

RESEARCH ARTICLE

Roadmap for Integrating BIM and Lean Methods Throughout the Lifecycle of Modular Construction Projects

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Abstract

The emerging modular construction sector has attained ample interest given the plethora of benefits compared to conventional construction. However, with incorrect execution and lack of early planning, exorbitant costs are witnessed. There is a lack of guidance to aid key decision-makers in integrating BIM and lean methods in the phases of modular construction. These tools and practices enable a team to work in full clarity involving all organizational levels. Hence, this study has as aim to portray the integrated usage of Building Information Modelling (BIM) and lean construction methods throughout the lifecycle of modular construction projects. The intended roadmap to be derived in the study shall allow decision-makers to acknowledge the corresponding BIM and Lean tools to be used at the correct stage of a modular project. As a generalized concept, the study aims shall aid early planning which will promise to achieve quality. In this scope, a systematic literature review was executed and validated with experts' interactions for developing a roadmap. The studies found were analyzed in terms of case studies performed. This enabled grasping information on how different countries and project types integrated BIM and lean methods at every step of a modular project. Previous studies depicted projects integrating these concepts at the design stage, supply chain, or during module construction. However, this research considers the whole lifecycle, and the methodology integrates hands-on experiences from qualified industry experts. Therefore, the contributions of this research are as follows: (1) Directing team members towards early planning and all-inclusive collaboration, (2) informing key decision makers of lean and BIM tools to integrate at specific stages of modular projects, (3) showcasing awaited benefits upon integration of the proposed tools, and (4) mitigating cost overruns and witnessing value-adding activities throughout the project upon consulting the roadmap.

1. Introduction

Modular construction has gained much attention throughout the years due to its applaudable benefits when executed correctly. In brief contexts, modules produced in the factory for various project types are

transported to the site ready to be installed and used. The time aspect is a remarkable element in this method of construction whereby site preparation is performed simultaneously with the module construction off-site. Similarly, modular

construction positively adds to a sustainable built environment while reducing construction and demolition waste production and enhancing the recycling possibilities of modules at the end of the project's lifecycle [1].

With the fruitful outcomes that are derived from this modern method of construction, offsite construction does witness real-time challenges which are being investigated by researchers to date [2]. The design, transportation, and installation phases of an offsite project come along with constraints not only structurally but also the movement feasibility to the site [3]. Zhang et al [4] emphasizes the need to consider production line and on-site installation of a modular project for process improvement. Current modular construction projects lack a lean integrated approach, and it is of utmost importance to showcase the effectiveness of lean tools and techniques to be used in different production stages [5]. Hence, this study has as aim to develop a structured roadmap showcasing the usage of Building Information Modelling (BIM) and lean construction methods throughout the lifecycle of modular construction projects. The research gap of lacking a general guide to aid planning for efficiency in modular projects will thus be tackled. The expected results shall include mitigating cost overruns, avoiding redundant waste production, and deriving quality end-products.

2. Research background

2.1. Lean construction methods

Initially used in the manufacturing industry, lean production methods determine work cultures that aim at waste elimination. With a single waste source, the expected forecast is like a ripple effect and as production is more than required, cost overruns are witnessed with an overall non-value-adding situation [5]. Most commonly compatible lean construction methods for the modular construction sector include but are not limited to the Last Planner System (LPS), Just in Time (JIT), Value Stream Mapping (VSM), and Kanban system. Zhing et al [6] investigated the implementation of multiple lean construction

techniques and deduced that the most adopted one is the LPS with a percentage usage of 77.3%. Another commonly used lean construction method is the Just in Time technique. The arrival of modules as per and when needed to the site enables eradicating inventory waste [7]. Design for Manufacture and Assembly (DfMA) has seen overwhelming application in the prefabrication sector whereby cost is minimized and overall value-adding activities are witnessed [8]. With the urge for continuous improvement, including all organizational levels from the start of a project and having set goals, enables value-adding activities throughout the project's lifecycle. Innella et al [5] denote that a clear guide for adopting lean approaches in offsite companies should be established no later than the design phase itself. This study aims to set a path for key decision-makers in the sector enabling them to understand the proper lean approaches to integrate from the design phase till the end of the project.

