Rahman, M.A. and Belayutham, S., 2022. BIM-Lean relationship assessment framework: A conceptual establishment. In: Sandanayake, Y.G., Gunatilake, S. and Waidyasekara, K.G.A.S. (eds). *Proceedings of the 10th World Construction Symposium*, 24-26 June 2022, Sri Lanka. [Online]. pp. 185-197. DOI: https://doi.org/10.31705/WCS.2022.16. Available from: https://ciobwcs.com/2022-papers/

BIM-LEAN RELATIONSHIP ASSESSMENT FRAMEWORK: A CONCEPTUAL ESTABLISHMENT

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ABSTRACT

The construction industry is seeking ways to reduce waste (material and production-related process waste) to improve productivity and efficiency. Building Information Modelling (BIM) and Lean are two vital innovations for the Architecture, Engineering, Construction and Operation (AECO) industry used in the industry to improve aspects of productivity and efficiency. BIM has been used to generate and compare designs to ensure optimum use of resources, reduce design time, improve collaboration between stakeholders, and reduce errors in design and construction. On the other hand, the main agenda of Lean is to reduce (both material and production process) waste, increase value, and thrive for continuous improvement. In the construction industry, BIM and Lean have been mostly used in isolation. However, studies suggest that BIM and Lean have mutual relationships and are complementary to achieve each other's objectives. To do so, it is very crucial to understand the mechanism behind the relationship and the interaction between BIM and Lean. Informed analysis and understanding of the mutual relationship would help construction management decision-makers to achieve the utmost benefits from the implementation of these two drivers. However, previous studies have explored BIM and Lean relationships, but limited studies were done to support construction management decision-makers in identifying relevant BIM functions to enable Lean or to identify relevant Lean principles to support BIM. Therefore, this paper aims to represent a conceptual BIM-Lean relationship assessment framework by using Design Science Research methodology to identify and measure the relationship between BIM and Lean to support construction management decision-makers.

Keywords: *BIM; Framework; Lean; Relationship.*

1. INTRODUCTION

Modern-day construction projects are getting more complex, fragmented, and challenging day by day. These complexities and challenges have mostly been related to productivity issues (Matta, et al., 2018). Studies on productivity have shown that at the global level, 30% to 50% of the time in construction was wasted on non-value-adding activities such as waiting, Requests for Information (RFI's), design change, and clashes (Horman and Kenley, 2005; Elfving, 2007). A study by McKinsey (2017) found that between 1995-2015, the compound rate of growth of value-added per worker in the construction sector was just 1.0%, while the manufacturing industry's growth reached a rate of 3.6% per year

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within the same time. Therefore, to improve productivity in construction, coordination and collaboration play a vital role. Effective coordination and collaboration can help to reduce design time and design errors which could lead to on-time project completion (Zhang, et al., 2018). Similarly, cost overrun, and quality problems have also been linked to the lack of coordination and poor information flow subsequently leading to reworks and waste (Doloi, et al., 2012; Shanmugapriya and Subramanian, 2013; Mahalingam, et al., 2015).

The construction industry has been identified as the major contributor to overall global waste (Wang, 2009). As an example, 25 to 30 % of the waste generated in the EU comes from the construction industry (European Commission, 2016). Apart from the commonly associated material waste, non-value-adding process waste is another type of waste recognized in construction. Multiple discrete construction organizations are typically associated with different tasks and due to the lack of well-defined management approaches, this often generates waste from waiting time for crews, reworking, unused inventories, and unnecessary movements (Mollasalehi, et al., 2016). Fundamentally, Lean is a management concept to eliminate waste from processes and improve the value through principles, techniques, and tools.

On the other spectrum, Building Information Modelling (BIM) is a technological innovation that helps to improve collaboration, coordination, and information flow in construction projects from inception to demolition. BIM 3D intelligent model can embed, update (design, cost, time, sustainability) and simultaneously share data with multiple stakeholders. BIM has multiple Uses (to perform different tasks) supported by different software to visualize, analyze and simulate virtual 3D models before the real construction begins, which could also improve productivity.

Concerning the low productivity, inefficiency, and wasteful approach, the AECO professionals are searching for new technological and management solutions (Mellado and Lou, 2020). Lean and BIM are two key innovations to improve the productivity and efficiency of the construction industry. However, to achieve the maximum benefits from BIM and Lean, it is important to ensure effective and informed use.

