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Benefits of Integration Between Lean and Bim in the Design and Construction Phase; Lessons Learned

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Abstract Lean construction and BIM are two swiftly developing applied research domains in the field of construction management. Lea's construction seeks to eliminate or get rid of refuse in the construction operation while BIM targets increasing collaboration between the project teams during the design and construction stages of the project. Project success is very much associated with the collaborative interaction between stakeholders and the exchange of information from the whole concerned workers all along with the duration of the project or the life span of the project. In BIM projects the interaction between the various participants is more resilient as the data are collected and shared transparently between the owners, the architects, structural and MEP engineers, consultants, the contractors, and the subcontractors. Establishing or building modeling assists in translating the value of the owner into a successful enterprise by providing an ongoing flow of data and information and coming up with a high-value outcome. In this paper, the application of Lean using BIM in the erection process is conducted. It has been noticed that BIM has a unique ability to pinpoint errors .omissions, collisions before the building process which facilitates it for us to more precisely analyze risks\benefits and prematurely in the development process. Research has demonstrated that BIM and Lean principles implementation at the University of Dammam project can boost the design stage. While BIM advocates the presumed design solution and data storage that can enhance the manufacturing and installation activities. Such support has been of astounding merit in handling an unsure environment. The lean technique has made the visualization and the better understanding of vital lead times to enhance growing contact between various project participants so that concept could be produced on time. On the other hand, BIM and Lean principles can sustain the construction stage by minimizing the number of modification orders and RFI.

Keywords:. Building Information Modelling; Lean construction; Lean construction refuse.

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1. Introduction

Construction is regarded as one of the oldest industries to be a series of activities that target a certain output. The construction process consists historically of various kinds or sorts of refuse that transform a good project into a bad one. Construction processes have been greatly supported for peerless features owing to their application in an environment characterized by varying levels of variation. Therefore while they aim for success these processes encounter plenty of stumbling obstacles. Conventionally, the construction technique after the designer has finalized drawings starts the real work or the execution stages which leads to a series of clashes that arise along with the matters found or discovered at the construction of the design process before the delivery of the output. Such conflict-based problems are increasing in the field that could be saturated by using outdated (old-fashioned) and classical facilities. And drafting took extensive, the shortage of coordination between the design and the construction stages and the low-quality visualization for sensual elements that are incorporated or involved in the project.

Lean management is a pattern shift, it is a modern and new approach of thinking that transforms the traditional understanding of the construction delivery process into a set of isolated, linked activities to see the construction as a movement of concepts, materials, and knowledge through time and space according to [1:3]. Lean construction would be more helpful to identify Lean regarding its purpose than its meaning. He recapped that Lean is a practical and a pragmatic collection of principles, axioms, approaches, and methods of thinking that hand in hand and with collaboration as a union can help to improve the systems.

Generally, The Lean production and Lean construction example view are that all those activities that produce a cost, direct or indirect. However, it does not add value or progress to the product as refuse or waste. Refuse is easily estimated when it is measured in terms of the cost but very difficult to be estimated when it is measured in terms of the efficiency of processes, equipment, or staff. This is because of the justification that the optimal efficiency is not always known. Decisions are taken at each stage or phase of the design and construction process which result in direct or indirect waste. The process of generating or producing refuse along with the design is complicated when for example a single product, a building, or a (HAVC) system can enjoy a large number of materials and processes to realize the outcome [4]. By cutting down refuse and lack of efficiency, both BIM and Lean effects are the vital modification in the architecture, engineering, and construction AEC industry. [5] The objective of this paper is thus to handle and tackle the benefit of the application of Lean and BIM in the construction process via a case study.

2. NTEGRATION BETWEEN LEAN AND BIM

According to [6:8] BIM is identified as a modeling system plus a linked set of processes. Developing contacts and analyzing the characteristics of the BIM is that it leads to a more transparent administration, [9] through a questionnaire study. [10] An essential relationship betwixt BIM benefit and its application. Sentience of BIM advantages and its applications could essentially maximize performance and project productivity. BIM is effective in running projects at any phase throughout the project lifestyle [11]. It reported that applying BIM application in project management could sure increase and support the management process and incorporated and included entirely the management fields equally.