2.2. BIM in modular construction

BIM deems as a suitable platform to be embedded in a project aiming for clarity and cooperability from start to finish. To date, a significant awareness rise was witnessed regarding BIM adoption for boosting the efficiency of projects. However, managers are reluctant when it comes to making the investment in the platforms for information sharing and collaborating teams due to the short duration of projects being worked on [2]. BIM has also seen integrations with other platforms for achieving environmental analysis of prefabricated elements [1]. For sustainability prospects, material passports are being digitalized into BIM to support an environmentally friendly project [9]. Internet of Things (IoT) and BIM have also witnessed significant attention in current research due to the real-time database which exactly pictures the demands for logistics purposes [10]. Smart BIM entered the industry with an aim to facilitate on-site assembly services [11]. As for the possible BIM authoring software, Yin et al [12] suggests Revit, Bentley, and ArchiCAD. Quality-wise BIM platforms are a rich and reliable option when opted

from the design phase [13]. As deduced by Atta et al [9], the use of BIM technology contributed to aiding the calculation process which resulted in faster progress with minimal mistakes. Similarly, this study's approach is to derive a roadmap which upon reference taken, projects shall see less cost overruns with timely completion of the projects.

3. Research methodology

The methodology consisted of a systematic literature review and precise analysis was performed with the case studies from the publications which were supported with semi-structured interviews with experts. A systematic literature review deems as a reliable method to perform an extensive review and spot the research gaps. This scientific approach is achieved successfully upon being conducted according to the following steps: (1) identifying research parameters such as keywords, year range, language, and document type, (2) analyzing the articles found, and (3) filtering the articles' content to produce valuable findings [5]. To further cover all aspects of the research topic, experts in the field were contacted and their valuable judgement was recorded as well as validations to the derived outputs. This addition ensured that hands-on perspectives were also

considered which strengthened the findings from the literature review. Fig. 1 summarizes the flow of the methodology and depicts how the outputs were derived.

3.1. Identifying research parameters

Throughout the literature search, it was deduced that Scopus was deemed as the most reliable and broad database which covered publications holistically. Hence, with some set criteria such as keywords, document type, language, and technical field, the systematic literature review turned out precisely. Focused on the modular construction sector, "modular construction" was used as a keyword followed by its synonyms "prefabrication" and "off-site construction". Additionally, diverging toward a specific topic in the field, "lean methods", "lean construction" and "BIM" were the major keywords incorporated in the literature search. To cover all document types, review papers, book chapters, and journal articles were all included with an exception of conference proceedings since these are not peer-reviewed studies. To acquire a holistic coverage of the published literature, studies published from all years were considered. In terms of language restriction, only documents published in English were included.