BIM and Lean could be complementary to each other. As an example, BIM can act as an effective tool to achieve Lean goals (the purpose of applying Lean) such as waste elimination and improving value. Similarly, Lean principles, techniques, or tools can ensure the effective implementation of BIM. BIM implementation often involves non-value adding activities and Lean can help to eliminate the non-value adding activities to ensure optimum outcomes from BIM implementation. In the literature, there are more than 30 BIM Uses and Lean principles that are evolving with time. Gaining a better understanding of the advantages a certain BIM Use has over a certain Lean principle or vice-versa would help practitioners to use and invest money in the BIM Use or Lean more wisely.

Past research works have identified the way BIM complements Lean and Lean complements BIM, where relationships were shown in developed frameworks. However, there is still no robust framework or guideline for the construction management decision-makers to determine what/ which BIM Uses can support Lean implementation to eliminate waste or what/ which Lean (principles, techniques, or tools) can support BIM implementation to improve collaboration and coordination. Against this backdrop, this study has proposed a conceptual framework, as a basis to identify how BIM Use can help to achieve Lean or how Lean could help in the implementation of BIM in the construction project. The established conceptual framework could be used as a guide for the practitioners to wisely use BIM and Lean to achieve their goals globally.

2. RESEARCH METHODOLOGY

Design Science Research (DSR) is a constructive research approach that has been used to solve real-life problems, where it has been widely used in the health care, information management, engineering, and construction management research domain (Hevner, et al., 2004; Van Aken, 2004). The DSR approach helps in connecting academic knowledge to solve AECO industry problems by creating tools, frameworks, models, methods, or guidelines (AlSehaimi, et al., 2013).

Pefferes, et al. (2006) have proposed a process model for the conduct of DSR, which consists of six steps in a nominal sequence to create the solution or artifact. The steps are as follows: i) Problem identification and motivation (to identify the main problem and explore the motivation to solve the problem) ii) Objectives of a solution (to represent the desired characteristics of the solution), iii) Design and development (artifact development stage which includes all the activities such as research, define functionality, architecture required to create the artifact), iv) Demonstration (to determine the efficacy of the artifact by testing or implementing it in the real-world scenario), v) Evaluation (to measure and compare artifacts desired and actual results after implementing it in the real scenario. Based on the result, the researcher can iterate back to the design and development stage to make the artifact more robust), vi) and Communication (to communicate the utility and novelty of the artifact to wider audiences via research articles).

This study is also aiming to develop a conceptual framework to use in real life, therefore researcher has chosen the DSR approach limited to a certain extent. Besides, the DSR methodology will provide the opportunity to refine the framework (after the initial establishment) and validate the framework. DSR structured analysis, refinement, and validation process are aligned with the objectives to develop the framework.

Nonetheless, the scope of this study has been limited to demonstrating the three initial stages of the DSR to develop the conceptual framework. The entire paper forms the DSR for this study, where the introduction section has elaborated on the problem and motivation, the literature review section discusses the objectives of the solution and finally, the conceptual framework section discusses the design and development of the artifact.

3. LITERATURE REVIEW

3.1 BUILDING INFORMATION MODELLING (BIM)

BIM has evolved from conventional two-dimensional (2D) drafting to an intelligent three-dimensional (3D) model that encompasses the physical and technical characteristics of a structure (Uddin and Khanzode, 2013). BIM can be defined as a software-based virtual representation of an actual facility rather than a set of paper-based two-dimensional (2D) drawings (Krygiel and Nies, 2008). National Building Information Modelling Standard (NBIMS) described BIM, as a product, process, and system to virtually represent the physical and functional characteristics of a facility and also act as a shared knowledge resource for information about a facility to make informed decisions in different stages of a project (Sacks, et al., 2018; Lu, et al., 2020).

In summary, the core functionalities of BIM are to (1) support collaboration in work processes between multiple team members; (2) create highly photorealistic virtual reality; (3) generate intelligent, data-based three-dimensional (3D) models; (4) share and merge intelligent model data with designers, construction management professionals and facility managers; (5) develop time (4D) and cost (5D) simulations; (6) support different sustainability features (such as energy) analysis; (7) support model-based communication through online and cloud systems; (8) enable data sharing with computer-controlled fabrication systems; (9) maintain information and design model integrity; (10) automate documentation; (11) use model data for different analyses (such as automated quantity take-off, and code checking) (Sacks, et al., 2010).

