Article

Lean Based Maturity Framework Integrating Value, BIM and Big Data Analytics: Evidence from AEC Industry

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Abstract: The construction industry is considered as one of the least productive, highest energy consuming, and least digitized industries. The Lean Management (LM) philosophy became a significant way for eliminating non-value-added activities and wastes during a building’s lifecycle. However, studies have shown that philosophies are not efficient by themselves to solve the issues of the construction industry. They need to be supported with the appropriate technologies and tools. Therefore, the integrated use of Building Information Modelling (BIM) with LM or Value Engineering (VE) were proposed in the literature. Nonetheless, it was also seen that BIM can provide more insights and improvements when BIM is integrated with data analysis tools to analyze BIM data. In the literature, the synergies between these concepts are generally addressed pairwise, and there is no comprehensive framework which identifies their relationships. Therefore, this study aims to develop a maturity framework that facilitates the adoption of LM, VE, BIM, and Big Data Analytic (BDA) concepts to address long-standing productivity and digitalization issues in the Architecture, Engineering, and Construction (AEC) industry. Design Science Research (DSR) methodology and its three-cycle view (relevance, rigor, and design cycle) were applied to build the proposed maturity framework. Two interviews were performed to identify and observe research problem in relevance cycle. In the rigor cycle, a comprehensive literature review was performed to create a base for the development of the maturity framework. In addition to the developed base of the framework, lean processes were added to this cycle. In the design cycle, the developed framework was evaluated and validated by five experts through face-to-face interviews. The importance of employer’s requirements to adopt the proposed methodologies, the negative impact of change orders, the importance of pre-construction phases to facilitate value creation and waste elimination, and the usage of common data environment with BIM were identified as the prominent application and adaptation issues.

Keywords: lean management; value engineering; building information modeling; big data analytic

1. Introduction

The architecture, engineering, and construction (AEC) industry is considered as one of the largest industries in the global economy in terms of its income generation capacity. However, the AEC industry is also considered as one of the least productive and digitized industries [1]. In addition to low productivity, the AEC sector is still suffering from rework, poor safety, material waste, inadequate customer satisfaction, budget and schedule overruns, poor production quality, lack of coordination, waste of productive time, supply chain fragmentation, sensitivity to market conditions, lack of strategic capability, competitive tendering mechanisms, and time and cost overruns as a result of insufficient practices regarding existing project management instruments [2–4]. In addition, increasing demand for construction projects leads to increased competition between the construction companies, which may cause value issues at the end of the project. These chronic problems have been discussed throughout the years and all discussions eventuate with the need for...
change in construction practices. The calls for changing construction processes require the adoption of new technologies and methodologies through the management of entire construction processes [5]. Accordingly, lean management (LM) and value engineering (VE) are frequently mentioned in the literature as the main practices to overcome the mentioned problems of AEC industry. Within this context, Tezel et al. [2] stated that the AEC industry issues induce the application of production management practices in the AEC industry such as Lean Construction (LC). However, the authors stated that LC was not at the intended level until cost cuts in projects were performed in the UK. In the literature, LM is a hot topic, and it attracts more researchers to increase the awareness level of companies about the depletion of resources and to eliminate wastes. Matthews & Howell [6] explain contractual problems and offer a solution with a lean construction approach to generating value and minimizing wastes. Salem et al. [7] explained lean techniques such as the last planner, fail-safe for quality, the five S’s, increased visualization, huddle meetings, and first-run with several case studies. Ballard [8] proposed a lean project delivery system for the design phase. Zimina et al. [9] showed that LM leads to improvement of project performance and solve cost overruns. After the recognition of BIM, the context of the LM studies shifted to the investigation of advantages of BIM usage in LM. As such, the primary advantages, collaboration, waste elimination, improved construction flow, and leaner process were indicated by numerous researchers. The integration of BIM and LM concepts reduces waste and the workload, prevents rework, and adds more value by eliminating “non-value-adding activities” [10,11]. Sacks et al. [12] offered the KanBIM concept, which sustains the visualization technique of lean management and its integration of the BIM system. Off-site construction is one of the proposals of LM to overcome construction industry problems. Within this context, BIM delivers several benefits for off-site construction such as reducing design errors and incompatibility between designers and manufacturers. These benefits contribute proactive design change management by minimizing rework and delays. BIM integration greatly reduces the planning and scheduling process as well as model approval, and consequently, it leads high quality fabrication [13].

Sacks et al. [14] presented that the integration of LM and BIM helps to perform faster design alternatives, creating predictive analysis, maintenance of the information and design integration, collaborative working, and the simulation of the work plan using the 4D aspect of BIM. Hattab et al. [15] proposed a detailed framework for managing design errors with the integration of LM and BIM that enhances project productivity and client satisfaction. Practitioners and researchers have also focused on VE practices that promote either improving function or reducing cost in LM studies. Ekanayake and Sandanayake [16] integrated VE with LM to enable obtaining competitive advantage for construction companies due to sinking profit margins. Additionally, the integration of VE and BIM was investigated to increase the offered value to clients or customers by Park et al. [17]. The capabilities of BIM and its integration with BDA aids to eliminate wastes by using available data in models. To create a BIM model, parameters and rules are used. These parameters could be used for creating levels for estimations and it authorizes to understand which parameters create more waste. Bi-directional associativity is complementary for parametric modelling in terms of availability for immediate control of design changes and automatically reproduces these changes in real-time. These two features of BIM and BDA integration predict the impact of these changes to the project instantly and help to continue with the best option that creates less waste. Therefore, this integration is conducive to creating functional change management [18]. Han and Golparvar-Fard [19] stated that BIM helps to partially solve productivity, construction coordination, planning, and cost overruns. Within this context, the authors proposed the usage of big visual data in the construction stage, since many data sources such as images and videos that are collected during the construction stage are not used. The authors believed that the integrated use of BIM and BDA will be a remedy for automated information flow and as-built status. Yin et al. [13] stated that the integrated use of BDA with BIM in off-site construction helps to retrieve valuable insights about the relationship between the design parameters of modular elements and
building performance and maintenance. Therefore, the authors believed that best practices can be integrated into off-site construction. Demirdögen et al. [20] proposed a framework which combines LM, BIM, and BDA for facility management (FM). In addition to [20], Fernandez-Basso et al. [21] reported that enormous data is created with the application of IoT devices in buildings, and the authors stated that new infrastructure and algorithms are needed to obtain meaningful insights.

Since attempts to integrate the concepts of LC, VE, BIM, and BDA to overcome the observed issues of AEC industry exist in the literature, the synergies between these concepts are generally addressed as being pairwise, and there is not a comprehensive study that focuses the integration of all these concepts. In addition, the studies given above proved that BIM is not enough to retrieve more valuable and lean processes by itself. Furthermore, LM requires continuous monitoring to reveal wastes and non-value-added activities. Within this context, the authors proposed the usage of BDA to discover hidden values, obtain meaningful insights and more value and lean process. Since, studies show that there are overlaps among these concepts intuitively, a mechanism that allows them to consider together needs to be identified and investigated to eliminate all wastes and non-value added activities. Therefore, the goal of this study is to develop a comprehensive maturity framework for improving the adoption of LC, VE, BIM, and BDA methodologies in sequence for overcoming the productivity problems of the AEC industry. The proposed framework will provide a broad explanation for the characteristics of each level and the logical relationships between value-oriented project management concepts. Thus, this study will be one of the limited studies available. This unique value will contribute to the body of project management knowledge. Considering that organizations have several problems for adopting these methodologies into their organizational structure, the proposed framework will contribute to the project practitioners by creating a clear picture and guideline for practitioners in implementation for overcoming the productivity problem of the construction industry by integrating all proven value-oriented project management processes and methodologies.