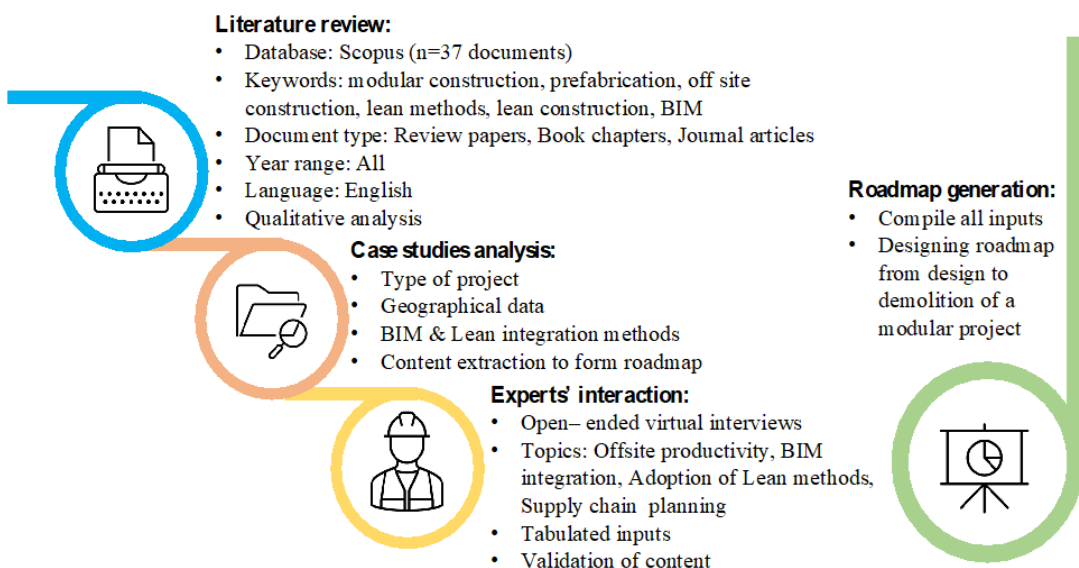


Fig. 1. Research methodology

3.2. Database Navigation

An example of the database search is as follows: (TITLE-ABS-KEY (modular AND construction)) AND (BIM AND lean) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "ch")) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (LANGUAGE, "English")). An average of 87 documents were found during the database search, given the specificity of the research scope.

3.3. Articles' analysis

With analysis of titles and abstracts, the duplicates were removed, and the most related document was downloaded. Mendeley was used for navigating through and saving documents. The finalized set of qualitative content was 37 documents. Full texts were checked, and publications that already performed case studies were then classified for data extraction. The focus on case studies was to incorporate real-life analysis to derive the findings. The qualitative analysis of the studies was thus complemented by the quantitative inputs from the papers that performed case studies.

3.4. Experts' Interaction

Data acquired from the literature review were processed with Microsoft Excel in the form of graphs and tables. In the quest to form a roadmap of BIM and lean construction methods inclusion throughout the lifecycle of a modular project, 3

industry experts were contacted. The interaction was semi-structured open-ended virtual interviews. The experts were picked according to their qualifications (holding at least a Bachelor's degree) and their years of experience in modular construction (greater than 3 years). Topics such as offsite productivity, BIM integration in construction, supply chain management, and overall current modular construction trends were discussed. Example of questions asked. This proved to be very enriching while experts incorporated their experiences to provide significant feedback on the subject. Hereafter, the experts were asked to validate the outputs derived from the investigation. Table 1 shows the profile of the experts that were considered for contributing to this study.

4. Findings

4.1. Case studies adopting BIM and lean in modular construction

Throughout the literature review, case studies were encountered, and the authors have portrayed productivity increase upon applying frameworks suggesting the usage of BIM and lean concepts in modular construction. Table 2 below shows the relevant case studies analyzed and the according methods applied to the productivity rise percentage. Zhang et al[4] formed an elaborate framework that demonstrates the usage of Value Stream Mapping at each stage of a production line which was segmented to tackle each stage such as floor framing, and panel fabrication, among others.

Table 1. Experts' profile

Expert no	Profession	Qualification	Years of experience in modular construction	Country	Interview duration (Minutes)
1	BIM consultant & founder	Bachelor's in Architecture	5	Ireland	40
2	Project coordinator	Bachelor's Applied technology (Architecture, project & facility management)	3	Canada	30
3	Project manager	Bachelor's Civil Engineering (lean 6 sigma black belt, Project Management Professional)	8	United Arab Emirates	25

Table 2. Case studies analyzed in the literature review

Project ID	Type of project	Geographical location	BIM-based methods	Lean concepts	% rise in productivity	Reference
1	Residential	Canada	-	Value Stream Mapping (VSM), Continuous flow, Balanced line	20	[4]
2	Commercial	Brazil	3D model- Revit & Dynamo	VSM	23.3	[2]
3	Residential	China	Luban BIM	-	-	[1]
4	Residential	USA	BIM & GIS	Just in Time (JIT)	90 (In terms of decreased idle time of module)	[10]
5	Commercial	Hong Kong	3D model- Solidworks	Kanban	50	[14]
6	Industrial	China	BIM & laser scanning	-	-	[13]
7	Residential	Hong Kong	BIM with IoT & Blockchain		50+	[15]
8	Commercial	Egypt	3D model- Revit & Navisworks	-	50	[21]
9	Residential	Iran	-	VSM, JIT, Total Productive Maintenance (TPM)	43	[16]