3.2 LEAN

The word Lean is based on the Japanese word Muda, which means waste: something that uses resources but creates no value. Taiichi Ohno (1912-1990) a Japanese engineer (Toyota Motor Company) first coined the word Muda concerning production that promotes productivity and destroys inefficiencies. To eliminate Muda, Ohno introduced the Toyota Production System (TPS) which inspired Lean thinking to create or specify the value and value-creating actions to achieve customer satisfaction (Rahman, et al., 2013; Singh and Kumar, 2019). Following TPS, Womack and Jones (1996) defined value as the first principle of Lean thinking and specified that all the activities in a process should focus to eliminate non-value adding steps and make value-added activities flow smoothly to achieve customers' requirements. Lean Construction (LC) follows the concepts and principles of Lean Production, which covers different aspects (such as design, supply chain, and processes) of a construction project throughout its life cycle (Ballard, 2008). LC can deal with the inherent construction industry problems like low productivity, poor quality, inefficient supply chain, poor safety, and time and space conflict (Tezel, et al., 2018). Therefore, LC has been recognized as an enabler in the construction production system to minimize waste and increase value (Koskela, et al., 2002; Tezel, et al., 2018).

3.3 BIM-LEAN BI-DIRECTIONAL RELATIONSHIP

BIM functionalities and Lean principles can produce significant benefits for AEC organizations even when implemented in isolation (Sacks, et al., 2010a). Past research has provided robust evidence about the positive impacts that the relationship between BIM and Lean can have on AECO organizations and projects (Sacks, et al., 2010). Theoretically speaking, the BIM-Lean relationship can be bi-directional, which means BIM can support Lean principles, and in turn, Lean can support the implementation of BIM (Bhatla and Leite, 2012).

When BIM influences Lean (BIM→Lean direction), BIM can help Lean achieve elimination of waste (concerning overproduction, reworking, and waiting time), reduce variability, and cycle time, and visualize production methods and processes (Sacks, et al., 2010). For instance, the BIM function of "automated quantity take off" can help to generate accurate, reliable cost estimation information without errors, reworking, and waiting, which are major concerns in Lean. Cost estimation for any project traditionally starts with the quantification of resources. Conventional manual quantification from 2D or CAD documents is a process that is time-intensive, laborious, and prone to human errors that tend to propagate inaccuracies (Hartmann, et al., 2008). As a result, it prevents the flow of correct, complete, timely information and creates variability in the production process (Eastman, et al., 2011).

Similarly, Lean has positive impacts on BIM (Lean→BIM direction), where Lean can help to promote effective BIM implementation by using different Lean principles, tools, and methods (Hamdi and Leite, 2012). BIM's success requires significant skill and knowledge to manage stakeholders, set up the workflow, and analyze supportive project documents such as plans and specifications (Hamdi and Leite, 2012). Lean can help to ease the BIM implementation process by eliminating non-value-adding activities and improving coordination and consistency. For instance, to implement BIM, good preparation, planning, and documentation are prerequisites for a client's representative and consulting architectural or engineering personnel who want to make the implementation happen.

"Standardization" is a Lean principle that helps to determine the best methods to use in a process and to reduce variation as much as possible (Feng and Ballard, 2008). Standardization has a close link to the successful implementation of BIM in any project or organization. To implement BIM, a client's representative has to clearly define the client's requirements in terms of project goals and project deliverables. Similarly, consultant architects or engineers have to evaluate BIM competency requirements and develop a process map of collaboration between different stakeholders regarding information management and maintaining common data environments. Therefore, a standardized system is necessary to carry out all the requirements for the successful implementation of BIM. The New Zealand BIM Handbook, UK BIM Level 2 guideline, and Natspec BIM (Australia) are examples of such standardized ways to implement BIM in any project (BIM Acceleration Committee, 2019).

3.4 OVERVIEW OF BIM AND LEAN RESEARCH

From the literature, researchers have investigated diverse aspects of BIM use and Lean in different areas of construction projects. Through Literature analysis, the researcher has found more than 80 scientific papers (journal papers and conference papers) discussing BIM and Lean in the last 5 years (2016-2021). In general, these papers can be categorized into the following themes i) BIM-Lean integrated application framework/ model development ii) BIM-Lean individual and mutual application advantages to improve the AECO industry, and iii) BIM-Lean interaction identification and interaction framework/model development. However, as this paper's focus is to explore the BIM-Lean relationship, the following section briefly discusses on BIM-Lean interaction identification and interaction framework/model development research.

