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Article

Lean and Sustainable Project Delivery in Building Construction: Development of a Conceptual Framework

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Abstract: The shortage of constructive philosophies, principles, techniques, and tools in construction project delivery and sustainability before the 1990s, together with the abundance of them after 2000, creates two different eras which are of prime importance. The former one's considerable advantage was a common understanding and set of practices (e.g., the critical path method for scheduling), which seems to be a goal to achieve in the later one. In this regard, the combination and integration of best practices, tools, and techniques in construction project delivery can be considerably helpful for benefiting from their advantages and covering their limitations. Thus, this study aims to develop a conceptual framework for lean and sustainable project delivery in building construction projects. To do so, a systematic literature review was carried out, through which 230 studies were located and analyzed via thematic analysis to realize the purpose of this study. The findings present a conceptual framework for project delivery which combines and integrates sustainability, lean construction, and building information modeling in terms of principles, practices, tools, and techniques. Practically, this study's results inform practitioners in the construction industry on the lean and sustainable delivery of building construction projects.

Keywords: building information modeling; building construction; construction project delivery; lean construction; sustainability

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1. Introduction

The changes and developments concerning construction project delivery and sustainability, from a chronological perspective, can be divided into two different, but very important, eras. The first era refers to the scarcity of constructive philosophies, principles, techniques, and tools before the 1990s, and the second one refers to the abundance of them after 2000. The former one's considerable advantage was a common understanding and set of practices globally (e.g., the critical path method for scheduling), which seems to be a goal to achieve in the later one. The later one's meticulously developed practices, techniques, and methods have contributed to the evolution of construction project delivery in a considerable manner. In terms of theoretical and practical developments in the recent four decades, lean construction, sustainability, and building information modeling (BIM) can be considered as the major ones which have been exceptionally useful in improving construction design, planning, and management, and in decreasing the destructive impacts of construction on social, economic, and environmental sustainability [1–9].

Lean construction, which emerged in 1993, refers to the adoption and application of lean production principles, techniques, and methods in construction to realize lean ideals in the big picture, which is to identify value from the customer's perspective and to deliver fit-for-purpose products/services with low waste and high value [10–13]. The emergence of lean construction led to an evolution in the world of construction project delivery in terms of shifting from traditional delivery models (focused on division, self-interest, push planning, and contracts), such as design–bid–build, toward collaborative delivery models (e.g., lean project delivery, alliance, and integrated project delivery) with constructive elements, such as joint design, planning, and control; pull planning; shared risk-reward; a single integrated project team; and transparent cost management [14,15].

Sustainability is another significant concept which emerged in 1990s as the subset of sustainable development goals, outlined by the UN, as a result of recognizing the destructive impacts of construction projects on society, economy, and the environment [16]. Sustainable construction refers to all efforts which are required for realizing the needs of current generations in terms of the built environment while avoiding sacrificing future generations' right to inherit sufficient raw materials, a clean and healthy environment, and a dynamic, as well as functional, economy and society [17]. BIM is the third major development in the last 20 years, and it enables project stakeholders to accomplish the design, construction, and operation of a facility in virtual space in a collaborative manner through efficient technologies, processes, and policies [18,19]. BIM deals with all phases of the project lifecycle, and all parties involved need to collaboratively work together [18,20–22].

Previous research efforts concerning lean construction, sustainability, and BIM have mostly been conducted in an isolated manner although recent studies have recognized, acknowledged, and addressed some undeniable synergies among these concepts (e.g., [23–25]). However, these great research efforts have not yet been able to provide a synthesized conceptual view of the potential of realizing the synergetic effects of these three concepts for developing a delivery model for building construction projects which can be applied globally regardless of contextual differences. The combination and integration of best practices, tools, and techniques related to these three major concepts in construction project delivery can be considerably helpful to benefiting from their advantages and covering their limitations. Thus, this study aims to develop a conceptual framework for the lean and sustainable delivery of building construction projects through combining and integrating the best practices, principles, tools, and techniques of lean construction, sustainability, and BIM.