By using BIM and Value Stream Mapping at the premanufacturing phases of offsite construction, Barkokebas et al [2] achieved a 23.3 % increase in productivity. In China, Luban BIM collaboration platform is commonly adopted for developing the 3D model, quantity take-off, and simulation while adding to the environmental assessment of modular construction projects [1]. The crucial start, which is the supply chain and logistics handling, can be efficiently tackled if BIM and Geographic Information System (GIS) integration is performed. With real-time information by subscribing to the Internet of Things (IoT) databases, the digital twin can indicate exact demands at the logistics stage [10]. In the highly digitalized sector, robot involvement in assembling modules proved to enable a 50% productivity rise alongside Kanban principles [14]. When it comes to a collaborative platform, Li et al [15] applied a blockchain-enabled IoT BIM platform that included all stakeholders alongside the project team members. A rarely applied lean construction method known as Total Productive Maintenance (TPM) was depicted by

Heravi et al [16] in a residential building with improvements seen in the timeline and cost-wise.

4.2. Experts' interaction outputs

The 3 experts contacted in this study all agree that good project management with BIM and lean construction methods form the stable foundation required to achieve efficiency in a modular project. Furthermore, based on their valuable hands-on experiences, a major point that was outlined is that the new technologies would require further investment, and this is linked to the major pillar which is the client. For example, knowing that investing in sensors to monitor the health of the structure, would guarantee a better future for the building and the facilities management, the client has the final verdict on this. Similarly, based on the location of the project, while being situated in an urban area, thought should be given to the commute and accommodation of workers during the installation phase. This is also another reason why the latest technologies are not being opted for by clients if the latter can be done the traditional way and cheaper. In terms of the demolition stage, since

modules can be recycled and reused most of the time, a similar approach to the supply chain management performed with BIM and lean construction tools can be integrated again to relocate or organize the demolition process. This shows how modular construction contributes to the circular economy in the sustainable built environment and adds value to the architecture, engineering, and construction industry.

4.3. Roadmap for integrating BIM and lean construction methods in a modular project lifecycle

Like a hierarchical representation, the roadmap developed proceeds in a systematic order that accompanies the team members of a project from the supply chain to the occupancy phase. The holistic consideration promises the mitigation of risks early on and prepares a project to achieve full efficiency with the integration of all organizational

levels. At the occupancy phase, remarkable efforts have been witnessed whereby integrating sensors to BIM platforms has shown how the structural health of components can be monitored in real-time [17]. Overall management of a project efficiently can be achieved via a cloud-based BIM platform (e.g., BIM 360 Field), storing all databases made accessible to project teams [18]. Taking into consideration case studies' performances and suggestions from industry experts, the roadmap in Fig. 2 paves a clear way for the project team to uplift the work culture and make the utmost of the highly digitalized industry. The roadmap also shows expected benefits upon integration of mentioned tools at the concerned stage noted from the literature review and interactions with experts. Furthermore, the roadmap is a general concept of how residential or commercial modular projects could integrate lean and BIM tools at each stage.