In the Lean (particularly in LC) community, BIM has been seen as a tool to support the processes towards attaining Lean goals (Dave, et al., 2013). Therefore, to reap the full benefits of BIM-Lean integration and implementation, it is vital to know their mutual interaction. Sacks, et al., (2010) have laid the foundations for investigating and advancing research around the relationship or relationship assessment between BIM and Lean. The most significant work on the BIM–Lean linkage by Sacks, et al., (2010) was in forming a matrix of BIM and Lean. After that, other researchers have also found BIM and Lean integration research to be an evolving and crucial area of investigation (Dave, et al., 2013) in different areas of the built environment. Oskouie, et al., (2012) remarked on the importance of BIM and Lean in the operation and maintenance (O&M) stages of a facility and validated BIM's contribution in the Operation and Maintenance stages to support Lean goals such as reducing waste. Besides that, Oskouie, et al., (2012) have used Sacks, et al. (2010) matrix to identify new relationships between BIM and Lean at the O & M stage. They have further added new Lean principles and BIM functions in the matrix related to O&M activities and further identified additional 17 relationships.

Ningappa (2011) also studied the relationship between BIM and Lean by further illustrating how BIM helped Lean as a tool to achieve Lean goals. Alarcon, et al. (2013) also conducted a study to understand BIM implementation from the Lean perspective. By analyzing different BIM-Lean papers, they have identified 107 new interactions apart from the 56 interactions from Sacks, et al. (2010). Elmaraghy, et al. (2018) researched to explore BIM and Lean integration in demolition projects. In this regard, Elmaraghy, et al. (2018) have used Sacks, et al. (2010) BIM, Lean interaction matrix as reference. Based on that, the researchers have identified the relevant BIM and Lean principles for the demolition project. Gomez-Sánchez, et al. (2019) conducted a case study project in Colombia to understand Lean and BIM implementation impact. The authors have analyzed the BIM functions and Lean Principles mentioned in Sacks, et al. (2010) interaction matrix. After analyzing the BIM output from the case study, the project team found 10 new synergies between Lean-BIM and concluded that there are a few that could be tested with a little more maturity of the project team and additional minimum investment.

McHugh, et al. (2019) investigated an integrated Lean and BIM implementation approach by analyzing a highly modular and offsite production process on a data center project. This research focused on exploring how Lean and BIM can help the project team to visualize and control the production, whilst supporting the continuous improvement process. Koseoglu, et al. (2018) conducted a case study to explore the relationship between BIM and Lean in Istanbul grand airport construction project. The researchers in the study understood how the implementation of BIM in such a mega project (76 million m2 of airport area with six runways) helped to achieve Lean efficiency. In this project, BIM has been used both in the design and construction stages. In design, BIM has helped to achieve Lean targets such as zero defects, eliminating waste, reduce rework by identifying design errors. In the project, more than 600,000 clashes have been solved which saves money, time, and rework. Apart from that, BIM has created a platform of collaboration and data sharing among different stakeholders, which reduces the variability (Lean principle). On the other hand, during construction, BIM 4D planning, 5D cost estimation, and as-built modeling helped to attain the Lean principles of reducing the cycle time of installation, reducing rework on site, and also reducing the non-value adding activities.

4. CONCEPTUAL FRAMEWORK

To develop the conceptual framework, a literature review was conducted on various scientific methods of framework development, such as Morphology Analysis (MA), Cross-Impact Matrix (CM), Multi-Criteria Decision Analysis (MCDA) methods (such as Analytical Hierarchy Process, ELECTRE, Multi-Attribute Utility Theory), Design Structure Matrix (DSM), System Dynamics and Quality Function Deployment (QFD). All of the methods were reviewed and analyzed. In the analysis, the relevance of the method to the research problem, and the pros and cons of the method, were determined and tested hypothetically. The hypothetical test used the above-mentioned methods to find a relationship between BIM and Lean. The aim of selecting the method was to meet the goal or requirements of the framework, which are:

1. able to determine the relationship between two variables,
2. pairwise in-depth and root level analysis,
3. able to measure the interconnection or relationship level.