The resultant paper is structured in six sections, of which the first one introduced the problem and proposed the potential solution. The second one explains previous research concerning lean construction, sustainability, and BIM. The third section contains the explanation of the methodology, which is followed by a description and then a discussion of the obtained results. Finally, the sixth section contains the conclusions drawn from the findings.

2. Background

Lean construction emerged in the construction industry through the adoption of lean production principles, tools, and techniques for responding to the low productivity of construction projects in general due to factors, such as unreliable planning, the unfair division of risks and rewards, mistrust among project participants, the dominance of a low-price criteria for contractor selection, and a lack of involvement of the contractor and their team in project definition as well as design and planning. Lean production originated in the Toyota Production System, consisting of 400 organizational routines, as Fujimoto stated in 2012 [26]. The emergence of the Toyota Production System itself was the unplanned and unexpected result of improvements, innovations, and initiatives which were evidently unrelated [26].

Lean construction is based on Transformation-Flow-Value theory, which was propositioned by Koskela in 1992 [27]. Transformation-Flow-Value theory represents a production management paradigm which is utilized for conceptualizing project-based production systems. Transformation refers to the production of inputs into outputs. Flow can be explained as movement which is smooth and uninterrupted. Value is what the client expects the project to deliver without any kind of waste [28]. The emergence of lean construction also provided a basis for the development of the lean project delivery system by Glenn Ballard [29]. Lean project delivery, according to Ballard and Howell [30], connects five lifecycle phases to each other. These include project definition, lean design, lean supply, lean assembly, and use. In lean project delivery, construction is seen as production, and production planning and control form an important part of lean project delivery system, which is handled through the last planner system [30].

The last planner system, also developed by Ballard as the outcome of his doctoral dissertation, was created as a reaction to the critical path method (CPM) approach, which is utilized for planning and control in traditional construction [31]. According to Ballard [32], the "last planner system aims to shield project production from the baneful influence of CPM by limiting project master schedules to the milestone level of the detail and by having those directly responsible for doing the work to also decide how to do the same within each phase". The last planner system has five components, which are master scheduling, phase scheduling, lookahead planning, daily/weekly work planning, and learning. The first two components (master and phase scheduling) represent a "should" perspective, while the next two components (lookahead and daily/weekly scheduling) represent "can" and "will", respectively. Finally, the learning component refers the "did" aspect [32].

The research community has been very active in conducting research for the further development of lean construction (LC). Analyzing the literature on LC reveals certain themes which have been studied considerably. These topics include, but are not limited to, LC and BIM (e.g., [33–38]), waste and value (e.g., [39–43]), LC and sustainability [44–49], design and planning (e.g., [50–53]), LC implementation barriers and enablers (e.g., [54–61]), and implications of LC application (e.g., [3,62–65]). LC–BIM and LC–sustainability themes are explained and discussed further in the following text, as they are closely connected to the purpose of this study.

Regarding LC and sustainability, exploring their synergetic effects by addressing their interfaces is one of the major aspects which have been studied by different scholars (e.g., [44,46,66–68]). Another major aspect has been discovering enablers, challenges, and benefits for realizing lean and sustainable construction [17,25,46–48]. Regarding LC and BIM, the mentioned patterns for LC–sustainability studies can be also recognized here, meaning that LC–BIM, as a research topic, has been studied from different aspects, which include the barriers, enablers, and benefits of the joint-application of LC and BIM [2,4,18,21,34–36,69], interfaces and synergies between LC and BIM [22,70–72], and their integration [9,33,73–75].