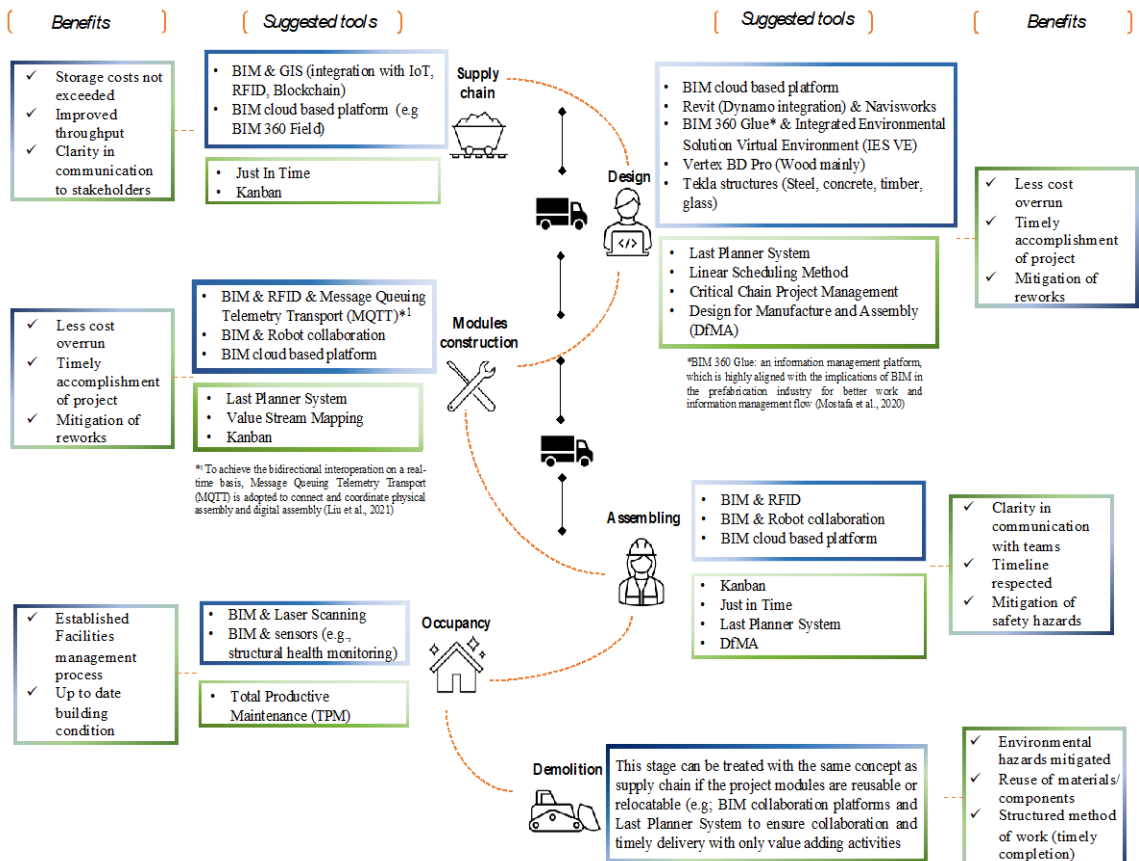


Fig. 2. Roadmap for usage of BIM and lean construction methods in the lifecycle of a modular project

5. Discussions

With a thorough exploration of BIM platforms and lean concepts used in the prefabrication sector, the most common and major issue withholding projects from making the change is the investment factor. Given the projects' short timeline, project managers are reluctant to invest and are not fully confident in the efficacy range to witness. While investigating the lean construction concepts, Just in Time principles are among the most needed throughout the modular construction lifecycle. However, with the waiting period for the supply chain to fully implement the latter, the other parties such as the contractor, client, and designers are left with no choice but to witness some barrier between their respective involvement stages [19]. Due to the working style of manufacturing industries, modular projects deem suitable for applying most of the lean concepts and when combined with BIM platforms, the exponentially rising costs could be tackled soon. Moreover, applaudable interest was denoted in

terms of blockchain, laser scanning, RFID, IoT, and Genetic Algorithms usage with BIM platforms. These had an aim to handle the large databases and provide real-time updates to all organizational levels; hence, decreasing the cost overruns and scheduling risks of modular construction projects. A remarkable investigation by Li X et al [20] introduces a concept namely RBL-PHP (RFID/BIM/Lean – Prefabricated House Production) and the latter displays how to decrease uncertainties from the logistics phase with evidence shown in workshops done with academicians and practitioners. Fig. 3 shows the identified frequency of the mentioned methods which are applied to modular projects. The frequency of appearance was acknowledged from literature review documents and the demolition phase was the sole item depending on experts' statements since there was an absence of literature relating to the latter. For example, the number of studies using RFID, sensors, and IoT at the supply chain stage was 2 among the literature reviews done in this research.