After careful analysis of different methods and considering the above-mentioned criteria, the researcher has found that Quality Function Deployment (QFD) is the most suitable tool to develop the conceptual framework. The following section has described how QFD helps to fulfill the criteria mentioned above.

4.1 QUALITY FUNCTION DEPLOYMENT (QFD)

QFD, as defined by Akao (1990), is a systematic way to represent the relationship between consumer demand and technical characteristics to improve quality and achieve greater customer satisfaction. Nowadays, QFD is extensively practiced in many industries (including aerospace, defense, and construction) and due to its enormous application and potential, QFD has been extensively researched and the literature has been enriched via comprehensive reviews of this topic (Sharma, et al., 2008).

Considering QFD's ability to support decision-making by translating customer requirements into design characteristics and measuring the relationship, this research has followed QFD to develop the initial framework. The next section discusses the QFD analysis process and how the researcher has embedded the QFD analysis steps into the conceptual framework.

4.2 QFD ANALYSIS PROCESS

QFD is also known as the House of Quality due to the pictorial structure of the analysis process. Figure 1 shows a typical "House of Quality (HOQ)" and represents the different elements of the HOQ. In QFD the analysis process is divided into 11 steps, which are discussed in the following sections.

Voice of customers (1)

The first step in the QFD process is to define the customer requirements. The customer requirement is prioritized customer demand, need, or needs which is usually expressed in general terms. These customer requirements can be gathered by survey, questionnaire, or focus groups.

Customer requirement weighting (2)

The next step is to prioritize the customer requirements (voice of customers) by assigning a weight. A given weight reflects the significance or importance of each requirement. Usually, the weight is expressed in percentages and can be determined via a survey or online questionnaire.

Design requirements (3)

In the third step, the design requirements must be translated into quantifiable technical measures, which represent ways to achieve the customer requirements. Design requirements are the technical requirements or design characteristics of a product or service, which have a significant impact on achieving customer requirements. These requirements represent the product characteristics in technical terms and are usually determined by the product development company. These characteristics are chosen in a way that best achieves the customer requirements.