The addressed topics in the areas of LC–BIM and LC–sustainability show that the research community has actively addressed different aspects of applying them together and benefiting from their collective advantages. However, there are two issues regarding the previous studies. The first one is that the majority of the mentioned studies have looked into the integration challenge either in the context of LC and BIM or LC and sustainability. Hence, there is currently very limited research-based knowledge concerning the integration of LC, sustainability, and BIM for different purposes. The second issue is that lean project delivery, although developed over time, has been taken for granted by the research community, and the development of a lean and sustainable delivery model for construction projects has received insufficient attention. Therefore, this study aims to fill the mentioned knowledge gaps through the development of a conceptual framework for the lean and sustainable delivery of building construction projects which combines and integrates the best practices, principles, tools, and techniques of LC, sustainability, and BIM.

3. Research Methods

3.1. Research Design

The literature study behind this paper aimed to explore the synergetic effects between LC and sustainability and between LC and BIM to develop a conceptual framework for the lean and sustainable delivery of building construction projects which benefits from the strengths of all the mentioned concepts. To do so, the relevant studies were located from the Scopus database, and then repetitions were excluded through reviewing the abstracts. Then, the relevant studies were reviewed, and the extracted research data were analyzed through the thematic analysis method [76]. The research process is shown in

Figure 1. Further details of the data collection and analysis are explained in the following subsections.

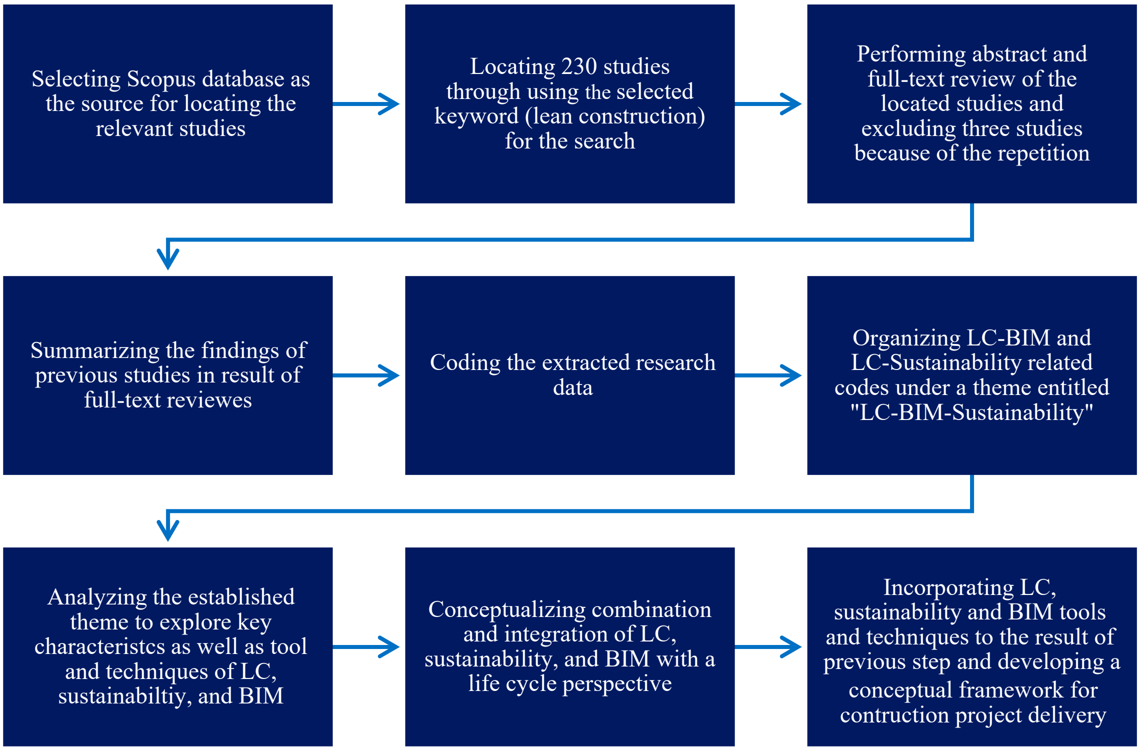

Figure 1. Research process.