There is not a straightforward link among Lean and BIM and the Integrated Project Delivery (IPD) method are accomplished minus BIM and the IPD method are accomplished minus BIM [12-13]. This is encouraged the BIM constitute essential accomplish the demanded co-operation (FBID) effectively the better workflow between different or various participants. BIM cuts down refuse and the effeteness of the general, a distinguished package of elaborated situations and minimizes waste litigation. Therefore, sustaining any company's project s lean outcomes [8;15]. Through integration BIM with the LPS the work package may be separated out and substance and assess of the flow will be maximized [16]. Also the research paper [17] and [18] pinpointed that applying 4D CAD modeling aids plan a stable workflow and continuity and yields standardised steps or you can say processes to the workers, They emphasized that BIM as well assistants in deporting materials exactly in the same way they necessitated and growing the design's assurance by raised co-operation and collaboration amongst the project staff.

Many reports have been submitted by [19] and [20] on the application of BIM. There are two cases focused on the projects where pre-manufacturing has extensively employed. Authors notice that intimate collaboration is necessitated among the chief contractor and the subcontractor n abiding by Lean throughout fabrication procurement of pre-manufactured components. Because BIM presents an appropriate design model.. Via a case study [21] double-clicked and stressed which if the BIM characteristics are not properly applied, this, in turn, will conduct to a challenging process.

3. Research Methodology

The hypothesis is examined in this document is that BIM are autonomous from each other. Optimal benefits can be achieved by applying both BIM and Lean simultaneously. Increased collaboration among project participants lowered the number of RFLs and Change Order result in more value and greater customer satisfaction.

The major goal of this research is to explore whether BIM can be used as a Lean tool or the BIM aids the construction process to fulfill Lean principles and cut down waste. To check if BIM can be utilized as a Lean tool. The BIM helps achieve Lean principles and minimize waste in the construction process. This was done to better understand the inherent practical issues associated with the simultaneous implementation of BIM and Lean-to find if the BIM can be used as a tool to fulfill Lean. The establishment at the University of Dammam accommodate the standards construction and was accustomed to prepare the finalization of this research. This paper goes deeper into the mingled application of Lean and BIM and tackles the potential gains of this implementation via a case study. In the current case study, the authors concentrated on a limited number of interactions applying them in a case study. Based on the exploration of a real-life project that is used to display the relationship between BIM and Lean experiences for improvement and lessons learned from the implementation.

CASE STUDY: THE CONSTRUCTION OF THE COLLEGE OF ADMINISTRATIVE SCIENCES AND COMPUTER

The University of Dammam has just finished The New Administrative, sciences and Computers College with an amount 36 million SAR that has 8 laboratories, 48 classrooms, and offices. The procurable method acting for the project is Design Bid Build (DBB).

The work is accomplished at November 2015 employing two-dimensional drawings (without using any of Lean principles or BIM). The design level adopted almost 4 months and the building outgrowth followed it for approximately 60 days, and so the construction phase that carried out 22 months. Fig1 shows the difference between two-dimensional CAD and three-dimensional BIM model.

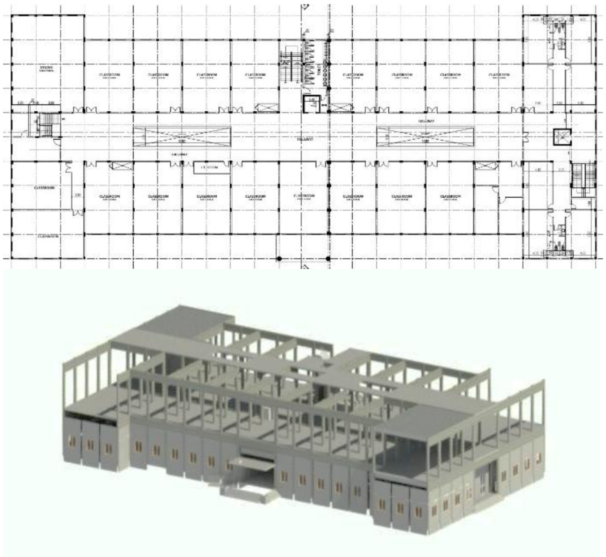

Fig. 1 3D BIM Model and 2D CAD Drawings

4. DESIGN PHASE

In the design stage, specific inputs are demanded to produce the required outputs. It is commonly perceived that the design process is concerned only with the process of thinking which transforms these inputs into outputs and neglects the chief role of exchanging information between the different members of the team of designers [22].