2. Research Methodology

In this study, a Design Science Research (DSR) methodology was used for the purpose of developing the maturity framework. DSR concerns the evaluation of design science outputs, which are artifacts [22]. The artifacts in DSR can be varied with the algorithm, construct, framework, instantiation, method, and model. DSR offers a general solution for the research problem by producing new knowledge, using of unknown things in design, developing scientific knowledge and addressing new important problems that are not solved before and endeavors to solve them in a new and effective way [23].

In DSR methodology, the Relevance Cycle, Rigor Cycle, and Design Cycle need to be followed to conduct research. In the Relevance Cycle, research problem is presented depending on business needs. In the Rigor Cycle, previous solutions about the research problem are investigated from the literature to create a base for new solutions or artifacts. In the Design Cycle, the proposed artifact is rearranged and evaluated iteratively depending on feedbacks [24]. The DSR methodology of the study was given in Figure 1.

2.1. Relevance Cycle (RelC)

This cycle does not only help to identify business needs, but it also helps to discover the acceptability criteria of the proposed artifact [25]. Thus, two interviews were performed with directors of two different local contractor firms with 13 years and 15 years of experience to identify issues in the business environment. The interviews were executed with participants having high experience in terms of expertise. Considering the importance of interviewees was the main part of perceiving the real issues of the AEC industry. The criteria set for the industrial respondents include high experience (on a yearly basis) and competency. For the competency perspective, all interviewees have experience and knowledge about all mentioned value-oriented project management methodologies and
processes (LC, VE, BIM, and Big Data). In addition, the firms to which they belong execute BIM and Lean methods. In the interviews, four open-ended questions were asked to the interviewees. Questions were built to obtain information about the confronted issues in the AEC industry; the contribution of LM, VE, BIM, and BDA concepts to overcome mentioned issues; and company implementations in the context of LM, VE, BIM, and BDA concepts.

Figure 1. Research methodology.

According to the findings of the interviews, it was found that practitioners commonly benefit separately from LM, BIM, and VE, whereas BDA has not been recognised sufficiently. They also expressed that the usage of BIM mainly depends on customer demands. According to responses of interviewees, unproductivity, cost overruns, delays, communication issues, data management issues, unskilled labour force, low technology adaptation rate, the lack of skilled white collar workers to adopt new methodologies and wastes in processes are still chronic problems. Interviewee #1 mainly highlighted the contribution of BIM to increase transparency of construction processes with visualization support whereas Interviewee #2 remarked profit margins can become more flexible in consequence of VE applications. Therefore, VE applications are unavoidable due to the intensive competition in AEC industry. Although interviewees used LM, VE, and BIM in some projects, the interviewees reported that they cannot fully benefit from these methodologies since they do not perform all steps of LM and VE. They also reported that synergies between these concepts are vital. However, due to a lack of technical guidelines, it does not apply. The lack of technical guideline for improving mentioned implementations and synergies between them has also been emphasized in the literature [26–29]. The findings of the interviews and literature review highlight the need for an informative framework and technical guidelines to enhance the implementation of LM, VE, BIM, and BDA concepts.

2.2. Rigor Cycle (RigC)

In this cycle, artifacts representing the synergies among LM-VE, LM-BIM, VE-BIM, BIM-BDA, LM-BDA, VE-BDA, and BIM-BDA have been investigated with an in-depth literature review. A literature review that sets a base for the rigor cycle shows that used concepts are generally greater in numbers in the field of LM-BIM integration [15,30–48]. BIM features are employed for more than only the visualization aspect of lean construction. Various design options that are created rapidly, producing predictive analysis, information and design integration, collaborative working, and simulation of work plans can be created using the 3D and 4D elements of BIM. For the integration of LM-VE and VE-BIM, studies are limited [17,49–51]. The BIM system provides a visual understanding of the whole project. This leads to ease in ranking VE ideas and evaluating them. VE applications give optimal solutions by combining function, quality, and cost. VE applications also used in Lean Product Development to save unnecessary cost while maintaining the greatest possible functionality. In the literature, the integration of BIM and BDA is used in maintenance management, retrieving object information from BIM for FM purposes, make queries on
BIM model, safety management, energy management, cost management, construction logistic management, waste management, design alternatives, and supplier data for off-site construction components. Furthermore, it is stated that BDA can be used to evaluate design alternatives, future trends and preferences, project performance, monitoring construction progress, and lean management (detecting off, idle, or busy status of equipment) [20,52–61]. Although some studies emphasized the selection or evaluation of design alternatives with BDA, there is no study for BDA usage in VE. The findings also showed that existing studies do not reveal the comprehensive synergies between all these concepts to offer more value to customers and clients.

In the rigor cycle, a maturity framework that consists of 5 levels was developed at the first step, as given in Figure 2 and as follows:

- **Level 0** is described as the conventional construction processes. The activities are planned and managed according to conventional practices. In this level, practitioners ignore productivity issues and non-value-added activities in the processes. Additionally, performed activities are unreliable, susceptible, and hard to control processes as they are all in the initial levels of maturity frameworks.

- **Level 1** focuses on LM. LM originates from the Japanese manufacturing industry (Toyota Production System). After the successful implementation of LC in manufacturing industry in terms of sustainable improvements in productivity, quality, waste management, and other performance indicators, LM was transferred and adapted to construction management projects [3,62]. LM helps to ameliorate the AEC industry in terms of reducing wastes and delivering the maximum value to clients. However, the implementation process of LM is complex, and it necessitates long-term strategies since organizational culture, lack of skills, cultural conflicts, economic barriers, social variation, etc., emerge while LM adaptation is performed [3]. In LM, there are five principles that need to be performed: value, value stream, flow, customer pull, and pursuing perfection. In the value principle, value that is related to the value perception of client is determined. Non-value added activities are found out in value stream principle. However, value stream is performed by considering all construction processes rather than in an isolated manner [4]. In the flow principle, production components are continuously in motion with the increase in value. Therefore, large material inventories, and interruptions in the production process and information distribution are eliminated. In the pull principle, the waste of overproduction is revealed, and the work package or service that is needed for clients is delivered to them [63]. In the final philosophy, products or services are delivered to clients by ensuring customer requirements [64]. In light of these principles, LM implementation with construction is described, and lean processes are defined. Since LM aims to increase offered value to customers/clients by eliminating non-value-added activities, the aim of LM is not only to design a solution that considers cost. Decision makers who take part in any part of the building’s lifecycle mainly focus on the implementation of the cheapest or optimum solution. Therefore, this negative impact of LM can be eliminated with the addition of the VE practices. Moreover, it is believed that LM can increase the effectiveness of VE [16]. Mandelbaum et al. [65] stated that VE is generally focused on potential gains and feasibility. However, VE has a problem collecting data from clients and the indirect acceptance and approval of VE recommendation by clients. Within this context, the authors stated that lean practices create data collection plans. Moreover, the authors reported that while lean practices enable a disciplined approach for implementation, VE helps to create an implementation plan. Furthermore, authors expressed that lean practices present better controlling plans. In VE, some wastes can be tolerated or ignored if its cost is not high. Additionally, while VE is focusing on costs, lean practices focus on the root-causes of problems. A VE job plan consists of eight phases: pre-study, information, function analysis, creative, evaluation, development, presentation, and implementation. In the pre-study phase, problems are refined to prepare workshops. In the information phase, the rules for workshops are
established, and the problem scope is refined. In the function phase, 40–60 functions are identified and recorded for the product, process, or service in workshops. After identification of the functions, these functions are classified and budgeted. The best opportunities are determined. In the creative phase, alternative ways for each function (ideas) are created. Ideas are elaborately criticized and ranked for specific value improvement in evaluation phase. In the development phase, the best alternatives are technically analysed and prepared for their presentation to decision makers. In the presentation phase, the course of action for alternatives are presented to the client for the first time. In other words, the client must be convinced of all actions. However, the implementation of alternative is performed at the last phase with the approval of client. The synergy between LM and VE is given in Figure 3 in detail.