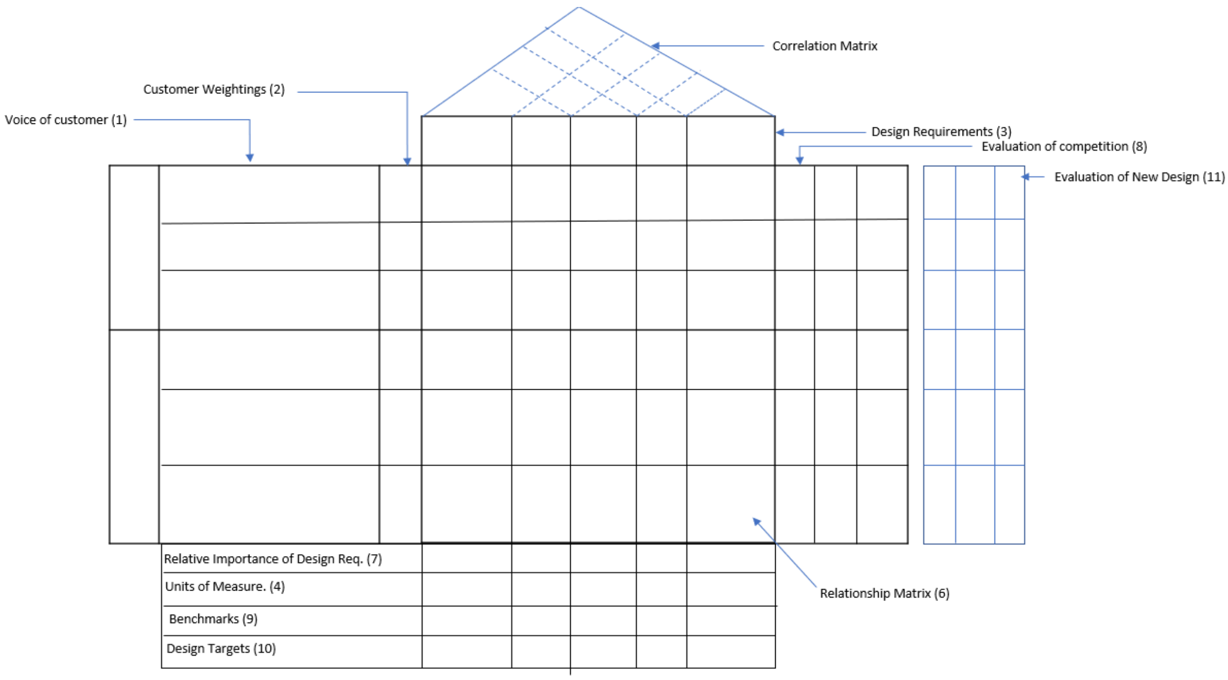

Figure 1: Formation (steps) of house of quality

Source: Adapted from Eldin and Hikle (2003, p. 318)

Units of measurement (4)

To ensure clear communication, units of measurement (such as meter for length) need to be established very clearly to avoid misunderstandings.

Correlation matrix (5)

The correlation matrix represents the relationships between design requirements. It helps to determine whether a design requirement negatively or positively affects other design requirements. The product development team evaluates the correlation among the technical requirements or design characteristics. It helps the product development team to understand how they are affecting each other's performance and how they affect the achievement of the customer's requirements.

Relationship matrix (6)

The relationship matrix indicates how design requirements affect customer requirements. By assigning weight (on a 1-9 scale, where 9 represents extremely strong and 1 represents extremely weak) in the matrix, the strength of the relationship can be determined. The relationship matrix is the core of QFD analysis. The relationship matrix determines the importance of the technical characteristics in meeting the customer's requirements. Based on the impact of technical requirements or design characteristics on achieving the customer's requirements, a product development team assigns a score for each customer requirement and design characteristic.

The relative importance of HOWs (7)

In QFD design characteristics also need to be prioritized according to their importance. To do so, each of the design characteristics weights (given in step 6) needs to be multiplied by the prioritization rating (determined in step 2). After that, according to the total score, each of the design requirements gets prioritized. This prioritization helps the product development team to allocate resources for specific design characteristics.

Evaluate current competition (8)

In this part of QFD, the product being designed is judged (through a rating scale) against other products from a customer viewpoint. This evaluation aims to determine the relative position of the designed product against other products, in terms of fulfilling customer requirements.

Benchmarks (9)

Benchmarking is an important part of QFD. Benchmarking helps to judge the product against a standard and guide the design to achieve customer satisfaction.

Design targets (10)

After analyzing the comparison with other products (in Step 8) and benchmarking, the next step is to set new targets to improve the product.

Evaluation of new design (11)

After setting the new targets, the next step is to re-evaluate the customer's requirements against the proposed design.

4.3 INITIAL FRAMEWORK DEVELOPMENT

The BIM-Lean Relationship Assessment Framework (BLRAF) is developed by embedding the analysis features of QFD. This framework maps the Lean principle needs into definable and measurable BIM function parameters, to understand their impact on Lean. To that end, this framework has followed several key steps of QFD, such as customer requirements and rating of importance, design requirements, relationship matrix, and relative importance of design requirements. However, the other parts of QFD such as the correlation matrix, evaluation of competition, benchmarks, and design targets were discarded because were found to be irrelevant to the requirements of the framework. The proposed framework (see Figure 2) is divided into four phases, as follows:

Phase I: Identifying All Relevant Governing Factors to Achieve the Purpose of Lean Principle and Prioritize

In the first phase, QFD assesses customer requirements. In this framework, the customer is Lean, and the requirement is that the governing factors help to achieve Lean's purposes or objectives. The governing factors can be identified via discussions in focus groups, expert opinion, interviews, literature reviews, or any other method. The governing factors represent the prerequisites or requirements to achieve the goals. As an example, "Reduce the non-value adding activities" is a fundamental Lean principle. This principle can be the customer in this framework and the requirement could be the different non-value-adding activities such as overproduction, motion, and waiting. These requirements or factors then need to be prioritized according to their importance. Each of the customer requirements is then scored on a scale and finally prioritized based on their cumulative value.