3.2. Keyword Selection and the Search for Locating the Relevant Studies

In this study, the Scopus database was selected as the main source for locating the relevant studies as it contains almost all of the relevant journals in the field of construction and project management. The application of "Lean Construction" as the only keyword is related to this study's focus on the previous research addressing LC together with BIM and/or sustainability. This focus is justified through the purpose of this study to develop a conceptual framework for delivering building construction projects through realizing the synergetic effects of LC, sustainability, and BIM. This means that using "lean construction" as the keyword was sufficient for locating those studies focused on LC and BIM or on LC and sustainability. The search was conducted in April 2022 by searching for the selected keyword in the titles of previous publications in the Scopus database.

3.3. Results of the Conducted Search

The conducted search primarily resulted in locating 230 accessible studies by the authors, of which 3 were excluded because of repetition. The full texts of the remaining 227 studies were then reviewed and analyzed. Figure 2 shows the publication period of the 227 analyzed studies. Table 1 shows the number and types of the 230 located studies. No specific timespan was utilized in the search so as to ensure its inclusiveness. However, as can be seen in Figure 2, 77% of the 227 analyzed studies were published between 2016 and 2022. This is very important as the relevance of state-of-the-art publications is usually higher.

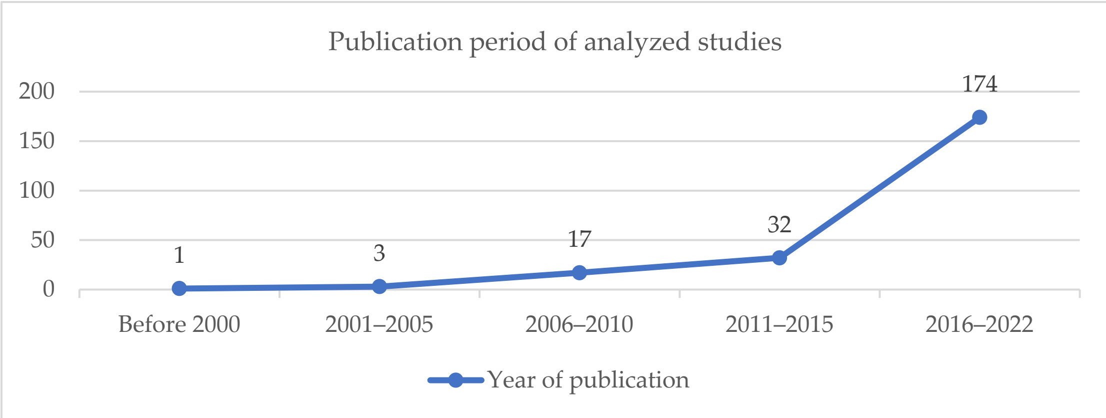

Figure 2. Publication period of analyzed studies.

Table 1. Types of the located studies.

Type of the Analyzed Studies	Number	Percentage
Journal articles	124	54%
Conference proceedings	103	44%
Out of scope (repetitions)	3	2%
Total	230	100%

3.4. Conceptualization: Thematic Analysis and Framework Development

After the completion of the search, the 227 located studies were analyzed through thematic analysis [76]. This was accomplished through reviewing full-text of the located studies and coding the obtained research data. According to the objective of this study, the codes representing LC–BIM and LC–sustainability were structured under a theme entitled "LC–BIM–Sustainability". This theme included 38 studies. Then, the codes under the developed theme were further analyzed for three main purposes: first, to conceptualize the combination and integration of LC, sustainability, and BIM with a lifecycle perspective; second, to incorporate LC, sustainability, and BIM tools and techniques which were relevant to the targeted delivery system; and third, to develop a conceptual framework for the lean and sustainable delivery of building construction projects which include BIM throughout the project lifecycle.

