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Lean-BIM Collaborative Approach for Sustainable Construction Projects in Malaysia

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ABSTRACT

Construction projects always deal with high-risk business activities, facing constant errors, and producing unwanted waste, leading to low productivity and sustainability. Lean Construction (LC) and Building Information Modelling (BIM) approaches have been recognized to resolve those issues. The implementation of both technologies is becoming popular amongst industry practitioners across the globe, claiming that they could also address the sustainability concerns in the construction industry. However, the usage of both innovations is fragmented, mainly, with their tools and processes being manipulated separately. Therefore, this paper aims to explore Lean-BIM collaborative approach towards establishing more sustainable construction projects, focusing on the Malaysian construction industry. The objectives of this paper are to identify the impacts of Lean-BIM collaborative approach on sustainability and to determine its capabilities in impacting the sustainability requirements for construction projects. This study conducted a survey by questionnaire in which 100 responses were successfully gathered from various stakeholders. Using Relative Importance Index (RII) of Statistical Product and Service Solutions (SPSS) software, the surveyed results were ranked concerning Lean-BIM impacts and capabilities. The findings acknowledged that the most-ranked Lean-BIM impacts towards sustainability in construction projects are in terms of productivity, quality, and safety and risks management. Whereas the highest-ranked Lean-BIM capabilities highlighted are Lean pull planning approaches, and BIM coordination and virtual mock-up. This paper could assist the construction practitioners' decision-making in managing sustainability for construction projects to venture competently into Lean-BIM innovation.

1. Introduction

The environmental effects of the construction sector are well-known. Depending on the contract type, complicated construction projects of a specific size are first designed before being built. The objectives of the project must be aligned with by a large number of players who must be coordinated in terms of content, quality, timelines, and costs. Everything that is improperly planned out during

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this collaborative process ultimately increases the danger of delays, increased expenses, or poor quality. It makes sense that everyone involved in the project, including the client, is interested in maximizing efficiency and mainly avoiding mistakes and issues. Lean Construction and BIM are the effective methods for accomplishing this goal as both are complementary to one another, particularly towards authorizing sustainability concerns in construction projects. Lean Construction and BIM are reliable methods to make construction processes in overall more profitable mainly in terms of reducing waste and eliminate anything that does not contribute value to the end result.

Lean Construction is a capable instrument that can be initiated in the industry to determine the case of construction waste including correction, over-processing, delay, inventory, conveyance, overproduction, and motion [1]. It is a planning mechanism that an organization can implement during the construction processes in which the method is a relentless enhancement approach that focuses on lessening construction waste [2]. Ogunbiyi *et al.,* [3] described that minimizing waste is the most significant value of synchronizing lean and sustainability. Whilst, BIM capabilities in evaluating sustainability could be described through criteria assessment of the BREEAM rating system with related processes need to be clarified before integrating the stages [4]. Chong *et al.,* [5] emphasized that the BIM approach could be potentially aligned with sustainable development frameworks with regulations and instruction to encourage sustainability in the built environment. According to the UK construction industry, a framework of Sustainable Strategic Development (FSSD) and BIM in enhancing strategies, policies and leadership towards sustainable production has been manipulated in a case study to be synchronized with Modern Method Construction (MMC) [6]. Additionally, the Green Star rating application has extensively governed BIM development in transforming its construction industry toward gaining more ozone-friendly and profitably in New Zealand [7]. Other than that, several past studies on BIM-sustainability related have been done focusing on BIM operation to improve existing building energy modelling (BEM) practices, optimization of energy consumption in building design through BIM and BIM sustainable indicators incorporated in the construction cost estimates preparation [8-10].

While BIM, lean principles, and sustainability concerns have become prominent trends as they strive to enhance buildings delivery throughout their entire lifecycle, there are still some issues need to be carefully addressed [11]. Although a significant knowledge emerges on the synergistic interactions of lean concepts applied in BIM for sustainable projects, there are very few studies that address both lean and BIM [12]. Undoubtedly, merging Lean Construction and BIM together improves efficiency far more than when they are applied separately. Lean Construction and BIM are significant change for both approaches contribute to greater efficiency in the Architecture, Engineering and Construction (AEC) industry. Understanding the client's values and incorporating them into the design and building process is made simpler by lean construction and BIM as both add value, reduce costs, and enhance communication and information flow throughout. Although these two techniques portray quite different approaches, there are many synergies between them as they both imply several overlapping benefits. Despite many challenges, lean construction and BIM, when integrated, will potentially produce a synergistic effect and ultimately give convenience towards sustainability establishment in the construction industry. Therefore, this study aims to explore the integration of Lean construction and BIM approaches in impacting sustainability aspects in construction projects.

