
3) **Case Study** – Comparative analysis of two Dubai high-rise projects:
   - **Elegance Tower** – CAD-based workflow, 26-storey, 52 pod types, manual coordination.
   - **Maritime Harbour Lights** – BIM workflow (Revit and Tekla Structures), 52-storey, 23 standardized pod types, using IFC (Industry Foundation Classes) for seamless data exchange and collaborative coordination between design, fabrication, and on-site teams

Key performance indicators included design hours per pod, revision numbers, RFIs, rework impact, installation rates, logistics efficiency, and cost distribution. This approach allowed quantitative and qualitative evaluation of BIM's effectiveness in enhancing design, fabrication, and installation.

3. Survey Findings

The survey involved 67 professionals with experience in modular construction, including BIM managers, architects, engineers, project managers, and factory staff from various companies and countries. The respondents were mostly recruited via LinkedIn post and through the Modular Construction Network. Over 72% had more than six years of experience, with nearly half exceeding a decade, providing a well-informed sample.

3.1 BIM Adoption

Nearly 70% of respondents use BIM for 3D modelling, visualization, and clash detection, while 15–20% still rely on AutoCAD, and only about 5% have advanced to 4D scheduling or 5D cost estimation. This indicates that BIM adoption is growing in modular construction, but full lifecycle utilization—including scheduling, cost estimation, and facility management—remains limited. Fig. 3 illustrates the current level of BIM integration reported by survey participants, highlighting areas where further digital adoption is needed.

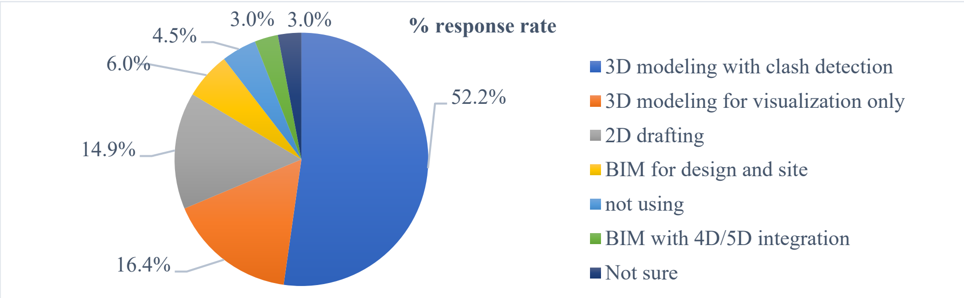

Fig 3. Question No. 4 in the Survey: Level of BIM integration in modular construction

3.2 Benefits of BIM

Respondents reported significant benefits of BIM in modular construction (Fig. 4). The most frequently cited advantage was improved design coordination (85.1%), followed by effective clash detection (71.6%), reduced rework (68.7%), and time savings (64.2%). Regarding time savings specifically, approximately 40% of respondents estimated that BIM reduces design time by more than 50%, 20% estimated savings between 30–50%, another 20% estimated less than 30%, and 10% were unsure. Additional benefits included enhanced collaboration (52.2%) and cost savings (43.3%), highlighting BIM's role in accelerating delivery, improving accuracy, and supporting integrated decision-making.

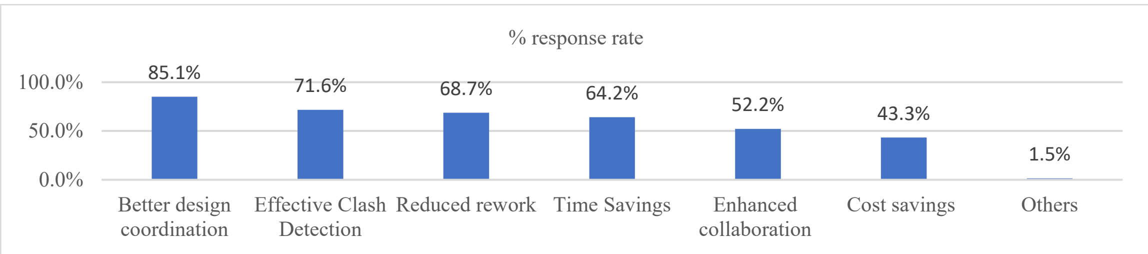

Fig 4. Question No. 8 in the Survey: Benefits Experienced from Using BIM in modular construction