The development of the framework was accomplished in four steps. The first step was dividing the lifecycle of building construction projects into four phases. In the second step, the lean project delivery system, the plan-do-check-act (PDCA) method, and sustainability attributes were utilized as a frame of reference and then combined in terms of principles to create a process through which lean, as well as sustainable, target value definition and management can be realized. Third, each step in the created process was explained in detail. Finally, the tools and techniques of LC, sustainability, and BIM were matched to each phase of the project lifecycle based on their practical and conceptual relevance.

4. Results

Conceptual Framework for Lean and Sustainable Delivery of Building Construction Projects

A conceptual framework was developed for lean and sustainable delivery of building construction projects through combining and integrating LC, sustainability, and BIM concepts, tools, and techniques (see Figure 3). As can be seen, project lifecycle in the developed framework has been divided into four phases, which are project definition, design and planning, construction, and operation.

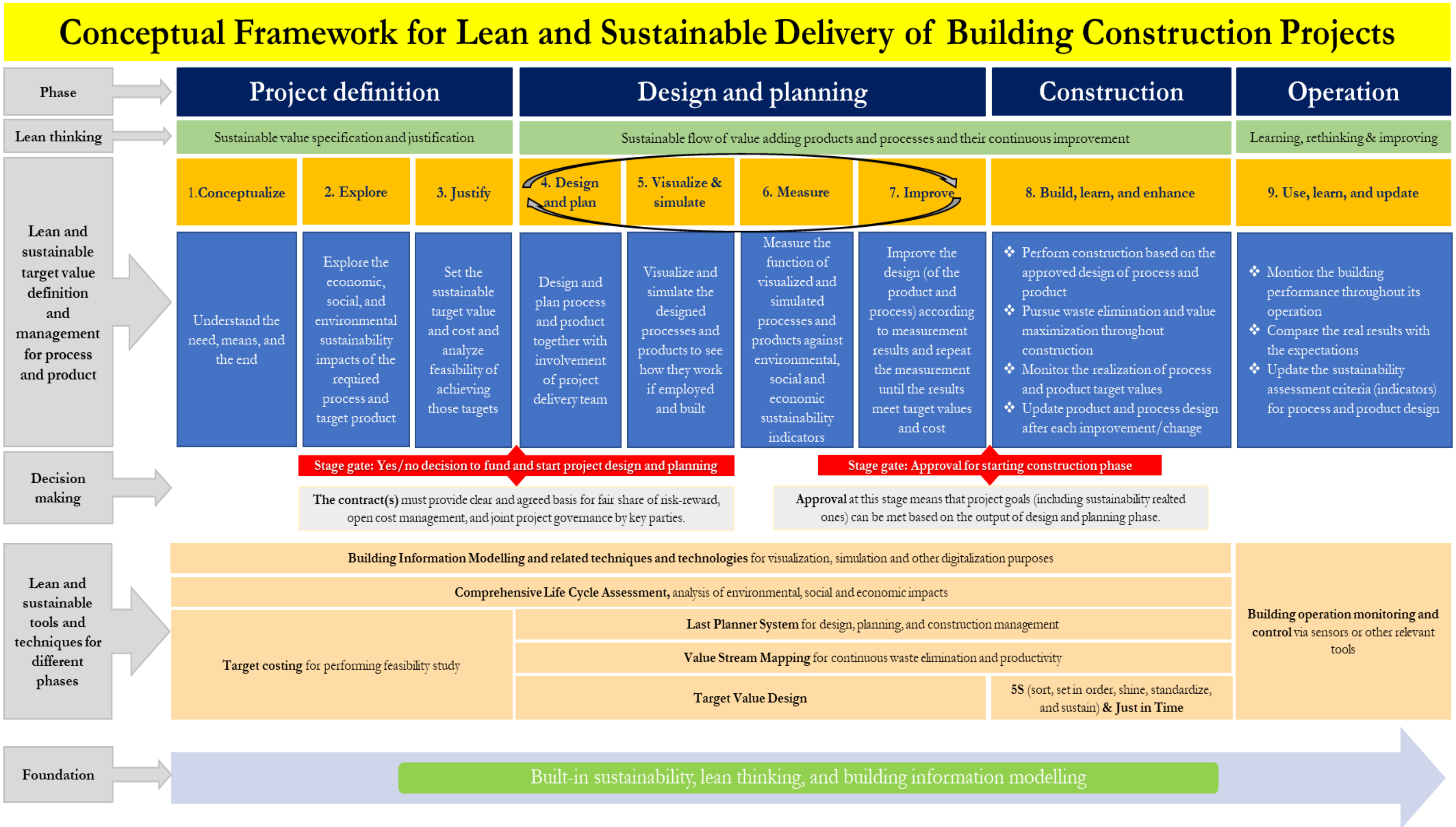

Figure 3. Conceptual framework for lean and sustainable delivery of building construction projects.

The project definition phase involves sustainable-value specification and justification, which happens in three stages: (i) Conceptualize (understanding the need, means, and the end), (ii) Explore (exploring the economic, social, and environmental sustainability targets and impacts of the required process and product), and (iii) Justify (setting the sustainable target value and cost, and analyzing the feasibility of achieving those targets).

After the completion of the third stage (Justify), there is a stage gate by which a yes/no decision is made for funding and starting the design and planning phase of the project. At this point, if the decision is positive, the awarded contract must provide a clear and agreed basis for the fair sharing of risks-rewards, open cost management, and joint project governance by all key parties. In terms of the tools and techniques, the target costing method, multiparty agreement, BIM, and comprehensive lifecycle assessment (an analysis of the environmental, economic, and social impacts) are proposed for fulfilling the objectives of the project definition phase.

The design and planning phase, focused on the sustainable flow of value-adding processes and products, is structured in four stages, which are (i) Design and plan (designing and planning the process and product together with the involvement of the project delivery team); (ii) Visualize and Simulate (visualizing and simulating the designed processes and products to see how they work if employed and built; (iii) Measure (measuring the function