2. Literature Review

2.1 Lean Construction

Ballard and Howell [13] explained on how lean production concepts and techniques help reduce the challenges in the construction industry's fast track, complex manufacturing and process plant sector projects. Whereas, with the lean construction paradigm, the construction industry has started to review and evaluate the possibilities of implementing these new lean perspectives of production concepts in the construction processes to optimize the overall construction performance on the construction stage as well as the design stage [14]. According to Dhamangaonkar [15], developing lean construction tools such as digital A3 Report can decrease reworks, minimize time waste, and cause better decision making. Additionally, one of the lean construction tools, the Last Planner System (LPS), effectively improves project planning reliability [16]. Aziz and Hafez [17] suggested lean construction projects to be easier to manage, safer, completed sooner, cost less and are of better quality as implementing lean thinking will lead to change in almost every aspect of project and company management [13]. Altogether, the purpose of lean construction is to enhance ways of eliminating waste, improving productivity, reducing costs, execution times and resulting in safer and more efficient projects. Lean methods have promising prospects for increasing construction sector productivity and creating a sustainable built environment, but these objectives must be attained through a critical mass uptake and ongoing application [18]. Nevertheless, despite the advantages shown, the Lean Construction technique also reveals a number of issues that must be overcome to foster its efficacy [19].

2.2 Building Information Modelling (BIM)

Building Information Modelling (BIM) is defined as a modelling technology associated with set of processes to produce, communicate and analyze building models which its components are characterized with digital representations [20]. BIM is used more often in the early stages of the project lifecycle where BIM have reported having cost reduction and control advantages through the project life cycle and time-saving [21,22]. Aim of BIM is to reduce waste from how the construction team delivers the construction projects to construction consumers [23]. Chen and Luo [24] further described that BIM helps improve the design quality by eliminating conflicts and reducing rework. In the case of Malaysia where the implementation is still at low level, the statistical research revealed that the participants' top priorities for BIM benefits were productivity, time, cost, conflicts, and communication, while the driving forces for implementation were found to be knowledge, trust, respect, and commitment [25]. By minimising the time-consuming and error-prone manual re-entry of information that characterises traditional paper-based workflows, BIM greatly enhances information flow amongst stakeholders involved at all stages [26]. BIM software is also one of digital tools that have been proved to bring many benefits towards the implementation of space management, life cycle analysis, training professionals and system integration platform management that will greatly reduce the operational costs [27]. All in all, BIM is already used in numerous construction projects all over the world because of its advantages. However, the building industry's fragmentation prevents it from being used more widely. There are still previous studies reporting on the implementation barriers that inhibit BIM technology to be successfully applied in the construction industry [28].

2.3 Sustainability in Construction Projects

Edum-Fotwe and Price [29] observed that the social dimension of sustainability has been growing in importance as a criterion for evaluating the viability of projects in the construction sector. According to Rooshdi *et al.,* [30], implementing sustainability has become a vital initiative discussed and undertaken by practitioners. Firms which make investments in research and development acts (R&D) in the construction industry of the future of the world by using strategic technology management and which can make their power sustainable to compete in the global market will be able to find a place for themselves in the market [31]. The government's intervention through policymaking and initiatives to go green presents the greatest strength, according to the results of the SWOT analysis by Shadman *et al.,* [32], while the weakness is the difficulty in implementing these policies as effectively as possible and the intermittency issues. Bamgbade *et al.,* [33] further clarified that the construction firms with well-organized resource competence tend to adopt more sustainability in project delivery. With regard to lean and BIM, both approaches are increasingly being used as reliable methods for sustainable construction practices [34,35]. These two methodologies when appropriately implemented can bring several benefits such as efficient collaboration and team integration, time reduction, cost reduction, quality improvements, efficient workflow, waste reduction and sustainability, customer's satisfaction, higher performance and risk reduction [36]. Yet, there are still several barriers exist towards the joint implementation of Lean-BIM [37,38].

Overall, past studies have demonstrated on how Lean Construction and BIM improve processes that could be further promoted for their potential impact on sustainability in the construction industry. Concerning sustainable practice, the application of BIM and lean construction principles can lead to a comprehensive improvement of the project scope, increased time efficiency, and lower overall project costs, which can serve as a foundation for redefining risks and challenges in the construction industry. To address the issue of underperformance of construction projects, an efficient management approach that incorporates BIM and Lean Construction is needed [39]. Workflow is improved by lean implementation, but not as much as when lean and BIM are combined [40]. It is then essential to investigate the relationship between lean principles and the BIM project delivery process to resolve many of the barriers exist especially when dealing with sustainability requirements [41]. Thus, this study is crucial in identifying the strategies to achieve successful application of these combined practices of lean, BIM and sustainability.