3.3 Challenges in BIM Adoption and Usage

Several barriers to BIM adoption were identified (Fig. 5). The most frequently reported challenges were organizational resistance to change (46.3%) and high software costs (44.8%) were among the most reported barriers, alongside low stakeholder awareness (41.8%) and lack of skilled professionals (41.8%). Other significant issues included inadequate training (38.8%), limited modular BIM standards (25.4%), and miscellaneous factors (4.5%).

Beyond these, respondents noted practical difficulties while using BIM such as delayed involvement of factory teams, weak stakeholder collaboration, incomplete or inaccurate models, lack of production-compatible details, software incompatibilities, and insufficient parametric object libraries, highlighting the multifaceted nature of BIM implementation hurdles.

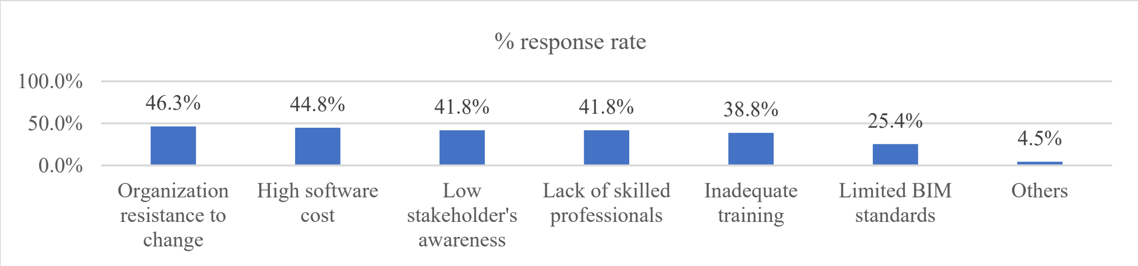

Fig. 5. Question No. 2 in the Survey: Biggest Anticipated Challenges in Implementing BIM

3.4 Future Improvements for BIM in Modular Construction

Participants highlighted several areas requiring attention to strengthen BIM workflows (Fig. 6). The most important, cited by 67.2%, was improving design-to-factory workflows and information exchange, supported by standardized BIM libraries. Other key improvements included stronger collaboration among project teams, enhanced training programs, and higher accuracy of initial models to reduce downstream errors. These priorities indicate that aligning digital tools more closely with factory processes and production requirements is critical for maximizing BIM's value in modular construction.

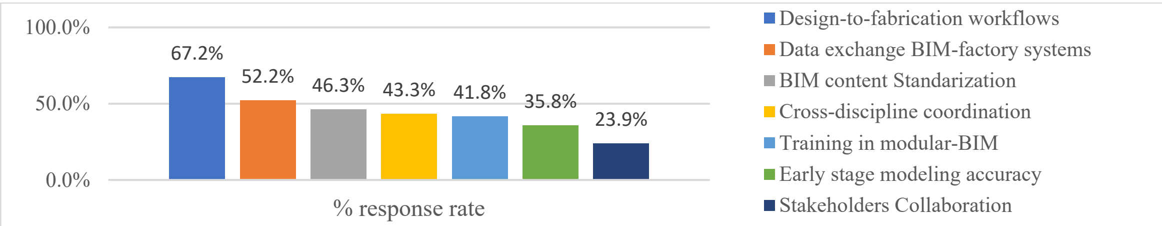

Fig. 6. Question No. 18 in the Survey: Areas Needing Improvement for Better BIM-Modular Alignment

The survey results demonstrate that while BIM provides measurable operational benefits in modular construction, its effectiveness depends on both human expertise and standardized processes. Addressing skill gaps, improving workflows, and developing reusable modular libraries are critical for maximizing BIM's potential and ensuring consistent improvements across projects.