- In Level 3, BIM integration into LM and VE methodologies is performed to obtain fine-tuned, value-oriented processes with the help of the simulation environment of BIM. BIM is another innovative construction management strategy to deal with wastes and optimization problems during the design and construction phase [66]. Maraqa et al. [66] stated that BIM is a more common tool implemented in the AEC industry than LM, since its implementation is compulsory in projects. Ahuja et al. [38] expressed that BIM is a paradigm shift for the AEC industry in terms of productivity, efficiency, reduced lead times, reduced cost and time overruns, quality, and sustainability. Authors reported that BIM can be used as a visualization, waste elimination, pull-flow, improved-flow, clash detection, and collaborative planning tool. Moreover, Park et al. [17] stated that BIM presents a perceptual reasoning opportunity for problem solving. Therefore, authors integrated BIM with the VE idea database to transfer past VE implementations into similar new projects. Therefore, synergies between LM, VE, and BIM are summarized in Figure 3.

- In Level 4, participants can create more detailed processes by analysing the available data to produce more effective and productive project management system. Therefore, the integration of BDA into decision-making processes is enabled into developed maturity framework. In the AEC industry, large heterogeneous data is created with increase in implementation of technologies [18]. Bilal et al. [18] stated that BIM files present rich information sources, and they can easily reach 50 GB in size. In addition to the BIM model, the application of sensors and smart meters into the building environment during the FM stage induce big data issues in the AEC industry. Rehman and Batool [67] stated that the heterogeneity of data and massive data production are the sources of big data problems. Big data problems are characterized with 5 Vs: volume, velocity, variety, value, veracity, and variability. Volume refers to data volume. Data needs to have high velocity in big data problems. Variety refers to the types of data formats. Veracity is measured with the trustiness of data sources to process them in BDA. Variability shows the effectiveness of the big data system in terms of peak-load times. Values refers to interest of the uncovered knowledge patterns. Big data consists of big data engineering and BDA. In big data engineering, big data processing, storage, and query interfaces are planned and integrated. In BDA, statistics, data mining and machine learning techniques take a part [18]. Bilal et al. [18] stated that BDA, with the help of BIM, can be used in resource and waste optimization, generative design, clash detection, performance prediction, visual analytics, and facility management. Therefore, BDA is conceived as a part of maturity framework, since it cannot only enable more lean process and activities, but it can also help perform VE applications.
2.3. Design Cycle (DesC)

In the design cycle, the designed artifacts are demonstrated, evaluated, and improved iteratively. Thereby, processes of LM, VE, BIM, and BDA, which are given in Figure 3, were also identified by compiling the studies of [12,16–18,33,64,68–75].

2.4. Relevance Cycle (RelC)

This cycle does not only help to identify business needs, but it also helps to discover the acceptability criteria of the proposed artifact [25]. Thus, two interviews were performed with directors of two different local contractor firms with 13 years and 15 years of experience to identify issues in the business environment. The interviews were executed with participants having high experience in terms of expertise. Considering the importance of interviewees was the main part of perceiving the real issues of the AEC industry. The criteria set for the industrial respondents include high experience (on a yearly basis) and competency. For the competency perspective, all interviewees have experience and knowledge about all mentioned value-oriented project management methodologies and processes (LC, VE, BIM, and Big Data). In addition, the firms to which they belong execute BIM and Lean methods. In the interviews, four open-ended questions were asked to the interviewees. Questions were built to obtain information about the confronted issues in the AEC industry; the contribution of LM, VE, BIM, and BDA concepts to overcome mentioned issues; and company implementations in the context of LM, VE, BIM, and BDA concepts.
After generating the tentative framework and its processes, expert interviews were used to evaluate the proposed maturity framework according to its processes, since Peffers et al. [23] indicated that the evaluation of proposed artifacts could be performed based on expert evaluations, logical argument, technical experiment, subject-based experiment, action research, prototype, case study, and illustrative scenario. In this context, five interviews were conducted with experts who have experience and/or knowledge about LC, VE, BIM, and BDA to evaluate the proposed framework and relatedness of lean processes with the defined principles. Each interview takes 2 h on average, and all items on framework have been evaluated by interviewees. Questions that were used in interviews were presented in Appendix A. Descriptive information of experts is given in Table 1.

![Figure 3. Processes of maturity framework.](image-url)

| Lean Phases | Level 1 - Lean Management | VE Phases | Level 2 - Integration of VE | Level 3 - Integration of BIM |
|-------------|----------------------------|-----------|-----------------------------|-----------------------------|
| Value       | LP1: Ensure comprehensive requirements capture | Pre-study phase | Value initiation phase | Determining the BIM strategy in accordance with the requirements in the specification |
|             | LP2: Customer value perfection | | | |
|             | LP3: Focus on concept selection - (Shade design into concept design and detailed design) | Information phase | Value establishment phase | BIM execution plan and creating visualization of form in 3D |
|             | LP4: Increase relatedness | | | Collaboration in design and construction |
| Lean Phases | Level 1 - Lean Principles | VE Phases | Level 2 - Integration of VE | Level 3 - Integration of BIM |
| Value-Driven | LP5: Select appropriate project planning and control tools | Functional phases | Value analysis output | Rapid generation and evaluation of construction plan alternatives |
|             | LP6: Reduce the share of non-value adding activities | | | |
|             | LP7: Draw-up requirements flow charts | | | |
|             | LP8: Reduce batch sizes | Value establishment phase | | Maintenance of information and design model integrity |
|             | LP9: Design the production system for flow and value | | | |
| Lean Phases | Level 1 - Lean Principles | VE Phases | Level 2 - Integration of VE | Level 3 - Integration of BIM |
| Flow        | LP10: Balance flow improvement with conversion improvement | Creativity phase | Value creativity phase | Online/electronic object-based communication |
|             | LP11: Simplify | | | Rapid generation of multiple design alternatives |
|             | LP12: Reduce variability | Evaluation phase | Value evaluation phase | Rapid generation of multiple design alternatives |
|             | LP13: Reduce the cycle time | | | Automated generation of drawings and documents |
|             | LP14: Increase process transparency | | | Collaboration in design and construction |
|             | LP15: Zero-time delivery | | | Site utilization plan/site analysis |
|             | LP16: Organizing continuous flow | Development phase | Value development phase | Monitoring construction process |
| Lean Phases | Level 1 - Lean Principles | VE Phases | Level 2 - Integration of VE | Level 3 - Integration of BIM |
| Pull        | LP17: Use visual management | Development Phase | Value development phase | 3D control |
|             | LP18: See and see for yourself | | | Site utilization plan/site analysis |
|             | LP19: Increase output value through systematic consideration of customer requirements | Presentation phase | Value verification phase | Online/electronic object-based communication |
|             | LP20: Focus “push flow” control on the complex process | | | Support the make ready process, Controlling and storing lifecycle data |
|             | LP21: Quality control framework Work in Process - production | | | Existing conditions modeling |
|             | LP22: Verify and Validate | | | Maintenance of information and design model integrity |
|             | LP23: Decide by consensus, consider all options | | | Collaboration in design and construction |
| Lean Phases | Level 1 - Lean Principles | VE Phases | Level 2 - Integration of VE | Level 3 - Integration of BIM | Level 4 - Integration of BDA |
| Perfection  | LP24: Institute continuous improvement | Post-study phase | Value achievement phase | Improving maintainability studies | Enabling institutional digital transformation with high graphic quality and data storage facility |
|             | LP25: Improvement results from reducing waste | | | Feasibility studies, Effectively locating building components and improving maintainability |
|             | LP26: Cultivate an extended network of partners/Increase collaboration | | | Advanced automation and analysis system provided by big data |
|             | LP27: Build continuous improvement into the process | | | Existing conditions modeling |
|             | LP28: Standardize | | | Providing more transparent, controlled and better performance data with uninterrupted data flow |

Figure 3. Processes of maturity framework.
Table 1. Descriptive information of experts.

| Expert   | Role                        | Experience | Company Type               |
|----------|-----------------------------|------------|----------------------------|
| Expert #1 | Director                    | 20 years   | International Engineering Firm |
| Expert #2 | Business Development Engineer | 11 years   | International Consulting Firm |
| Expert #3 | BIM Specialist and AEC Consultant | 7 years   | Local Consulting Firm |
| Expert #4 | BIM Specialist               | 7 years    | Local Contractor            |
| Expert #5 | BIM Coordinator              | 10 years   | Local Design Firm           |

3. Evaluation of Maturity Framework

Assessments of experts related to lean processes (LP) of proposed maturity framework are given below:

- **LP1**—Expert #1 expressed that if specifications which define “employer’s requirements” are unclear or if the employer does not have enough information/experience on the project, capturing the comprehensive requirements of the employer would not be possible in every condition. Therefore, the clarity of contracts will be helpful to determine both the scope of the work and the value requirements. In regard of employer’s requirements that enable inputs for the development of the BIM strategy, the usage of BIM or any other highly technical process needs to be stated in the specification. Similarly, Expert #5 stated that BIM strategy on specifications need to be parallel with the lean and VE concepts since the usage of BIM is limitless. According to Expert #4, some subcontractors avoid using BIM due to its high costs. This preference impedes the identification of lean processes and the discovery of non-value-added activities.