3. Methodology

The methodology for this study is portrayed as shown in Figure 1. The first stage of the methodology for this study was to review related literature from previous research combining various perspectives of multiple disciplines in the construction industry. Following the reviewed literature, a questionnaire survey deploying 5-Likert scale measured questions was developed and administered to gather the data required for the study. The respondents for the survey were amongst the various stakeholders such as Architects, Engineers, Quantity surveyors, Project Managers, and Contractors in the Malaysian construction industry, registered under their respective professional bodies (Board of Architects Malaysia, Board of Quantity Surveyors Malaysia, etc.). Samples were selected using a systematic random sampling technique, narrowing the scope to only respondents working around Klang Valley. The survey eventually obtained 100 responses from numerous construction industry players, regardless of whether the respondents are Lean-BIM, or non-Lean-BIM users, to demonstrate diversified views on issues studied in this study. The survey results were then descriptively analyzed and ranked adopting Relative Importance Index (RII) of Statistical Product and Service Solutions (SPSS) software using the formula RII = $\Sigma W / (A*N)$.

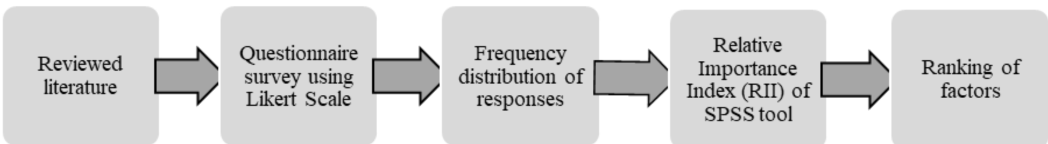

Fig. 1. Flowchart of RII analysis

RII is the mean for a factor which gives its weight in the perceptions of respondents, and was used in this study to calculate the weightage of each indicator involved and rank it accordingly. The five-point Likert scale was transformed to relative importance indices for each item of the impacts of Lean-BIM collaborative approach and also the capabilities of lean construction tools and BIM applications. The indices were then used to determine the rank of each item. These rankings made it possible to cross compare the relative importance of the items as perceived by the respondents. The weighted average for each item was determined and ranks were assigned to each item representing the perception of the respondents. RII is an appropriate tool to prioritise indicators rated on Likert type scales and its analysis allows identifying the most important factor based on survey responses Rooshdi *et al.,* [30]. The relative importance index (RII) was calculated for each item as shown in Figure 2;

$$\mathbf{RII} = \Sigma W / (A*N)$$

W = weight given to each factor by the respondents in a range from 1 to 5 (1 = strongly disagree , 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = strongly agree)

A = Highest weight (in this study, is 5)

N =Total number of respondents

Fig. 2. Relative Importance Index (RII) formula

4. Results and Discussion

100 respondents from various construction team players participated in the questionnaire survey for this study. The highest participation was from Contractor Firm with 17.2%, followed by 15.2% from Engineering Firm, Quantity Surveying Firm, and Local Authorities/Government Agencies respectively. Whilst 14.1% were from Academic institutions, 12.1% from Architectural firms and 11.1% from Developers. With regards to the main findings of the survey, Table 1 shows the RII ranks of the impact of Lean – BIM collaborative approach on sustainability in construction projects, while Table 2 shows Lean and BIM capabilities in impacting sustainability requirements for construction projects.

From Table 1, it was observed that the most-ranked impacts of Lean-BIM collaborative approach towards sustainability elements in construction projects are in terms of productivity, quality and also safety and risks management. For productivity, Lean-BIM approach enables the work plan to be synchronized with the actual site condition and material availability. It also enables early detection of conflict in design and planning which can improve the overall construction performances in relation to quality aspect. It is in line with a study by Maraqa *et al.,* [40], proving that the integration of Lean construction and BIM in owner-dominated megaprojects can improve management performance and achieve high quality standard where those integrated methodologies effectively support project teams in improving production flow in construction. Whilst, for safety and risks management, the Lean-BIM approach allows errors identification in design drawing involving structural element at early stage, subsequently expects the higher probabilities of identifying potential conflicts. Therefore, the implementation of both Lean Construction and BIM will crucially influence the construction project performance, starting from the project inception to the project completion as the number of critical issues that arise throughout the project is significantly reduced [42]. Consequently, cost reduction, efficient workflow and quality improvement are three main benefits of integrating these two methodologies [38].