4. Case Study: Comparative Analysis of CAD and BIM Workflows in Bathroom Pod Projects

To assess the impact of BIM integration, a comparative case study was conducted on two high-rise Dubai projects: Elegance Tower, using a conventional CAD workflow, and Maritime Harbour Lights, delivered with a BIM-centric approach. Both projects utilized prefabricated bathroom pods, providing a clear basis to evaluate performance differences in design, fabrication, and installation.

Bathroom pod production involves multiple stages and materials, including GRP and plywood bases, automated wall tiling, separately manufactured ceilings, and fixture installation. Light-gauge steel framing requires precise alignment of MEP systems and structural supports. This complex, multi-stage workflow highlights the need for accuracy and interdisciplinary coordination—challenges effectively addressed through BIM implementation.

4.1 Project Backgrounds

Elegance Tower is a 26-storey residential building with 594 bathroom pods across 52 types, covering approximately 3,500 m², designed using traditional 2D CAD. Manual coordination and clash detection led to multiple revisions and increased error potential (Fig. 7).

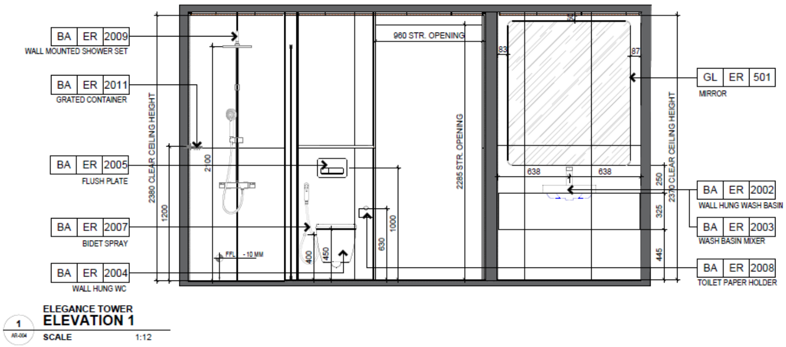

Fig. 7. Elegance Tower – Sample CAD drawings of a bathroom pod elevation, illustrating manual coordination and multiple design revisions

Maritime Harbour Lights, a 52-storey mixed-use development with 617 pods across 23 standardized types, covering around 4,100 m², employed BIM (Revit for architecture, Tekla for structure) with IFC interoperability. Automated clash detection and parametric family reuse streamlined workflows, reduced coordination errors, and improved efficiency (Fig. 8).

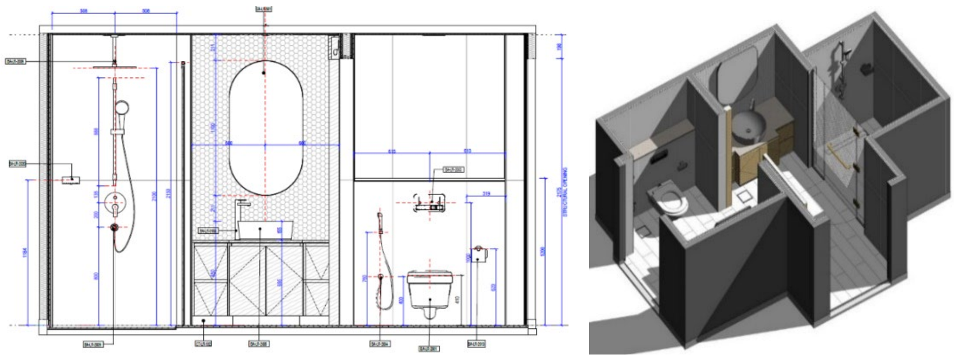

Fig. 8. Maritime Harbour Lights – Left: 3D Revit view of a bathroom pod; Right: BIM-generated elevation showing coordinated MEP, structural, and architectural elements, highlighting clash-free, parametric design.

Both projects were designed by the same pods team, produced in the same factory, and executed during the same timeframe. The major difference was in design duration: Elegance took 17 months, whereas Harbour Lights required only 7 months, demonstrating the efficiency gains attributable to BIM.