- **LP2**—Expert #1 and #3 stated that defining value is a hard process in the beginning of a project since it is already committed to how long it will be to deliver the design within the contract. Expert #3 mentioned that savings can be made in the design phase in terms of time, but this will bring a certain expenditure as well, since creating a BIM model also requires additional workforce at the design stage. However, Expert #1 agreed that BIM models increase the quality and efficiency of the design and provides more opportunity to identify value improvements and wastes. Expert #4 emphasized the difficulty of understanding customer value. Expert #4 also expressed that the BIM model provides great savings during the construction phase, since the conflicts and clashes can be proactively solved in association with the lean and VE concepts. Another important remark was on the usage target of the model. If it is not targeted to use the BIM model in FM, a model with so much information would create productivity loss and waste after the construction phase as well. Expert #5 exemplified that gathering information about purchasing process is vital in creating a BIM model for FM. However, in their case, the employer had limited information about these processes, so they needed to relate them with employer’s real needs to eliminate waste in terms of time, budget, and manpower. This example again highlighted the importance of match-up between project scope and employers’ requirements to understand the required value of employers.

- **LP3**—Expert #1 mentioned that the identification of the BIM execution plan helps to complete the necessary data requirements and scope identification in terms of value identification (Level 2). Thus, the identification of the BIM execution plan would enable easier design creation and selection, as well as a collaborative project management. If the working style is not supported with exact rules in the BIM execution plan, all disciplines would create their design or tasks separately, which would increase waste and non-value-added activity. Additionally, Experts #1 and #5 proposed that when BIM models are managed in a Common Data Environment (CDE), clash detections to eliminate wastes would be more efficient due to the accuracy of updated models. Expert #2 emphasized that one of the most important principles of
LM is to detail and finish everything in the pre-construction period, and in line with this view, Expert #3 stated that value creation in the pre-construction period is more valid and easier.

- **LP4**—Collaboration and communication are especially important both to increase relatedness between stakeholders and to enable lean processes and value-added activities. Therefore, Expert #1 shares a project where, while the project details continue with 2D drawings, the architectural designs continue with 3D models. Expert #1 said that this experience causes loss of man-hour and delays, but it teaches the importance of collaboration. Expert #2 offered to choose integrated project delivery methodology as a collaborative project delivery method involving all project participants to use maturity framework. Expert #3 offered software usage (Revit or Navisworks) as a solution to eliminate collaboration and communication issues. Expert #4 and 5 mentioned the importance of BIM to solve collaboration issues, enabling lean processes and increasing value in the building life cycle (Level 2). Expert #4 thought that if construction companies have properly coordinated models, they can obtain accurate quantities in earlier stages of construction. This leads to the creation of proper purchasing and budget preparation processes, and this also leads to increased quality and time savings to apply VE while selecting construction materials, etc.

- **LP5**—Experts #1, #2, and #4 stated that the greatest value can be added within the pre-construction phase within the selection of appropriate project planning and controlling. Expert #2 said that “uninterrupted flows in the construction process can be created with longer pre-construction period, more detailed work program and more detailed design”, and added that if the 3D model is detailed with the work program at the Level 2, a 4D model would reduce the complexity and waste. Although Experts #4 and #5 confirmed the importance of 4D BIM usage to identify appropriate project planning and control routes, they specified updating issues in 4D models and separation between the designer and contractor who prepares work schedules as important issues in practice. Expert #5 also stated the alliance requirement between designers and planners in BIM models, especially in the design process.

- **LP6**—Experts #2 and #3 believed that “Reducing the share of non-value adding activities” needs to be done in the pre-construction period. If the reduction is made by work site engineer on the worksite, this would not be helpful to fully reveal lean process (Level 1). Expert #4 also shared that they use BIM models to verify the accuracy of their determinations related to non-value-added activities. Expert #5 gave an example from previous experiences in a subway project. Since the contractor company has several experiences on subway projects, sometimes it was not possible to understand the project details from 2D projects. Herein, 3D BIM models help to increase value, constructability, and decision-making processes.

- **LP7**—Expert #2 mentioned that the determination of work packages in line with worksite conditions is crucial to increase value and eliminate wastes. Additionally, it was reported that details of each subcontractor’s work package can be revealed more clearly by using the BIM methodology. Expert #2 exemplified a project in which they worked with 20 subcontractors on the worksite and experienced confusion in identifying which work belongs to which contractor. Therefore, delays in the project were observed since the focus was on finding proper contractors rather than the project requirements by employers. Expert #5 gained attention for creating budget estimation on this process, since the usage of technologies such as BIM makes budget estimations easier.

- **LP8**—Expert #1 mentioned that, in some cases, BIM models need to be updated during the construction phase since the contractor can suggest different materials or different types of manufacturing. Therefore, these changes need to be seen in the model to manage projects effectively. Experts #2 and #5 expressed that 4D simulations can be used to visualize the worksite and activity relationship, hence, activities can be reduced and optimized. Expert #4 stated that a company’s workflow would depend on sub-
contractor work schedules, and even though the company tried to reduce batch sizes, this process was affected by the activities of subcontractors such as reworks, delays, and errors, etc. Expert #4 also stated the difficulty in finding a subcontractor who seriously works with high technological advancements such as BIM along with proper project management methods such as LM and VE. Likewise, Expert #5 underlines that work schedule should be always updated, and when reducing the batch sizes, they must track the time schedule based on changes.

- **LP9**—The practitioners need to provide uninterrupted flow to enable elimination of non-value-added activities. Expert #1 gave an example from an airport project in which communication and continuous workflow issues were observed. BIM models and tablets were used in the controlling of the worksite. However, due to the usage of different BIM models and different versions of BIM software, coordination problems arose. According to the expert, even if the main model was updated, the data from the subcontractor was not consistent. Therefore, the expert recommended that the main contractor should take the responsibility of coordinating workflows in multi-stakeholder projects, and the main contractor should use BIM models to enable continuous workflow. Experts #2 and #3 added that keeping the model updated in the construction process and delivering the newest version of information to the worksite also provides an increase in value because it also improves the workflow. Expert #3 stated that it may be difficult to make changes, especially in terms of design, after manufacturing begins, since approval from employer is needed. Therefore, Expert #3 recommended that VE need to be performed prior to construction phase. Expert #4 believed that BIM prevents delays, reworks, and errors by using clash detection. Expert #5 thought that creating production systems which do not have any reworks and waiting, etc., requires tracking the budget as well, since the company owners always want to see changes of effect on budget. Additionally, the interviewee stated that if the quantities of project are known, the purchasing process can be more accurately managed since BIM is a suitable tool to try different alternatives.