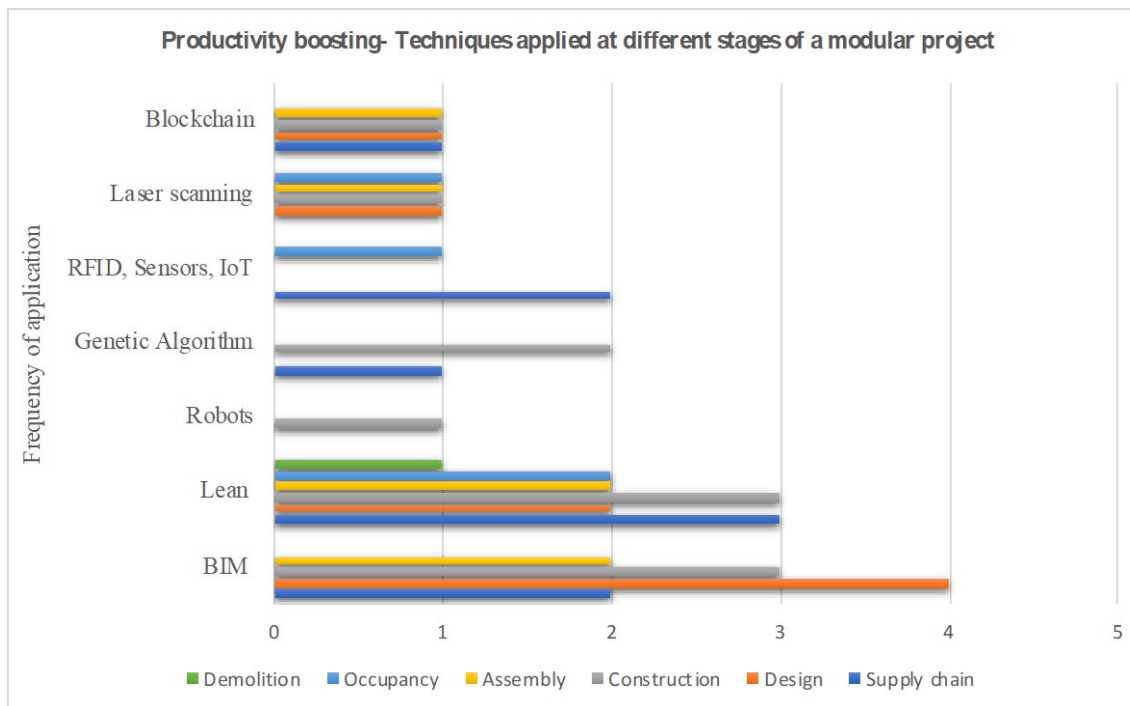


Fig. 3. Application frequency of methods for efficient modular construction

6. Conclusion

This study specifically indicates how efficiency can be achieved with BIM and lean construction methods used throughout the lifecycle of a modular project. With the holistic consideration from supply chain to demolition, the roadmap did not leave any loopholes. Contributions of this research are depicted as follows: (1) Directing team members towards early planning and all-inclusive collaboration, (2) informing key decision makers of lean and BIM tools to integrate at specific stages of modular projects, (3) showcasing awaited benefits upon integration of the proposed tools, and (4) mitigating cost overruns and witnessing value-adding activities throughout the project upon consulting the roadmap. BIM platforms have justified their performance in multiple cases as analysed in this study. From the logistics handling to the occupancy stages, with commitment to

collaboration and accessibility, the productivity of a modular project is guaranteed. Lean construction methods have depicted the positive integration of all organizational levels while promoting value-adding tasks in the projects. One limitation of this study included the lack of projects or expert's awareness of how the demolition phase could take place efficiently with BIM and lean construction methods. This is mainly due to the lack of BIM and lean adoption in the demolition phase of modular construction projects in the current industry. Future studies could focus on how to handle the early integration of technologies such as IoT, blockchain, RFID, sensors, and Genetic Algorithms which will lead modular projects toward on budget achievements alongside quality optimization. Precise attention can also be given to the demolition stage of a modular project while bearing in mind the plethora of potential in terms of sustainability achievements.

Declaration

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Author Contributions

S. Khodabocus: Conceptualization, Methodology, Investigation, Writing- Original draft preparation, Visualization; S. Seyis: Conceptualization, Methodology, Resources, Validation, Writing-review & editing, Supervision, Project administration.

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Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

Not applicable.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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