4.2 Design and Production Analysis

Parametric modelling in BIM reduced pod typologies, allowing similar or symmetrical pods to be grouped for enhanced standardization and reuse, whereas CAD required each pod to be drawn individually. Detailed BIM shop drawings increased the number of drawings by 64%, supporting production.

Factory reworks dropped by 92% in Harbour Lights due to coordinated drawings, while Elegance Tower experienced recurring issues such as misaligned MEP, tile layout errors, and clashes between fixtures and structural frames. BIM largely eliminated these problems through early clash detection.

BIM integration also positively influenced sustainability. Reduced rework, lower material consumption, and fewer transport requirements led to a 5–10% reduction in environmental impact, demonstrating that digitally coordinated modular workflows can enhance both efficiency and sustainability.

4.3 KPI's Cost Benefits Analysis

The KPI comparison between Elegance Tower (CAD) and Maritime Harbour Lights (BIM) summarized in Table 1, demonstrates BIM's measurable impact on modular workflows. The data, compiled from the Engineering, Estimation and Quality Department at the factory, was selected to focus on indicators most directly influencing the design and production process. Total design effort was significantly reduced in the BIM project. Key metrics—such as revision frequency, RFIs, production drawing changes, rework, and pod production rates—highlight how parametric modelling, automated clash detection, and integrated design-to-fabrication workflows streamlined processes and enhanced efficiency across all project phases.

KPI	**Elegance Tower** (CAD)	**Harbour Lights** (BIM)	**Improvement** (CAD vs BIM)	**Effect** ↑ Initial Value Increase / ↓ Initial Value Decrease	**Observation**
Design hours per pod	185 hrs	100 hrs	**45.9%**	↓	Less hours per pod
Pod types	52	23	**Optimized**	↓	BIM reduced duplicates and optimized pod types
Total design hours	9,620 hrs	2,300 hrs	**76%**	↓	Significant overall reduction in design effort
Revision number	3–4	0–1	**85.7%**	↓	Fewer design revisions due to improved coordination and clash detection
RFIs per 100 pods	22	9	**59.1%**	↓	Reduced questions and clarifications due to accurate BIM models
Production drawing changes	246	7	**97%**	↓	Detailed, coordinated drawings minimized revisions and rework
Rework impact (issues)	381	32	**91.6%**	↓	Less improvisation required in factory due to clash-free design
Pod production rate (pods/day)	4–5	7–8	**66.7%**	↑	Faster production supported by better planning; fewer workers per pod
Logistics efficiency	100%	92.5%	**7.5%**	↓	Improved efficiency in rework handling and factory coordination
Cost per pod	Baseline + 7.4%	Baseline - 0.2%	**7.0%**	↓	Overall cost reduction due to lower rework and optimized resources

Table 1. Key Performance Indicator Comparison

The cost analysis of labor, overheads, materials, and transportation, as shown in Table 2, demonstrates that BIM delivers measurable savings per pod and across the project, with software investment providing additional efficiency gains beyond productivity.

Cost Category	**Baseline** (% Budget)	**Elegance** (CAD) – Actual % of Budget	**Elegance** (CAD) – Change vs Budget (%)	**Harbour Lights** (BIM) – Actual % of Budget	**Harbour Lights** (BIM) – Change vs Budget (%)	**Comments**
Labor	17%	19.0%	**11.8% ↑**	17.0%	=	BIM reduced excess labor costs.
Overheads	8%	11.5%	**43.8% ↑**	7.75%	**3.1% ↓**	Significant savings in overheads with BIM.
Joinery	20%	20.0%	=	20.0%	=	No change – consistent across both workflows.

Sanitary (fixed)	15%	15.0%	=	15.0%	=	No difference, fixed scope item.
Materials (variable)	38%	39.9%	**5% ↑**	37.25%	**2% ↓**	BIM optimization reduced material waste.
Transportation	2%	2.0%	=	2.0%	=	Logistics performance consistent.
[1] Software Cost (Gross Annual)	–	–	–	0.8%	**N/A (from 0)**	Annual BIM license cost.
[2] Software Cost (Actual Usage)	–	–	–	0.2%	**N/A (from 0)**	Net savings after software investment
Total per Pod	100%	107.4%	**7.4% ↑**	[1] 99.8% / [2] 99.2%	**[1]0.8% / [2] 0.2% ↓**	BIM achieved overall cost reduction per pod.