- **LP10**—When Level 1, 2, 3, and 4 are performed, the practitioners need to create collaboration between disciplines and stakeholders to enable linear workflow within the scope of the project. Using technological devices such as tablets here improves coordination, since sometimes it may be necessary to take faster actions on the worksite. Expert #2 expressed that creating reports from the worksite and sharing them with the office can be thought as a linear workflow to enable a lean process and as a value enhancement. Additionally, Expert #4 proposed usage of online/electronic object-based communication such as “Notification for Inspection” and “Test and Commissioning Request” documents. These documents not only reduce waste in creating paper-based copies, but they also help to eliminate time for signing papers. The most important thing is that all these documents can be reached by every stakeholder via CDE.

- **LP11**—Simplification in the processes and activities is needed to enable lean and VE processes. Experts #1 and #3 expressed that simplification in processes or alternatives is only possible if the required time is given to the designer and decision makers since employers give limited time for pre-construction activities. Expert #2 stated that practitioners can provide simplification in material selection, design improvement, or work method. Moreover, the project delivery method was expressed as the most convenient approach to simplify processes. Expert #4 corroborated that the application of Level 2 would increase creativity in VE applications and provides simplification as well. Expert #5 emphasized that every change in the AEC industry would be finalized with the increase in the budget. Therefore, Level 2 and 3 are crucial to determine simplification alternatives.

- **LP12**—It is important to reduce the temporal variability in production processes to create continuous workflows. Additionally, produced solutions or alternatives need to be compiled and ranked within employer’s requirements. Experts #1 and #3 stated that the determination of work packages in the pre-construction phase is very convenient
to reduce variability, whereas Expert #4 expressed that all work packages need to be managed and coordinated by the project management team to enable reductions in variability. However, in practice, every discipline creates its own work plan, and this management style causes issues in terms of value creation.

- **LP13**—Expert #1 recommended that this process needs to be performed with the advice of subcontractors in the re-construction phase since the change in construction phase increase expenses exponentially. Expert #2 gave an example and mentioned that the same work packages are performed by different workers, and these works are controlled or monitored by different engineers. Therefore, increases in cycle time were observed. Expert #3 also gave an example in which materials chosen based on previous experience lead to exceptionally long processes and reworks. However, the expert expressed that if this process was performed with BIM, the material requested from the employer could be placed on the model and processes and their requirements in advance, and that would be helpful in reducing cycle time.

- **LP14**—Expert #2 mentioned that if processes are transparent, the decision-making process takes less time, and it provides an opportunity for value creation. Expert #3 gave an example from his experience in which suspended ceiling details were needed. Therefore, project details were requested from the architecture company. However, the architect shared limited data in a pdf format due to data privacy issues. Therefore, the expert expressed that non-transparent process cause decreases in productivity. Expert #4 believed that if the project management does not belong to one entity, there is confusion and people tend to hide information. Expert #4 also recommended that BIM teams should allow access to the BIM models of other stakeholders, either as viewer or owner, especially in mega projects. Expert #5 proposed the usage of CDE to increase collaboration and transparency between the site, the design team, and the office.

- **LP15**—Expert #1 stated that timely purchasing, timely feedback to the BIM model, and timely request of the employer have a great influence on delivery processes. In parallel, Experts #2 and #3 asserted that 4D BIM simulations would help contribute to the purchasing and delivery schedules of materials, whereas Expert #4 stated that monitoring these processes through BIM can be problematic. Expert #4 also recommended that purchasing schedule should be created separately with design but collaboratively with planning team.

- **LP16**—Expert #1 stated that if manufacturing details are processed into a BIM model, they can provide continuous flow by reducing reworks in processes. Expert #3 proposed that the marking of finished and started building elements with colours in the model aids to create continuous flow and reduce delays. Additionally, the expert recommended that elaborated work schedule and optimization in the work schedule can be a solution to improve the workflow arising from imperative and unexpected changes.

- **LP17**—Visual knowledge sharing is an important part of continuous improvement in Level 1. However, cost-benefit analysis needs to be performed to determine the effectiveness of the usage of visual management tools in Level 2. Additionally, BIM models can be used as visual management tool. Experts #2 and #5 mentioned that visual management systems such as Kanban, which creates systematic work plans to see what mission will come next, can be used to track construction and payment progress. Additionally, Expert #1 stated that SP17 is an exceptionally good idea for the maintenance phase.

- **LP18**—Expert #4 mentioned a mega project implementation with a high number of subcontractors and stated that while subcontractors use 2D shop drawings, contractor use 3D BIM models to control shop drawings. If the contractor identified any conflict between shop drawings, revision was requested from subcontractors. Therefore, it was stated that BIM models help solve possible conflicts proactively and BIM contributes “Go and see for yourself” applications.
• LP19—Consideration of employer’s requirements enhances the value and facilitates new innovative solutions that can be used in the development of VE alternatives. Expert #1 stated that employers need to be supported in the identification of their requirements, since sometimes employers cannot foresee the impact of the existence or non-existence of subsidiary tools at the operation and management stage. Therefore, when practitioners are developing alternatives for VE application, the building lifecycle needs to be considered. Expert #4 stated that object-oriented communication can increase output value since it will increase understanding of customer requirements and ensure the meeting of these requirements by all participants.

• LP20—“Push flow” means that only demanded works create output. Therefore, planning for a flow should be started from the smallest part of the organization. Special focus should be given on subcontractors to deliver improved value while work demands are reorganized or reviewed, since construction works are generally subcontracted. Expert #3 attributed push flow to the experience of practitioners in the worksite since they continuously monitor critical production processes.

• LP21—Expert #3 stated that in conventional methods, the control of completed works or health and safety conditions is performed with site visits, which cause productivity losses. However, BIM or sensors can be used as technological solutions to increase productivity while decreasing health and safety issues. Additionally, Expert #1 believed that if the detail level of the model is increased, rework activities on the construction site can be reduced. Experts #4 and #5 stated that records of quality control process are embedded in the BIM model to provide more benefits at the operation and maintenance stage.

• LP22—This principle points out the necessity of verification based on the specifications and customer requirements. Expert #4 expressed that normally these processes are conducted with meetings in conventional project management approaches. Within this context, Experts #1 and #4 offered the advantage from BIM’s visualization and data storing capabilities to record approvals and updates to prove verification and validation processes.

• LP23—Decisions need to be supported with people and/or processes to increase the applicability of decisions, to create value, and to eliminate wastes. Expert #2 stated that face-to-face communication, which can be performed in daily meetings, can be effective to increase the understanding of stakeholders. Expert #5 expressed that they have coordination meetings, and they also use CDE and BIM models for illustrating issues that they discuss. Moreover, the company of experts enabled participation of every stakeholder especially facility manager in these meetings.

• LP24—Expert #1 stated that they can enable knowledge accumulation from their value practices and performed updates in the BIM library to increase productivity in the next project. Expert #2 believed that as-built BIM models need to be updated to enable continuous value flow and improvement. Expert #3 expressed that creating company culture depending on information archiving or documentation is one of the issues in front of value-added practices in the AEC industry. Likewise, Expert #4 proposed the usage of BIM models to record lessons learned and suggested that BDA would help to improve value generation and store more data. Expert #5 mentioned that continuous improvement is only possible by recording data, and the BIM file must be saved in IFC format to prevent data loss for future needs. Expert #5 also reported that the usage of BDA will be helpful at the operation and maintenance stage due to documentation needs such as equipment specifications, manuals, etc. Moreover, Expert #5 pointed out the importance of having a proper data storage environment BDA to retrieve critical information by analysing unstructured data later.

• LP25—Expert #1 stated that the usage of software for visualization (such as Grasshopper) helps them save time due to automation, high graphic quality, and more detail. Expert #3 stated that wastes from construction processes can be considered as a performance indicator. In the calculation of wastes, the expert stated that BDA can provide
automation and efficiency. All experts acknowledged that as-built models and model created design stage need to be compared to identify wastes.