of the visualized and simulated processes and products against environmental, social, and economic sustainability indicators); and (iv) Improve (improving the design of the product and process according to the measurement results and repeating the measurement until the results meet the target values and cost). The cyclic nature of the design and planning phase in the developed framework contributes toward sustainable target definition and management. At the end of the design and planning stage, there is a stage gate at which the approval for starting construction phase is obtained. This approval means that the developed and validated targets for the project can be fulfilled in the construction phase. The required tools and techniques in the design and planning phase include BIM (for visualization, simulation, and other digitalization purposes), comprehensive lifecycle assessment (for analyzing environmental, social, and economic impacts), the last planner system (for planning and scheduling), value-stream mapping (for continuous improvement through waste elimination and value maximization), and target value design (for the joint design of the process and product to the target cost).

The construction phase in the developed framework, similar to the design and planning phase, focuses on the sustainable flow of value-adding processes and products through an integrative step called "build, learn and enhance". These are realized through performing construction based on the approved design of the process and product, pursuing waste elimination and value maximization throughout construction, and updating the product and process designs after each improvement. The proposed tools and techniques for the design and planning phase also apply to the construction phase with a small difference: target value design is replaced with 5S (sort, set in order, shine, standardize, and sustain) and just-in-time techniques.

The last phase, operation, is the best opportunity for complementary learning, rethinking, and improving. Thus, its principle is Use, Learn, and Update. This is expected to happen through the monitoring of the building performance throughout its operation, comparing the actual performance of the project outcome with the expectations, and updating sustainability assessment criteria for process and product design.

5. Discussion

A conceptual framework was developed for delivering building construction projects through the integration of the concepts of LC, sustainability, and BIM. Since the emergence of lean project delivery (LPD) in 2000, there have been considerable changes and developments concerning the delivery models of construction projects, based on which collaborative delivery models (e.g., alliance, IPD, and partnering) have been widely utilized in a few countries (e.g., the USA, Finland, Norway, Australia, UK, Chile, Brazil, and India) [5].

