buildings

Review

Lean-BIM Approach for Improving the Performance of a Construction Project in the Design Phase

Karim EL Mounla [1,2,*], Djaoued Beladjine [1], Karim Beddiar [1] and Bélahcène Mazari [3]

[1] CESI LINEACT, 230 Rue Roland Garros, 29490 Guipavas, France
[2] Brest Métropole, 24 Rue Coat ar Gueven, 29200 Brest, France
[3] CESI LINEACT, 1 Avenue du Président Wilson, 92074 Paris, France
* Correspondence: kelmounla@cesi.fr; Tel.: +33-763-692-061

Abstract: Over the last decade, the construction industry has suffered from various issues affecting the planning processes, team management, and decision-making during the design phase. Today, the concepts of Lean construction and Building Information Modeling (BIM) overlap and bring solutions to all phases of a construction project. Numerous studies have shown that leveraging BIM data through Lean principles can significantly improve the overall management of a project. However, the literature is still limited to optimizing the design phase to anticipate any deviation before the start of the work. This article aims to provide an updated review of the interaction between BIM and Lean in the design phase. The study is based on a systematic review of 61 articles selected using the Systematic Literature Review (SLR) approach. The obtained results allowed for the analysis of different Lean methods and tools that interact with BIM. Digitizing these methods and using them together is necessary to facilitate their application in a construction project. Finally, our study provides recommendations for researchers and professionals by identifying future scientific challenges.

Keywords: Building Information Modeling; Lean; design phase; LPS; SBD; TVD; VDC; IPD; Big Room; construction project

check for updates

Citation: EL Mounla, K.; Beladjine, D.; Beddiar, K.; Mazari, B. Lean-BIM Approach for Improving the Performance of a Construction Project in the Design Phase. *Buildings* **2023**, *13*, 654. https://doi.org/10.3390/buildings13030654

Academic Editor: Heap-Yih Chong

Received: 7 February 2023
Revised: 22 February 2023
Accepted: 27 February 2023
Published: 28 February 2023

1. Introduction

The construction sector has been experiencing a decline in productivity compared to the manufacturing industry for years [1]. It seems that it suffers from workflow optimization problems and a lack of technological advances [2]. Construction projects are becoming increasingly complex and demanding in terms of cost, time, quality, and environmental impact [3]. To achieve these objectives, it is important to find an effective combination of these different aspects, and provide professionals with the necessary methods and tools adapted to each stage of the building's life cycle. However, high competition, project complexity, and tight deadlines exacerbate these difficulties.

As a result, new paradigms have emerged in the industry to promote collaborative work using the principles of Lean Construction and BIM functionalities. These two approaches have been independently adopted for years and have been successful in improving the performance of construction projects. Scientists have hypothesized that the synergy between Lean Construction and BIM is very promising and will further optimize workflows and create added value [4].

The design phase of a construction project is often characterized by a high level of uncertainty due to inaccuracies in the instructions. While all phases of a construction project can contribute to waste production, the primary cause is often linked to poor performance during the design phase, which is then discovered during the execution phase [1]. This phase makes a significant contribution to the quality of the project, which has a significant impact on the project's overall performance, with immediate effects on both the design and construction phases [2]. In addition, during the design phase, poor team performance or inadequate design can lead to project delivery delays, due to the need for rework and cost overruns. In fact, approximately 30% of the activities involved in a construction project are reworked tasks [4]. Significant time and resources are required to rework a process or activity that initially performed poorly, which can have a major impact on project planning and budgeting [5–7]. Specifically, up to 12% of construction costs are wasted on reworking defective components discovered late in the construction phase [8–10]. Effective application of Lean and BIM principles during the design phase can result in considerable savings for the project [11]. The association of Lean and BIM has recently generated a lot of interest towards the objective of optimization. This is because several lean tools and methods can address the issues faced in BIM projects, such as communication, project management, instructions, and skills [12]. The information present in a BIM model helps in controlling costs, meeting deadlines, and reducing the project's impact throughout its entire life cycle, which is particularly important in a fragmented industry. Lean management provides a strong foundation for the correct implementation and use of information from the digital model through its simple-to-implement tools.

Lean production processes and principles were created by Toyota, and then implemented in the construction industry during the 1990s [13]. Lean construction focuses on reducing waste, generating value, and continuous improvement by using the minimum resources that can lead to more valuable products [1]. Several researchers have explored its efficiency in the design stage, and they have found positive results in terms of reducing design variations at later phases. Adopting a lean approach to design process management takes into account three different facets: improving both value generation and waste reduction, transforming inputs into outputs, and ensuring accurate and timely information flow [14].