As discussed in [23], stress that design is an open and iterative process where stress and iterations are vital for improving the design and the final product; iterations are seen as wasteful from a traditional perspective when they are necessitated to make corrections, whereas linear processes are regarded as positive in terms of improving productivity. The claim that if design iterations lead to an uprising in customer value, they are not regarded wasteful arguing that iterations are important to be innovative and to find adequate concepts and designs that add value. Lean thinking is designed primarily to reduce waste and maximize the value for the various stakeholders in the process.

4.1 3D Direct Digital Workflow

One of the most significant aspects of BIM is the facilitation of storing and exchanging information to improve communication and cooperation in the design and construction process. In our case study, the stage of design came the traditional phase data flowing (2D CAD) design. Commenced on conceptual design stage, came after by a follow-up and loops period. Once the proprietor follow-ups and accept the design, then the schematic design phase began. Once the schematic design stage came to an end, the design team can then proceed to the elaborated design phase afterward getting the owner's approving.

By comparison between the traditional two-dimensional CAD techniques on the given BIM-founded Model, a lot of waste can be eliminated and plenty of gains could be obtained of the newly 3D model. The completed model was easily extracted from fully-coordinated 3D model which included all the required data and design factors, all plans, elevations, sections, details, and final documentation drawings.

Amended visualization: 3D models are built up and carried through 3D Revit on a physical model that allots the declarers to easily perspective and picture details of the project by the appropriate embedded data. Waiting time waste: unlike the conventional 2D CAD design stage, the structural\civil engineers and MEP engineers needn't wait till the architectural design is complete to proceed or carry on. Instead, early and easy sharing is possible before data completion, so the three cross-functional conditions can simultaneously develop designs. BIM helped to cut down the time needed as this design action about 50% through lowering the expecting time dissipation in the conventional design. Cut down Steps: Through eliminating sequential steps the traditional 2D CAD report workflow enabled a larger level of substance. Also, the BIM model has opened up other time-saving chances, like collision detection and pre-manufacturing which could be applied with relative ease given an appropriate model.

Continuous data continuity and flow: BIM-based design allowed early and timely exchange of incomplete data among participants by sharing and integrating team-building data models at any time. This permits adaptation, modification, and development in real-time to the design. The information is then up-to-date, and the clear visualization of design intent facilitates communication among players and allows for the ongoing flow of data instead of interrupting the batch continuity. BIM lets the owner be involved and have him on board all along the design process by having the capacity to deduce any design data from integrated or individual models when necessitated. In this project, the early feedback from the owner is of great value because it removes the last-moment decision on the design data which if objected, leads to a waste of rework, cost, and time. Also, by the ongoing incorporation of the owner as the design process goes on and progresses its value proposition will be properly translated via the life cycle of the project.

4.2 Prefabrication/As-Built before Construction

A Hollow Core Slab (HCS) was the statistical method utilized in the university project. The executing company had to wait till the completion of the concrete beams that identify the dimensions of the hollow core slabs to apply the hollow core panels. Then, the precise dimensions raised from the site and wait until the panels were prefabricated and installed on-site which adopted 3 weeks for one stone slab, as shown in Figure 2.

By utilizing the generated BIM Model, It is easy to pre-manufacture the HCS before the beam girders are installed. After the completion of structural designs, an inactive process between the AE and the manufacturer of the hollow core slabs (HCS) should be initiated. This process will be based on a mixed release by individual parties of the 3D Model prepared. The AE will integrate the HCS fabrication model into the design model and check for interferences. The design of mechanical-electrical plumbing (MEP) will start in parallel, and the subsequent activities will be based on the as-built structural model before construction even starts. In this way, the design and shop modeling were merged.