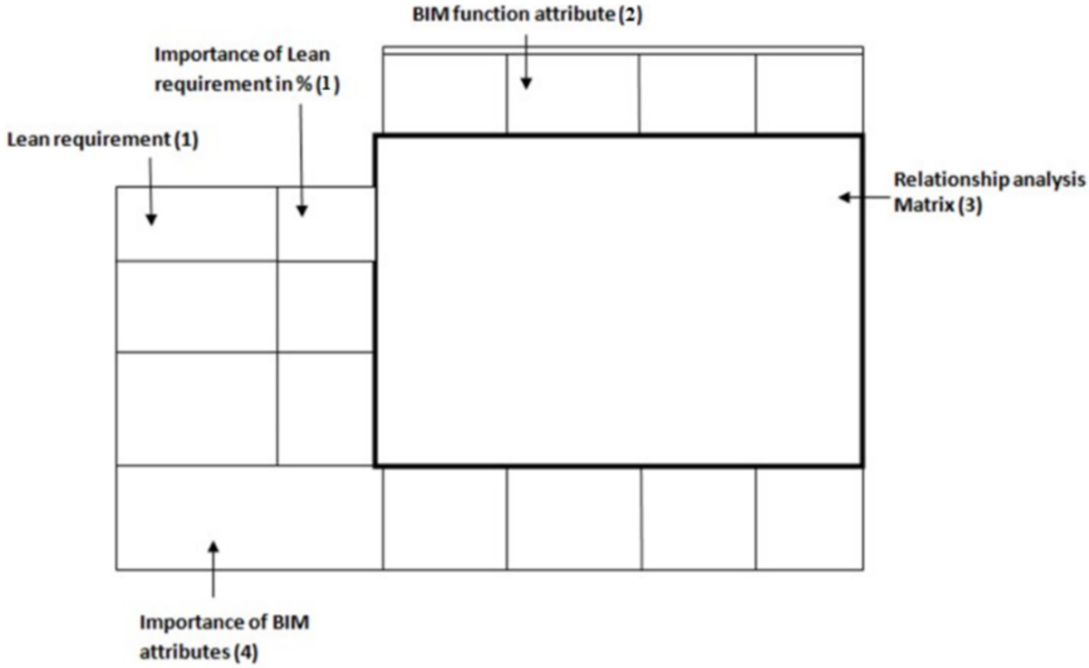

Figure 2: BIM-Lean relationship assessment framework structure

Phase II: Identifying All Relevant BIM Function Governing Factors

In this framework, the BIM function represents the design requirement of QFD to support Lean principles. In this step, BIM functions will be divided into the key governing factors. The governing factor means the core features or usage of a particular BIM function. Consultation with relevant BIM experts focus group study or literature review may help to determine the governing factors of BIM functions.

Phase III: Relationship Matrix

The House of Quality (HOQ) is the key tool used to represent the process of QFD analysis (Bolar, et al., 2014). The middle section of the HOQ represents the relationship matrix, which systematically evaluates the relationships between the customer's requirements and the associated design requirements. The assigned score or points indicate the strength of the relationships between each of the customer requirements and their associated design requirement.

In this framework, the relationship matrix will determine and measure the relationship between Lean principles and BIM functions. The influence level of each pair of Lean and BIM factors is judged by experts, who will focus on assessing whether the BIM factor supports achieving the Lean factor. According to the impact on Lean factors, each of the BIM factors will be assigned a weight (as in QFD analysis). The given weight will represent the level of influence.

Phase IV: Absolute Weight and Ranking of BIM Factors

The bottom section of the HOQ determines the relative importance of the design requirements. To prioritize the ranking, each relationship value is multiplied by the prioritized customer requirement. The sum of the values for each design requirement column then provides the relative ranking or importance of that design requirement. The relative percentage of these individual factors helps to determine, for a certain BIM function, which factor has the greater impact. Similarly, all the BIM factors are ranked to understand their relative impact on Lean factors.

Using this framework, BIM and Lean relationships can be assessed to a finer level of detail because the framework breaks down Lean and BIM into relevant factors. This will enable a greater understanding of how the characteristics of a particular BIM function help to achieve Lean principles. The weights in the relationship matrix and ranking can also help to generate an understanding of how much BIM influences a Lean principle.

5. CONCLUSION

BIM and Lean are two critical factors to improve the performance of the construction industry. However, to get the utmost benefit from BIM and Lean a careful analysis is important to understand how they are fulfilling each other purposes to improve efficiency. This research has presented a framework to assess the relationship between BIM and Lean. This framework will guide the construction management team to identify the right BIM function to achieve Lean and therefore improve efficiency. As a part of ongoing research, this framework would be tested and revised to make it more robust in future studies.

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