Table 1
Impact of Lean – BIM collaborative approach on sustainability in construction projects

Item	Impact of Lean – BIM collaborative approach on sustainability in construction projects	RII	Ranks
1	Productivity		
	It enables the project team to deliver the product faster than traditional methods.	0.810	4
	It maximizes the workflow with the suitable construction process.	0.818	3
	It produces new technologies that can improve the productivity of the work process.	0.830	2
	It increases the labour productivity.	0.771	6
	It enables the work plan to be synchronized with the actual site condition and material availability.	0.846	1
	It produces high productivity site manager.	0.802	5
2	Quality		
	It enables early detection of conflict in design and planning which can improve the overall construction performances.	0.846	1
	It provides improvement in asset lifecycle management.	0.789	5
	It enables the construction team to make effective decision in improving the project outcomes.	0.828	2
	It helps the site managers to manage daily work by proper earlier plan.	0.818	3
	It monitors and controls the construction output in maintaining the construction quality.	0.785	6
	It processes the client needs in the design phase effectively.	0.802	4
3	Operation		
	It enables the construction team to make effective decision in improving the project outcomes.	0.834	1
	It helps the site managers to manage daily work by proper earlier plan.	0.802	2
	It monitors and controls the construction output in maintaining the construction quality.	0.794	4
	It processes the client needs in the design phase effectively.	0.798	3
4	Efficiency		
	It enables the optimization of sustainability practice in construction team.	0.790	3
	It reduces the energy usage of such building typologies.	0.752	6
	It analyses and improves the building performance earlier with reduced coordination issues.	0.814	1
	It eases the process to obtain building plan approvals and construction permits.	0.760	4
	It encourages the implementation of clean technologies that require less energy consumption.	0.758	5
	It facilitates project management processes during bidding, pre – construction, construction and post – construction.	0.790	3
	It generates the ability to track change in cost in real time due to change of projects scope.	0.800	2
5	Cost		
	It Integrates design and detailing competencies during the early stage and contributes for cost saving.	0.800	4
	It provides cost benefit analysis of different waste management alternatives.	0.790	5
	It helps to instantly generate precise quantity take offs from the building model materials.	0.826	1
	It helps with full control of material quantities in project which leads to cost control.	0.808	2
	It contributes to the reduction of overall total cost project.	0.788	6
	It improves the financial and investment opportunities.	0.788	6
	It minimizes the cost of the building components with identified material waste elimination earlier.	0.806	3
6	Safety and risks management		
	It identifies errors in design drawing involving structural element at early stage.	0.842	1
	It expects the higher probabilities of identifying potential conflicts.	0.840	2
	It improves the distribution of construction sequences through identification of irregular elements.	0.796	4
	It minimizes in site-based conflicts.	0.810	3
	It reduces claims or litigations risks.	0.796	4

7	Waste management		
	It helps to get the right quantity of construction material.	0.808	3
	It helps the project team to deal with wastages with practical ideas and techniques.	0.814	1
	It measures the practicability of measuring the deconstructability of building design to reduce waste.	0.784	7
	It helps manager to alleviate the different causes of waste generation, such as clashing structural and mechanical elements.	0.812	2
	It helps to integrate information for detailed planning to minimize the abilities of over ordering raw materials.	0.800	4
	It helps to eliminate the construction waste during the design and pre-construction phase.	0.796	5
	It facilitates the selection of sustainable materials and components.	0.792	6
8	Project duration		
	It reduces project duration, delay and process activities.	0.768	2
	It identifies work sequences errors in original schedule.	0.802	1

Whereas Table 2 tabulated the ranking of Lean and BIM capabilities towards influencing the sustainability components for construction projects. It is shown in the table that the highest-ranked Lean capabilities are in terms of pull planning approaches in ordering materials based on master schedule prepared and keeping the inventories bare minimum and new inventories are ordered based on current demand. Meanwhile, for BIM application, in impacting sustainability requirements for construction projects, the most-ranked BIM capabilities are in terms of its coordination for architectural, structural, and MEP models in a project by way of clash detection. BIM is acknowledged for its capabilities to be able to detect errors, omissions, and clashes before construction, hence it helps reduce waste and make the construction processes more linear towards more sustainable practice [43]. Other than that, BIM was highly ranked on its capabilities of virtual mock-up in aiding contractors in quantity and material estimation accuracy, as well as cost control efficiency and quality. Additionally, BIM capables to provide instantaneous generation of accurate building element quantity, materials, and cost estimation based on elements in the model. As suggested by Ayman *et al.,* [44], uncertainties in sustainable construction processes can be handled by employing BIM technical capabilities in order to manage resources.