- **LP26**—Expert #2 emphasized the importance of information sharing in the company, since the organization’s culture is facilitated via information sharing. Likewise, Expert #5 stated that the collaboration between contractors and employers is vital since, when employers are satisfied with a service, the employer would want to collaborate with the same contractor again. However, Expert #1 stated that collaboration between stakeholders after a project can be very problematic due to copyright or conflicts between parties.

- **LP27**—Expert #2 proposed the usage of BIM since it helps to foresee operation processes. Expert #4 mentioned a mega project in which maintenance activities were performed based on retrieved data from a BIM model, even if FM was performed, depending on different software. Likewise, Expert #5 mentioned the importance of data interoperability requirements between FM systems (such as SCADA, etc.) and BIM since the employer requests the usage of the same code in both SCADA and BIM from the interviewee’s company in a subway project.

- **LP28**—Standardization processes help to reduce variability, whereas feedbacks and lessons learned lead to continuous improvement. Expert #1 emphasized that BIM model also helps standardization process if the model is supported with real-time data. Expert #2 gave an example from their projects in which past project experiences were used to solve a suspicion about which part of building should start construction first, such as the core or tower to build steel-reinforced concrete. Expert #3 mentioned a budget estimation process in which data of previous projects were used to make a budget predictions for a new one and added that BDA will help to perform more accurate budget estimations by enabling data storing and analysis at any time. Expert #4 explained standardization process with one implementation from their companies in which checklists for every production process were prepared as a result of experience and lessons learned documents. However, Expert #5 expressed that it would be hard in practice to create standardization process due to tight schedules.

Highlights of experts’ evaluations related to lean processes (LP) of proposed maturity framework are given in Table 2.

**Table 2.** Highlights of experts’ evaluations related to Lean Processes (LP) of proposed maturity framework.

| Lean Process | Highlights |
|--------------|------------|
| LP1—Ensure comprehensive requirements capture | Clarity of contracts and clear specifications for defining scope of work, employer’s requirements, value requirements of customer, and BIM Strategy |
| LP2—Customer value perfection | Usage of BIM to enhance the quality and efficiency of the design, value improvements/The usage of BIM with the integration of LM and VE to reduce conflicts and clashes/Usage of BIM model for FM in accordance with employer’s needs to eliminate waste in terms of time, budget, and manpower. |
| LP3—Focus on concept selection | Identification of BIM execution plan to enable easier design creation and selection, and a collaborative project management. |
| LP4—Increase relatedness | Strong collaboration and communication to increase relatedness between stakeholders and to enable lean processes and value-added activities. Choosing integrated project delivery methodology that involves all project participants. |
| LP5—Select appropriate project planning and control route | Selection of appropriate project planning and controlling route in pre-construction phase; 4D BIM usage to overcome appropriate project planning and control route. |
| LP6—Reduce the share of non-value adding activities | Focus on reducing the share of non-value adding activities should be done in the pre-construction period. |
| Lean Process | Highlights |
|--------------|------------|
| **LP7**—Ensure requirements flow down | Determination of work packages in line with worksite conditions; Revealing the details of each subcontractor’s work package clearly by using BIM methodology; Creating budget estimation within 5D BIM. |
| **LP8**—Reduce batch sizes | BIM models and work schedules should be regularly updated during construction phase; 4D BIM use to visualize worksite and activity relationship; Working with (sub)contractors that have high technological advancements (such as BIM, LM, and VE); Tracking the time schedule based on changes when reducing the batch sizes. |
| **LP9**—Design the production system for flow and value | Providing uninterrupted flow to enable elimination of non-value-added activities (avoiding using different BIM models and different version of BIM software, etc.). |
| **LP10**—Balance flow improvement with conversion improvement | Necessity of collaboration between disciplines and stakeholders to enable linear workflow within the project scope; Reports from worksite should be shared with the office as linear workflow to enable LP and VE; Usage of technological devices and online/electronic object-based communication methods to improve coordination. |
| **LP11**—Simplify | Required time should be given to decision makers to achieve simplification in pre-construction activities; Project delivery system selection as the most convenient approach to simplify processes. |
| **LP12**—Reduce variability | Determination of work packages in pre-construction phase to reduce variability; Coordination of all work packages reduce variability. |
| **LP13**—Reduce the cycle time | Usage of BIM will reduce cycle time based upon the ability of tracking material requested from employer. |
| **LP14**—Increase process transparency | Project management should be carried by one entity; Unlimited data sharing should be provided between stakeholders of the project; BIM teams should allow access to BIM model for other stakeholders either as viewer or owner; Usage of Common Data Environment (CDE) to increase collaboration and transparency between site and office. |
| **LP15**—Zero-time delivery | Use of 4D BIM for purchasing and delivery schedules of materials. |
| **LP16**—Organizing continuous flow | Processing manufacturing details into BIM model; Marking of finished and started building elements with colours in the model; Elaborating work schedule and optimization of the work schedule. |
| **LP17**—Use visual management | Usage of BIM and Kanban to track construction and payment progress visually. |
| **LP18**—Go and see yourself | Usage of BIM solve possible conflicts proactively and to contribute “Go and see for yourself” applications. |
| **LP19**—Increase output value through systematic consideration of customer requirements | Consideration of building life cycle in developing alternatives for VE application in terms of existence or non-existence of subsidiary tools at the operation and management stage; Object-oriented communication to increase output value. |
| **LP20**—Focus “push flow” control on the complete process | Planning flow should be started from the smallest part of the organization. |
| **LP21**—Quality control framework work in process production | Usage of quality control process that are embedded in BIM and sensors to increase productivity while decreasing health and safety issues. |
| **LP22**—Verify and Validate | Usage of BIM’s visualization and data storing capabilities to record approvals and updates to prove verification and validation processes. |
Table 2. Cont.

| Lean Process | Highlights |
|--------------|------------|
| LP23—Decide by consensus, consider all options | Performing daily meetings and coordination meetings with every stakeholder; Usage of CDE and BIM models for illustrating to get a consensus on the issues. |
| LP24—Institute continuous improvement | Usage of knowledge accumulation from value practices and performing updates in BIM library to increase productivity in the next projects (archiving/documentation/recording lessons learnt); Usage of BDA to store more data and to analyse unstructured data. |
| LP25—Improvement results from reducing waste | As-built models created in design stage need to be compared to identify wastes; Usage of BDA to provide automation and efficiency. |
| LP26—Cultivate an extended network of partners/Increase collaboration | Information sharing and collaboration between contractors and employers; Generating solutions for issues arising from copyright or conflicts between parties. |
| LP27—Build continuous improvement into the process | Usage of BIM to foresee operation and maintenance processes; Importance of data interoperability requirements between BIM and FM systems. |
| LP28—Standardize | Usage of BIM with the support of real-time data to standardize processes. |

4. Discussion

As a result of the expert evaluations in DesC, (i) clarity of contract, BIM execution plan, employers’ requirements, and communication in value phase; (ii) pre-construction activities, and 4D/5D BIM usage in the value stream phase; (iii) project delivery system, and CDE in the flow phase; (iv) IoT integration and BIM usage for conflict management in the pull phase; and (v) BDA analysis to retrieve value from projects and BIM-BDA integration in the perfection phase come into prominence.