Most internal reviews will be performed using digital data which will introduce overhead saving typically associated with paper-based workflow, although the extraction of the shop drawings will still be demanded approval purposes. The project team will not also have access to the laborious production of the as-built documentation at the end of the project.

Fig. 2 Onsite installation of the HCS.

4.3 Detection of Collision

Conventionally, the design advisor utilizes overlaid drawings on a light table to manually define clashes. Correspondingly, plenty of detection of the clashes was left to constructors in the past. Clashes and errors can be easily detected via BIM which means that significant cost savings can be realized compared to incomplete design data in-built in a traditional 2D process. One of the major problems which had been encountered during the application of the university project in the presence of numerous conflicts among technical acts and fire alarm and eliminating exercise that diverged between minor and major conflicts.

The main conflict that had been encountered during the implementation of the project was the insufficiency of the sizes and dimensions of the central air-conditioning channels as they intervened on the concrete beams of the classrooms as a result of the total depth of the beam was 1.0 meters. Due to the limitation by the height of the suspended ceiling, It was possible to pass the air-conditioning under the beams with those dimensions. The mechanical design drawings didn't include insulations, thus did not represent the full depth of the element precisely. This element had interfered with the ceiling height during construction. This case necessitated a major redesign of the HVAC systems leading to simultaneous design iterations and process details. Collateral waste is created as early trades had to re-detail their draftings to coordinate with the revised mechanical system.

This problem arose or showed up as a consequence of the shortage of visualization and synchronization of the current site layout and communicating break down within the contractor and the subcontractor concerning the design of the HAVC system and also as a result of the owner not holding back the completion of all designs for the project. In particular the design of the HAVC. The HAVC designs were made by the general contractor via a subcontractor which came incompatible with what was applied with the rest of the drawings of the project.

Fig. 3 On-site improper Installation for Air-Conditioning channels

Fig.3. portrays compare among the trouble which took place in the front of a conflict within the air

conditioner ducts and the concrete beams. Revit and Naviswork programs are utilized to observe collision and Conflicts for the project. A lot of clashes and errors (over 100 Interferences) are defined and solved dealing with architectural Components, complete structures HVAC, mechanical equipment, lightning cable tray, and ducts. Fig. 4. Demonstrates how the clash between elements of different disciplines could be identified easily in the 3D model. Clash detection was achieved easily with functions included inside the digital software of the project which can identify the geometric clashes and generate a list automatically. Double-clicking on an item within the list will take the user to the clash's virtual geometrical location. Then the structure is corrected and redesigned. The user can specify clash-check tolerance and this check tolerance will be ably designated as standard.

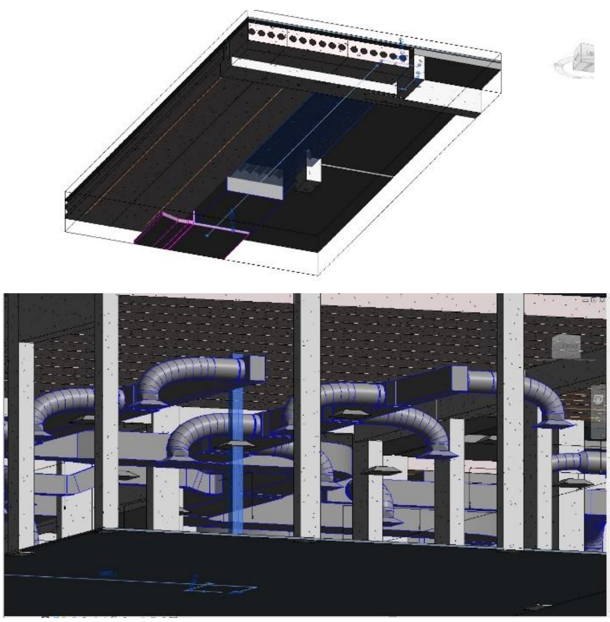

Fig. 4 Clashes of distinguished fields in the 3D Model

The 3D model displays exactly how each item interacted with each other and enabled close collaboration between the various trades. At this point, it reported that via the BIM model. Clash detecting can economize approximately 3 weeks and 200000 SAR in the project resulting from the design error.