Table 2. Cost Analysis

The combined KPI, cost, and production analyses show that BIM-enabled workflows significantly improve efficiency in prefabricated bathroom pods. Parametric reuse and automation reduce design hours, revisions, RFIs, and rework, while integration with scheduling and logistics enhances production and installation rates. Upfront software and training costs are offset by savings in labor, overhead, and materials. Overall, BIM transforms modular construction into a more industrialized, data-driven process, boosting productivity, quality, and cost-effectiveness.

5. Linking Survey Insights with Case Study Outcomes

The survey-reported benefits and barriers are directly compared with measurable outcomes from the case study, illustrating how BIM addresses real-world challenges in modular construction (see Table 3). Survey findings on time savings, reduced rework, and improved coordination are confirmed by the Harbour Lights project, which achieved a 76% reduction in design hours, fewer revisions and RFIs, and over 90% less rework. Notably, 40% of respondents believe BIM saves more than half of design time, aligning with these measured results.

Although software cost was flagged as a potential barrier, the initial 0.8% per-pod expense was offset in the first project, resulting in a 7 % net saving, demonstrating that cost is not a lasting obstacle. The primary challenge remains the skills gap, emphasizing the need for targeted training. Together, the survey and case study evidence confirm BIM as a strategic enabler of industrialized, future-ready modular construction.

Survey-Reported Benefit / Barrier	**Case Study Evidence (Elegance vs Harbour Lights)**
Time savings (62.9% of respondents; 40% specifically estimated BIM saves more than 50% of design time)	76% reduction in total design hours per pod in Harbour Lights (BIM)
Reduced rework (67.7%)	91.6% decrease in factory rework issues in Harbour Lights
Better coordination (85.5%)	85.7% fewer design revisions and 59% fewer RFIs in BIM project
High implementation cost (44.8%)	The initial 0.8% per-pod BIM cost in the first project, where BIM was newly implemented, was quickly offset, delivering a 7% net saving—demonstrating that software is an investment with immediate returns rather than a lasting barrier.
Lack of skilled professionals (51.6%)	Requirement for advanced Revit and Tekla training emphasized in Recommendations

Table 3. Alignment of Survey-Reported Benefits and Barriers with Case Study Evidence (Elegance vs Harbour Lights)

6. Recommendations for Practice (6 Key Points)

- **Early BIM Integration:** Initiate BIM at conceptual design for early clash detection and coordination.
- **Develop Reusable BIM Libraries:** Use standardized parametric families with clear guidelines to improve efficiency and scalability.

- **Engage Fabricators Early:** Involve factory teams during design to align with production capabilities and reduce errors.
- **Leverage 4D/5D Simulations:** Integrate scheduling and cost estimation for better planning and decision-making.
- **Targeted Training:** Ensure advanced skills in Revit, Tekla, and collaborative workflows.
- **Adopt Centralized Data Environments (CDEs):** Enhance transparency, coordination, and information exchange across stakeholders.

7. Conclusion

BIM is a strategic enabler of modular construction, significantly reducing design hours, revisions, RFIs, rework, and production time while enhancing coordination, cost efficiency, and overall quality. Both survey findings and the case study confirm that BIM workflows outperform traditional CAD, providing scalable, standardized, and digitally integrated solutions that streamline design-to-fabrication processes.

This study is limited to two high-rise projects in Dubai using prefabricated bathroom pods. Outcomes may vary depending on project location, workforce expertise, and company practices, though similar trends are expected for other module types.

Future research should expand KPI frameworks to include full lifecycle costs, carbon metrics, and facility management. Testing BIM integration with other modular systems, such as panelized structures, modular buildings and MEP modules, is recommended. Development of open BIM libraries standardized parametric families, stronger institutional support, and targeted training remain essential to fully realize BIM's potential in industrialized construction.

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