(i) According to the interviewees’ responses, employer’s requirements which are not fully detailed in pre-project phases lead ambiguity. Parallel to this result, Bashir et al. [76] reported that poor project definition and lack of customer engagement are barriers for the implementation of lean methodology in the AEC industry. Therefore, there is a need for checklists or structured contracts such as FIDIC, etc., to understand the employer’s requirements in detail. If the employer’s requirements are not adequately detailed, conflict and disputes can appear in the projects [77]. Within this context, the usage of the proposed maturity framework is not only beneficial to collect and determine customers’ requirements, but it will also prevent conflict related to ambiguities in contracts. Kim and Park [78] also considered contracts as a success factor for LM, since contracts are one of the dimensions of organizational relationships, and contracts show the self-interests and the roles and responsibilities of stakeholders. Therefore, authors proposed that the involvement of project participants into LM is supported with contracts. Moreover, the study findings emphasize on the importance of BIM execution plans. BIM implementation procedures should be laid down in a BIM execution plan that identifies the responsibilities of stakeholders in terms of BIM [79]. According to expert evaluations, it was observed that a BIM execution plan is vital to achieving maximum value and minimum waste for the AEC industry. In their study, which explores the BIM and lean synergies in the Istanbul Grand Airport construction project, Koseoglu et al. [40] stated that stakeholders were gathered periodically, and procedures were followed as determined in the BIM execution plan. The authors reported that this helps to improve the quality of the designed product as well as clash detection in the project. Pedo et al. [80] also stated that BIM execution plans provide information such as level of details, clash detections, etc., about client requirements at the start of the project. Authors also stated that the identification of these requirements helps to detect clashes in early stages. Thus, the authors reported that rework activities (waste in terms of LM) can be eliminated.
Furthermore, it is explicit that the structured contract clauses and BIM execution plans need to be reviewed and revised to enable more opportunity for waste elimination practices and value increase in the AEC industry. From this viewpoint, it is obvious that preparing clear contracts and operationalizing BIM execution plan would also enhance collaboration and communication between project partners, since they will set up the required substructure for collaborative project management.

(ii) Pinch [81] emphasized the importance of bringing together stakeholders before the construction stage to perform LM activities. Experts also recommended that waste elimination and value engineering activities should be performed at the early stages of projects with the participation of all stakeholders. Thus, interviews believed that the commitment and awareness of stakeholders can be increased to implement methodologies in the proposed maturity framework. Moreover, the expert evaluations showed that 4D and 5D BIM implementation helps to value stream in construction projects. The time factor is added into 3D models of the building to obtain a 4D model that helps to visualize the construction process over time. With the usage of a 4D model, the controlling and performance tracking of projects are more explicit. Additionally, 4D implementation helps to reduce errors, increase collaboration, evaluate the design and process alternatives, and test strategies. With the addition of cost information into the 4D model, a 5D BIM model is obtained. A 5D model is important to explore different scenarios [78]. The implementation of 4D and 5D BIM models in construction processes increases transparency in terms of the construction sequence and procedures. It is obvious that experts can have full knowledge of the project and they can see the value stream in terms of VE and LM.

(iii) Trust, intellectual property rights, miscommunication, data loss, data inconsistency, errors, and liability for incomplete or wrong data are common issues in conventional construction projects. Moreover, when BIM is adapted into projects, BIM makes these issues more complicated. Therefore, the usage of CDE that provides data accessibility is recommended to solve collaboration issues [82]. Evans et al. [83] stated that cloud technologies and access to project information have facilitator roles in the performance of waste elimination activities. Furthermore, the usage of CDE helps to share design changes with site within minutes. Additionally, workflows for resource and performance monitoring, information management, communication, and coordination practices, which are lean management practice areas, can be easily managed with CDE BIM [41]. In parallel to the literature, experts acknowledged that CDE BIM helps to solve issues related to communication, data, transparency, and data visualization. There are different CDE platforms in the AEC industry. While one such CDE platform is superior to the others in terms of model visualization, others are superior in document management. Therefore, CDE usage in projects needs to comply with employers’ and stakeholders’ requirements. Considering BIM usage with tablets, CDE, etc., would facilitate more innovative solutions to eliminate wastes and deliver value concurrently, and the application of proposed maturity framework will facilitate these innovative solutions to obtain and deliver more value to customers. The selection of delivery method for construction projects is found to be important to implement the proposed framework by experts in DesC. Delivery methods are defined as a value generation path for customers and stakeholders by combining and transforming resources [84]. Within this context, Collins and Parrish [85] stated that the design-bid-build (DBB) delivery method causes a lack of sufficient scope review, collaboration during design, and a lack of the owner’s actual needs. Therefore, the authors expressed that DBB focused on individual optimization rather than the whole project. Depending on this issue, the IPD delivery method, which considers the total project’s success collaboratively, emerged. Additionally, project performance metrics in terms of time, cost, quality, and change orders are better than other project delivery methods in IPD. Mesa et al. [84] stated that IPD aims to increase value, reduce waste, and maximize efficiency according to IPD definitions. Dave et al. [86] stated that
production controlling on the construction site is still challenging. To overcome this barrier in the construction industry, ad-hoc solutions are implemented. In the LM, the last planner system plays a role in partially tackling these issues. However, the authors stated that this procedure takes a long time to respond to dynamic conditions on the construction site. Therefore, the authors investigated IoT communication interfaces to retrieve the right production information. Additionally, the authors stated that IoT data is important to minimize waiting time of workers. Guerriero et al. [87] expressed that the IoT and human–machine interfaces are promising technologies for further developments in LM practices. Parallel to the literature, expert evaluations showed that IoT applications in the AEC industry will pave the way for leaner applications.

(iv) In the construction industry, every stakeholder has their own expectations, values, and goals. Depending on these characteristics, conflicts are inevitable in the AEC industry. Moreover, delays, fragmentation, or the suspension of projects can be observed because of conflicts [88]. Therefore, Charehzehi et al. [88] and Zhang and Hu [89] stated that 3D visualization, 4D scheduling, 5D cost estimating, clash detection, safety analysis, and structural analysis with BIM helps to eliminate conflicts in the AEC industry.

(v) One of the first goals of companies pursuing to gain a competitive advantage is to develop new products and services by leveraging digitalization. They may seek to figure out ways to do it more affordably while reaching this goal to maintain competitive advantages. The capacity to use BDA is a powerful tool to improve organizational performance. However, it requires combination of all resources such as BDA management, proper IT infrastructure and sufficient human resources that capable for analytics skill or knowledge. Decision makers of these organizations should be ready to adopt flexible and technologically innovative behaviour. BDA adoption with VE, BIM, and LM affects an organization’s capabilities in collecting and maintaining quality data. An organization’s predicted benefits, business value perception, decision maker approach, company culture, and infrastructure should all be transformed. Organizational readiness is determined not just by internal capabilities, but also by external capabilities such as market orientation in the construction industry [90,91]. The interview results showed that the AEC industry has limited knowledge about the implementation of VE and BDA. Andújar-Montoya et al. [92] stated that there are limited case studies that show the benefits of the implementation of these concepts together in projects. Likewise, the results indicated that the consideration of LM together with BIM is still in its infancy. In addition, BIM adoption is not at the intended level because of the conservative structure of the AEC industry [93,94]. In parallel to the literature, the results highlighted that usage of BIM is still problematic due to the lack of customer demand, interoperability issues, undetailed employer’s requirements, incapability of subcontractors for BIM implementation, etc. For that reason, it is crucial to reveal how each concept (LM, VE, BIM, and BDA) can be integrated to each other to overcome efficiency, quality, and productivity issues. Therefore, it is believed that the proposed framework and its processes will be beneficial to increase the awareness of construction companies and how they can apply other methodologies and tools together to obtain more waste-free applications.

5. Conclusions

However, because the integrated uses of BIM with LM, VE, or BDA were addressed in the literature frequently to overcome the productivity and digitalization issues of the AEC industry as pairwise, there is no comprehensive framework which identifies their relationships. Therefore, this study aims to develop a maturity framework to overcome adoption issues and explore synergies between LM, VE, BIM, and BDA methodologies for the AEC industry. In this regard, DSR methodology was used to develop and evaluate the proposed maturity framework. First, two interviews were conducted to explore the issues that require an integration of LM, VE, BIM, and BDA in the AEC industry in the relevance
cycle of DSR methodology. Secondly, a tentative maturity framework that consists of five levels was developed in the rigor cycle of DSR methodology. The presented maturity framework, which was developed in the rigor cycle, consists of five levels. Level 0 presents the inaction level during the lifecycle of building. In this level, conventional management methods and tools were followed. Level 1 consists of 28 lean process (LP), which were identified as a result of a comprehensive literature review. The integration of VE, BIM, and BDA were adopted in Levels 2, 3, and 4, respectively. Thirdly, the developed framework was evaluated by five experts in the design cycle of DSR methodology. As a result of experts’ evaluations related to LPs of the proposed maturity framework, (i) clarity of contract, BIM execution plan, employers’ requirements, and communication in value phase; (ii) pre-construction activities, and 4D/5D BIM usage in the value stream phase; (iii) the project delivery system and CDE in the flow phase; (iv) IoT integration and BIM usage for conflict management in the pull phase; and (v) BDA analysis to retrieve value from projects and VE-BIM-BDA integration in the perfection phase were mentioned as the prominent application and adaptation issues through the integration of VE, BIM, and BDA concepts with lean processes to enhance innovativeness, waste elimination, value, and organization culture.