5. Construction phase

Efficient and faultless management plays a pivotal role in the successful execution of construction projects, but there is a lot of waste in the application of the conventional document-based environment. The major cause of those wastes is inadequate, inaccessible, or missing information in construction projects. Several parties produce the necessary data and often it is fragmented, incoherent, or in an impractical format. Plenty of time is wasted, meaning the value is destroyed in searching for information needed for construction site activities since it is not easily obtainable even if the information exists somewhere in the documents.

The General Contractor (GC) Responsibilities entail typical tasks like selecting subcontractors, planning and monitoring construction, coordinating the rest of the project team, and authorizing outside agencies in charge of permits. An essential requirement for the General Contractor is to coordinate the construction process with a full understanding of the interdependencies between various contractors. Those dependencies had to be grasped to define the last responsible moment for reaching a decision. For instance, before sizing the roof members, the structural manufacturers needed data, such as weight, dimensions, and location of mechanical equipment. The structural members were not able to be sized till these obligations were set.

5.1. Direct Fabrication from BIM

BIM's chief merits during construction are the extraordinarily high level of prefabrication, pre-reassembly, and a well-organized construction site. Fabricators will reassemble their systems into configurations that reduce demands on site. They will also count on Just In Time (JIT) delivery of materials and equipment which will be the result accomplished via full coordination before construction starts.

The detailed collision-free model and the need for no field alterations will enable prefabrication and pre-assembly and will lead to a more accurate ordering process of materials and saving time using JIT delivery. This will reduce refuse and the related costs therefrom. The different field teams would be able to install their work based on the BIM model and depend on the findings proposed. Utilizing pre-cast and pre-fabricated concrete can cut down on-site construction waste. Prefabrication is technically demanding and challenging since meticulous proportions are needed early in the design process and appropriate installation on-site then required BIM digitally provides a precise geometric data of each building component and permits the export of geometric information to the data format used in fabrication shops. Fabricators can run and automate the fabrication process utilizing data deduced from BIM models. Moreover, BIM-based digital prefabrication permits for efficient lean construction and material tackling through cutting down the number of materials dealt with on-site. The BIM model will make the prefabrication process better and the subcontractors will fabricate straightforwardly from the BIM model. There will be fewer cases or errors, tolerance, and buildability problems as the model include all the details they are required to fabricate The dependability of the BIM model adds value to the BIM project as other trades can coordinate the precision of the fabrication model with a high degree of confidence.

For our case study, as referred to previously, a Hollow Case Slab (HCS) was used the statically system. To apply the hollow care panels. The executing company had to wait until the completion of the application of the concrete parts that define the dimensions of the hollow core slabs, then the precise dimensions raised from the site, and wait till the panels were fabricated which in turn took three weeks to be installed on-site, as shown in Figure 2. These three weeks of expecting for the prefabricated HCS are regarded as expecting time waste. If the BIM model had been utilized, the three weeks per one-story slab could have been saved and nearly one and half months as a holistic saving in time. Via the BIM model, HCS prefabrication could begin at the same time as pouring the concrete beams to be ready when the casting process is complete. Also, this will fulfill what lean philosophy supported by removing the waste of the waiting time. Using the pre-fabrication and pre-assembly technique, the HCS, the HVC, and MEP systems will be installed in minimum time without any on-site re-work. Moreover, since-field changes and on-site movement of people and materials will be minimal. Site safety will be made much better and will be sustained. Field teams' morale will be promoted and they'll have greater confidence, and pride in their work. Establishing a precise 3D model entails all trades and necessitates the early engagement of subcontractors who would typically be involved after construction has started. On our case study project, most of the key subcontractors were engaged recently and participating in the 2D drawings which have not assisted removing conflicts and co-ordinate planning sequencing, etc. However, the designers and the subcontractors did not utilize the 3D design tool. This resulted in deficiencies in the field problems, for instance, the HVAC designer used 2D CAD drawings. Because of the quick-track nature of the project, they didn't have time to figure out conflicts with other trades which created problems during construction for the piping subcontractor. This illustrates the significance of building a meticulous and comprehensive model for a design prior to the construction.