Moreover, in recent years, there has been another trend of combining collaborative practices (co-located project team) with traditional contacting methods, such as design–build [15]. Alongside the developments in construction project delivery, sustainability and BIM, as two important initiatives, also emerged which have proven to be very useful and aligned with the principles of collaborative project delivery.

However, it has been realized that the individual application of sustainability, LC, and BIM has fewer benefits than when they are all integrated and utilized together (e.g., [21,44,49]). In this regard, there have been a few studies that tried to make partial combinations of LC and BIM, and/or LC and sustainability by exploring the contextual attributes that could contribute to that objective [22,34,48,68,69]. However, there is still a need for an inclusive project delivery system which integrates the principles and practices of LC, sustainability, and BIM. The developed conceptual framework in this study contributes toward this knowledge gap as it puts together 30 years of research and development in construction project delivery models. The developed framework can be also a great contribution toward the "delivery" of designed zero-energy buildings, as it is of prime importance according to Laconte and Gossop [77]. The significance of delivering designed zero-energy buildings is related to the performance gap between the designed and actual energy use of the buildings [77]. Thus, the developed framework directly contributes to the realization of sustainable developed goals (SDGs) in the area of zero/low-energy buildings.

The novelty of this conceptual framework is related to its features and functions. First, it is very easy to understand for project practitioners and managers. Second, it has the advantage of mixing sustainability and lean principles for value creation and delivery to the client. Third, it provides a lifecycle-based perspective on the application of the tools and techniques of LC, sustainability, and BIM throughout the project and also during its operation phase. Fourth, it has embedded the features of sustainability assessment and target costing from the very beginning, in the project definition phase, through which the sustainability and leanness of the processes and products in the design and planning and construction phases are better assured. Finally, the operation phase in the developed framework provides a cycle of data generation and analysis in the current project and also in future ones, which eventually ends up creating a valuable database to be used in the project definition phase of future projects when drawings are not even ready for decision making. This feature, in turn, enhances the learning capability in construction project delivery.

The developed framework is also customizable to various contexts as it provides a routine process which can be utilized with minor adjustments in different types of construction projects. The application of the developed framework in case projects will help with its further development and validation, thereby moving us one step ahead toward a lean and sustainable built environment. The contribution of the developed framework toward the sustainability of individual buildings will eventually affect the next levels of sustainability as well because, in the big picture, urban-level sustainability is the result of the neighborhood level, consisting of individual building blocks [77].

6. Conclusions

This study aimed to realize the synergistic effects of LC, sustainability, and BIM through the development of a conceptual framework which integrates these concepts and their practices. The obtained result has provided the basis for the following conclusions concerning the lean and sustainable delivery of building construction projects:

- Developing and incorporating context-specific sustainability indicators in project definition can be very useful for developing sustainability-aligned targets for the project.
- Incorporating the operation phase in the project delivery system can provide a continuous cycle of performance data collection, more reliable project definition and design, and productive construction.
- The design and planning phase with a cyclic nature contributes toward sustainable target definition and management.

- Lifecycle-specific illustration of the required tools and techniques enhances the practicality of the project delivery for the practitioners.
- Combining the principles of LC and sustainability on the conceptual level ensures the realization of their synergistic benefits in all lifecycle phases.
- The designed zero-energy buildings require a corresponding framework for project delivery to realize the design targets.
- BIM seems to be a very effective tool for sustainable target definition and management in the developed conceptual framework.

The developed conceptual framework in this study contributes to the existing literature on the lean and sustainable delivery of construction projects by providing academic and practical insights for integrating LC, sustainability, and BIM. However, the developed framework in this study requires application in case projects in different contexts. Another limitation of this study is its utilization of a certain keyword in the Scopus database, which might have affected its reliability and external validity (generalizability). Finally, it is worth highlighting that any novelty in construction project delivery needs to be complemented with the development of a compatible contractual framework, which is a potential area for future research.

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