The results of the study also show that the proposed framework is applicable and informative as a guideline for practitioners. In addition, the application of maturity frameworks necessitates changes in the organization of companies. To overcome a possible resistance of workers, organization culture needs to be strengthened. In addition to these, the study findings clearly showed that the level of employers and sub-contractors affect the implementation level of management practices. Therefore, the awareness level of employers needs to be increased and the attention to small to medium-sized companies needs to be given to internalize concepts under these management practices.

Though the need for technical guidance for integrating all proven value-oriented project management processes and methodologies (such as LM, VE, BIM, and BDA) is emphasized frequently in the literature, as mentioned above, studies which comprehensively explore and explain the synergy between these concepts are limited. Likewise, the integration of these project management processes and methodologies are not clear for many practitioners due to lack of knowledge about these methodologies. With that background, the proposed framework will provide gradual solution for overcoming the productivity problem of the construction industry. Additionally, it will contribute to the AEC industry in the following ways: (1) to determine which steps practitioners should take to be leaner and value oriented; (2) to specify companies’ implementation level; (3) to determine which actions practitioners should take to increase the offered value for customers/clients; (4) to benchmark company’s current position/goals for providing competitive advantages; and (5) to provide a gradual solution for overcoming the productivity problem of the construction industry. Further studies can focus on the analyses which can be made in terms of the human factor in the institution in order to eliminate barriers that can be created for applying the proposed framework.

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Appendix A

Maturity Framework Assessment Questions

Question 1—Are the levels specified in Figure A1 enough and correct?

Figure A1. Maturity framework for lean construction.

Question 2—The first of the lean management principles, “Value”, is defined as defining the value and understanding the pursuit of value.

Consider the compatibility of the sub-processes presented in Table A1 with the “Value” principle based on your experience and applications from construction projects. Which item should be added or removed? In your opinion, can these sub-processes be evaluated as the Value initiation phase and Value establishment phase? Comment on the role of BIM functions in the realization of this subprocess.

Table A1. Lean integrated value engineering stages and sub-processes: Value Principle.

| Integration of VE | Value initiation phase | Value establishment phase |
|-------------------|------------------------|---------------------------|
| LM                | LP1—Ensure comprehensive requirements capture in the specification | LP3—Focus on concept selection (Divide design into concept design and detailed design) |
|                   | LP2—Customer value perfection |                       |
| Integration of BIM| Scope of BIM processes and determination of their roles in these processes | BIM execution plan and creating visualization of form in 3D |
|                   | Collaboration in design and construction |                       |
**Question 3**—The second of the lean principles, “Value Stream Stage”, is defined as the creation of the entire flow map leading to the defined value. Consider the compatibility of the sub-processes presented in Table A2 with the principle of “Value Stream” based on your experience and applications in the projects. Which item should be added or removed? Do you think these sub-processes can define as “Value analysis scaling”? Comment the role of BIM functions in the realization of these sub-processes.

**Table A2.** Lean integrated value engineering stages and sub-processes: Value Stream Principle.

| **VALUE STREAM** |
|------------------|
| Integration of VE |
| Integration of BIM |
| LM |
| LP5—Select appropriate project planning and control route |
| LP6—Reduce the share of non-value adding activities |
| LP7—Ensure requirements flow down |
| LP8—Reduce batch sizes |
| LP9—Design the production system for flow and value |
| Rapid generation and evaluation of construction plan alternatives: |
| Rapid generation and evaluation of construction plan alternatives: |
| Maintenance of information and design model integrity |
| Automated generation of drawings and documents |
| Maintenance of information and design model integrity |

**Question 4**—The “Flow” phase, which is the third of the lean management principles, is defined as the phase of reaching the determined value without interruption by planning the flow. Please comment on compliance of the sub-processes presented in Table A3 with the principle of “Flow” based on your experience and applications from the relevant construction projects. Which item should be added or removed? Can LP10 and LP 11 be considered as value creation stages? Can LP 12, LP 13, LP14 be defined as “Value Creativity Phase”? Can LP15 and LP16 be evaluated as “Value Evaluation Phase”? Please comment on the role of BIM functions in the realization of these sub-processes.

**Question 5**—The “pull”, the fourth of the lean management principles, is defined as the improvement and evaluation of the stages of reaching the defined value. Please comment the compatibility of the sub-processes presented in Table A4 with the “Perfection” principle. Interpret the compliance of the sub-processes presented in Table A4 with the value flow principle. Which item should be added or removed? Can LP17 and LP 18 be considered as “Value development phase”? Can LP 19, LP 20, LP21, LP 22, and LP 23 be evaluated as “Value verification phase”? Please comment the role of related BIM functions for these sub processes.
Table A3. Lean integrated value engineering stages and sub-processes: Flow Principle.

| Flow Phase | Integration of BIM | Integration of VE | Integration of BIM |
|------------|--------------------|------------------|-------------------|
| LM         | Integration of VE  |                  |                   |
|            | LM                |                  |                   |
|            | Value development |                  |                   |
|            | Value verification |                  |                   |
|            | Value Creativity   |                  |                   |
|            | Value Evaluation   |                  |                   |

| Sub-processes | LM         | LM         |
|---------------|------------|------------|
|                | Balance flow improvement with conversion improvement | Value Creativity Phase |
|                | Simplify |             |
|                | Reduce variability |                |
|                | Reduce the cycle time |                |
|                | Verify and Validate |                |
|                | Increase process transparency |                |
|                | Zero-time delivery |                |
|                | Organizing continuous flow |                |

Table A4. Lean integrated value engineering stages and sub-processes: Pull Principle.

| Pull Phase | Integration of BIM | Integration of VE |
|-----------|--------------------|------------------|
| Pull      | Integration of VE  |                  |
|            |                    |                  |
|            | Value development  |                  |
|            | Value verification |                  |
|            | Value Evaluation   |                  |

| Sub-processes | LM         |
|---------------|------------|
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |

| Sub-processes | LM         |
|---------------|------------|
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |

3D control
Site utilization plan/Site analysis
Online/electronic object-based communication
Support the make ready process, Controlling and storing lifecycle data
Existing conditions modeling
Maintenance of information and design model integrity
Collaboration in design and construction

| Sub-processes | LM         |
|---------------|------------|
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |

| Sub-processes | LM         |
|---------------|------------|
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |

| Sub-processes | LM         |
|---------------|------------|
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |
|                |            |

Integration of BIM
Integration of VE
Integration of BIM
**Question 6**—Perfection, which is the last lean principle, is defined as creating lessons learned from the processes of creating value, learning them, and aiming to improve the processes with these lessons. Please comment on the compatibility of the sub-processes presented in Table A5 with the “Perfection” principle. Which item should be added or removed? Please comment on the role of relevant BIM functions about below sub-processes. Please comment on the use of big data on issues such as storing the design results mentioned in the table and speeding up the analysis and relationship between related sub-processes.

| Table A5. Lean integrated value engineering stages and sub-processes: Perfection. |
|---|
| **PERFECTION** |
| Integration of VE |
| LM |
| Integration of BIM |
| Integration of BDA |
| **Question 7**—In the solution of these adoption problems, do you think that structure that determines sub-process as Tables A1–A5 such as proposed framework benefits to improve conventional construction methods? Why?
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