In Currently project, the BIM model can engage on-site activities, for instance, the sub-contractor on the case study of the university project reflected a disinterest in taking part in the coordination of skylight final touches. A detail of the design portrayed a pyramidal shape for the skylight see Fig. 5. The General contractor working with a subcontractor to take in the traditional 2D detailing would not satisfy the requirements of the field layout staff owing to the shortage of 2D drawings details which doesn't specify plenty of details required to apply the skylight, particularly the heights of the pyramid shape of the skylight. In this case, the model's application intensity will increase with the increase in meeting the needs of the owner.

Fig. 5 On-site installation of the skylight

5.2 Change orders

Change orders have a vital influence on the cost and schedule of the project and therefore require improvements. To improve existing research, this study will check how BIM has impacted change orders and change order management. A change order is generally the effect of alteration in the evaluation of the time frame. Unseen considerations demanding alteration or a design error that result in an alteration. A proprietor-initiated exchange at its effect is a change duration of the project for which the owner asks. Typically, this sort of modification is direct and results in little conflict.

There are several techniques to avoid change orders such as 3D modeling. For accomplishing the wanted or desired outcome which is a little to no change orders, a change order management, and prevention program should contain all of the projects, following a tough deadline. This study calculate the cause of each change order and permit for more accurate depict of the real impact BIM applies on exchange orders if BIM has the most effect on, we need to categorize each change order. The three major categories are change initiated by the owner, change in design error\omission, and unpredictable circumstances.

Table 1 Numbers and Types of Change Orders

Change Order Type	No. of change orders
owner-initiated changes	15
design errors/omissions	5
unforeseen conditions	3

It can concluded from table 1 that it obvious the owner-initiated alters are the source of the project's largest cause of change. Throughout the project implementation, the owner made a lot of modifications to the project. Since there has been a lot of site visits to the project from the owner (particularly from the Vice President of the university) during the construction stage. The outcomes of these visits reflected several modifications that are requested to be compatible with the academic use of the project, plenty of changes were made such as the changes in lots of classrooms by the re-division to be discrete for academics. Around 12 exchange orders are made to be suitable for what the owner demanded and the influence of this was addressed and calculated on the time and cost of the project, additional periods were added and new costs were approved for those changes made by the owner is that at the project start the owner didn't have a comprehensive vision or full visualization of the project. At the early stage. He almost didn't understand what those drawings reflect. During the application and with the repeated or frequent visits of the owner, the vision or the picture becomes much more obvious, and that is what makes the owner make changes during the implementation. BIM technology has a great feature and permits us to go on a walk through the building.

Because of design error, we also detect 5 change orders, one of the principal design errors as it has been referred to previously be the poor HVAC system design with other trades. The exchange order led to 21 days' time lag in finishing the project and be almost 200000 SAR to redesign and get rid of the installed from channels and alter the opening places. Approximately 17 change orders from 20 change orders (more than 80%) could have been prevented when utilizing the BIM model. Those 17 change orders which belong the owner-initiated change and design error\omission alterations may have been voided when employing the BIM model.

6. Conclusions

Wastes in the construction process are generated mainly owing to improper design of the building. Building Information Modelling (BIM) offers and supplies a meticulous and precise model of the design and the material resources required for each segment of the work which can be managed efficiently by avoiding design problems and improving the communication and collaboration in the design and construction process. The causes of the design and construction waste can be addressed and solved via an integrated building which could be facilitated by building information modeling (BIM) and Lean construction. The outcome of the comparison between the 2D CAD Drawing and BIM model demonstrates a high ability to transform the traditional design and construction stage into a Lean process by using building information modeling. As a result of this study, we can prove that the building information modeling (BIM) will allow a design review and coordination effort that has never been possible with the traditional 2Dimensional modeling.