Table 2
Lean and BIM capabilities in impacting sustainability requirements for construction projects

	Lean and BIM capabilities in impacting sustainability requirements for construction projects	RII	Ranks
A	Lean Construction Tools		
1	Pull Planning Approaches		
	It is capable to order the materials on the basis of the master schedule prepared.	0.792	1
	It is capable to keep the inventories bare minimum and new inventories are ordered based on current demand.	0.786	2
2	Multifunctional task groups		
	It is capable to reduce worker time for waiting for each other to complete work.	0.772	2
	It is capable to recombine thinking and doing by the construction team.	0.778	1
3	Total Quality Improvement		
	It is capable to reduce costs and increasing efficiency.	0.764	1
	It is capable to involve the construction team to update the workers to suggest new idea regularly.	0.762	2
	It is capable to implicate cost reduction and zero defects in final stage of construction.	0.747	4
	It is capable to improve the construction result quality.	0.753	3
	It is capable to focus on continuous improvement to achieve high quality of works.	0.762	2
4	Digital A3		
	It is capable to mention any situation that needs improvement and follow up plan on digital A3 tools.	0.784	2

	It is capable to highlight the important points for discussion.	0.776	3
	It is capable to helps the management to do analysis using digital A3 tools such as fish bones analysis, pareto analysis, etc.	0.786	1
	It is capable to improve communication between the employees and pushes them to meet the deadline.	0.745	4
5	Last Planner System		
	It is capable to generate the decision-making power distributed well among the project team.	0.782	1
	It is capable to convey project team to complete designated task in a given week.	0.776	2
6	Statistical Process Control		
	It is capable to use control chart to track the performance of a process.	0.774	1
7	Value Stream Mapping		
	It is capable to create finished product from raw materials to meet customer demands.	0.750	2
	It is capable to generate a current state map, future map and implementation plan.	0.752	1
B	BIM applications		
1	Coordination		
	It is capable to coordinate material ordering, fabrication and delivery schedule.	0.810	4
	It is capable to trade coordination for architectural, structural, and MEP models in a project by way of clash detection.	0.832	1
	It is capable to offer efficient manner of uncovering and identifying potential conflicts between trades and effective resolution through coordination.	0.814	3
	It is capable to manage the technical issues and decision making, providing support to design development.	0.816	2
2	Integrated Site Planning		
	It is capable in adding a level of detail, particularly in more vertical construction.	0.800	1
	It is capable in integrating intelligent equipment and objects that communicate with humans that will make jobsites safer and more productive.	0.772	2
3	Virtual Mock-Up		
	It is capable to provide instantaneous generation of accurate building element quantity, materials, and cost estimation based on elements in the model.	0.826	2
	It is capable to aid contractor in quantity and material estimation accuracy, as well as cost control efficiency and quality.	0.832	1
4	Digital Fabrication		
	It is capable to do the work process like design, material processing using digital tools.	0.800	1
	It is capable to speed up the schedule and streamline with the entire process.	0.800	1
	It is capable to facilitate the construction team rely on its accuracy to deliver a project to the owner on time.	0.780	2

5. Conclusions

In conclusion, this paper identified the impacts of the Lean–BIM collaborative approach toward ascertaining the sustainability of construction projects in Malaysia. It has been shown that Lean–BIM can solve many of the industry's problems thru the collaboration of these two latest technologies and tools in upgrading the construction projects to become sustainable. This paper also explored Lean and BIM capabilities on construction project sustainability requirements. It potentially helps the construction team players increase their productivity and knowledge in Lean–BIM practice. This Lean-BIM approach will help the stakeholders in the construction industry to evaluate their overall project performance efficiently and effectively, including financial and project delivery. Additionally, the study further aligns with the Malaysian Government's aspiration to drive the Malaysian construction industry towards higher productivity, developing disruptive technologies and increased sustainability, as highlighted in Construction 4.0 Strategic Plan 2021 – 2025 and Shared Prosperity Vision 2030. Subsequently, it assists the industry players in sustaining and remaining competitive locally and globally in the construction industry. The inclusion and exclusion criteria of the respondents' background characteristics including working experience in the construction industry and the field studied, current organization and the usage of Lean-BIM approach, determined the eligibility of the study population in a reliable manner. Nevertheless, the study is limited in terms of lacking details in the quantitative survey as the responses are fixed, inhibiting the respondents in reflecting their true feelings towards the study. Therefore, further studies should be conducted in a qualitative means to additionally detailing the relationships between the critical factors encompassing Lean-BIM criteria identified in this study to be aligned with more focused sustainability attributes in a construction project.

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