References

[1] Koskela, L., Application Of The New Production Philosophy To Construction, Cife Technical Report #72. 1992: Stanford University , CA.

[2] Tommelein, I.D. and S. Gholami. Root causes of clashes in building information models. in Proc., 20th Annual Conf. of the Int. Group for Lean Construction, Curran Associates, Red Hook, NY. 2012.

[3] Mossman, A., What Is Lean Construction: Another Look - 2018, in 26th Annual Conference of the International Group for Lean Construction. 2018. p. 1240-1250.

[4] Alarcón, L., Lean construction. 1997: CRC Press.

[5] Sacks, R., et al., The Interaction of Lean and Building Information Modeling in Construction. Journal of Construction Engineering and Management, 2010. 10.1061/(ASCE)CO.1943-7862.0000203, 968-980.

[6] Hardin, B. and D. McCool, BIM and construction management: proven tools, methods, and workflows. 2015: John Wiley & Sons.

[7] Eastman, C., et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. 2011: John Wiley & Sons.

[8] Eastman, C., et al., A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators. 2008, John Wiley and Sons, Hoboken, NJ.

[9] Kymmell, W., Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations (McGraw-Hill Construction Series): Planning and Managing Construction Projects with 4D CAD and Simulations. 2008: McGraw Hill Professional.

[10] Al-Ashmori, Y.Y., et al., BIM benefits and its influence on the BIM implementation in Malaysia. Ain Shams Engineering Journal, 2020. 11(4): p. 1013-1019.

[11] Shaqour, E.N., The role of implementing BIM applications in enhancing project management knowledge areas in Egypt. Ain Shams Engineering Journal, 2021.

[12] Sacks, R., et al., Interaction of lean and building information modeling in construction. Journal of construction engineering and management, 2010. 136(9): p. 968-980.

[13] Eckblad, S., et al., Integrated project delivery-a working definition. AIA California Council, Sacramento, CA, 2007. 25.

[14] Clemente, J. and N. Cachadinha, <BIM-lean synergies in the management on MEP works in public facilities of intensive use a case study.pdf>. 20th Annual Conference of the International Group of Lean Construction, 2013.

[15] Sacks, R., M. Radosavljevic, and R. Barak, Requirements for building information modeling based lean production management systems for construction. Automation in construction, 2010. 19(5): p. 641-655.

[16] Sacks, R., M. Treckmann, and O. Rozenfeld, Visualization of work flow to support lean construction. Journal of Construction Engineering and Management, 2009. 135(12): p. 1307-1315.

[17] Sacks, R., et al., Analysis framework for the interaction between lean construction and building information modelling. 2009.

[18] Rischmoller, L., L.F. Alarcón, and L. Koskela, Improving value generation in the design process of industrial projects using CAVT. Journal of management in engineering, 2006. 22(2): p. 52-60.

[19] Khanzode, A., M. Fischer, and D. Reed. Case study of the implementation of the lean project delivery system (LPDS) using virtual building technologies on a large healthcare project. in 13th International Group for Lean Construction

Conference: Proceedings. 2005. International Group on Lean Construction.

[20] Khanzode, A., et al., A guide to applying the principles of virtual design & construction (VDC) to the lean project delivery process. CIFE, Stanford University, Palo Alto, CA, 2006.

[21] Gómez-Sánchez, J.M., J.L. Ponz-Tienda, and J.P. Romero-Cortés, Lean and BIM Implementation in Colombia; Interactions and Lessons Learned, in Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC). 2019. p. 1117-1128.

[22] Al Hattab, M. and F. Hamzeh. Information flow comparison between traditional and BIM-based projects in the design phase. in Annual Conference of the International Group for Lean Construction, Fortaleza, Brazil 21. 2013.

[23] Hansen, G.K. and N.O. Olsson, Layered project–layered process: lean thinking and flexible solutions. Architectural Engineering and Design Management, 2011. 7(2): p. 70-84.