Lean construction shares many similarities with BIM, as both aim to optimize construction projects. BIM was introduced as a solution to inefficient construction projects, and was gradually adopted by the Architecture, Engineering, and Construction industry (AEC) in the mid-2000s [15,16]. Furthermore, it has been demonstrated for years that the appropriate implementation of BIM can significantly improve construction project performance and productivity. BIM is a project life cycle process that utilizes digital models of construction, or building information management, to virtually simulate the physical, functional, and task-related attributes of the project. Additionally, BIM enables the definition of equipment and material needs for each phase of the project. BIM technologies also assist the design team in detecting errors using digital models, thus avoiding conflicts and identifying clashes and interference during the design and construction phases [17]. These technologies have been shown to save up to 10% of the contract value [18]. In fact, BIM has been proven to reduce specific work-flow, reworks, document errors, and omissions by 48%, 39%, and 52%, respectively [4,19]. Furthermore, it facilitates the integration of the design and execution process to deliver better quality work on time and at a lower cost [20].

Lean and BIM are increasingly popular in both research and practice. Recent studies suggest that integrating BIM and Lean construction can result in a more effective and practical waste reduction approach [21,22]. The synergy between Lean and BIM is crucial in all project phases, particularly in the design phase, where changes cost relatively less compared to future phases, and decision-making significantly impacts subsequent stages [23]. Several Lean methods or techniques have been implemented with BIM in the design phase, such as the Last Planner System (LPS), Big Room, Set-Based Design (SBD), and Target Value Design (TVD) [24]. These methods have been efficient in reducing waste during construction phases, but there are always limitations to achieving optimal performance.

While several studies have focused on the interaction between Lean principles and BIM functionalities, few have incorporated Lean methods and techniques with BIM to enhance project performance during the design phase. Poor planning and decision-making during this phase can have a negative impact on the entire project life cycle, resulting in wasted time and high costs. Therefore, we conducted an extensive bibliographic study to identify the best Lean tools and methods that can be applied in tandem with BIM to improve performance during the design phase. This study analyzed techniques and methods that enhance the implementation of Lean and BIM in the design phase of construction projects.

This paper is structured as follows: the first section describes the research topic and scope. It gives an overview of Lean and BIM in the construction industry, particularly in the design phase. Section 2 explains in depth the research methodology used, which is the SLR applied in this study. Section 3 presents the synthesis of the findings, focusing on the influences of Lean/BIM interactions in the design phase. It introduces Lean methods and tools implemented with BIM, and discusses their role, benefits, and limitations in the design stage. The fourth section discusses the results and their possible implications for practice in implementing Lean techniques using BIM. Finally, Section 5 contains the conclusion, where the main findings and implications of the study are summarized.

2. Systematic Literature Review Methodology

In order to conduct a comprehensive literature review, we employed the methodology of SLR in our study, rigorously following the most commonly used SLR steps in bibliographic studies [25–27]. The purpose of this manuscript was to thoroughly examine the existing literature in order to highlight the knowledge of the synergy between BIM and Lean during the design phase of a construction project. To achieve this, we identified relevant documents using specific keywords and then applied inclusion and exclusion criteria [28]. The review begins by addressing the following research questions:

- Q1: How can BIM and Lean interact effectively in the design phase?
- Q2: What techniques are used to achieve BIM/Lean interactions in the design phase?

In order to elaborate our research protocol, we followed several steps. These steps are described as follows: (1) We identified a set of keywords relevant to our case study that would be used in the research procedure; (2) We conducted a search string using web search engines, such as Google Scholar and Scopus databases, taking into account synonyms and abbreviations to ensure a more reliable result; (3) We used specific operators to improve the search system, including adding date range, document types, using keywords with AND, OR, and ALINTITLE (all keywords mentioned in the article's title), and source types to acquire high-quality and up-to-date papers; (4) We eliminated duplicated documents; (5) We evaluated the remaining article and conference papers by reading their titles and abstracts to determine whether they addressed our research question and met our inclusion and exclusion criteria; and (6) We extracted useful information from the filtered documents required for our research topic [4].

Figure 1 depicts the process of applying SLR methods. In the first step of our research procedure, we conducted a literature search for articles using relevant keywords and search strings. To ensure more accurate results, we took into account keyword abbreviations and synonyms, as described in Table 1.

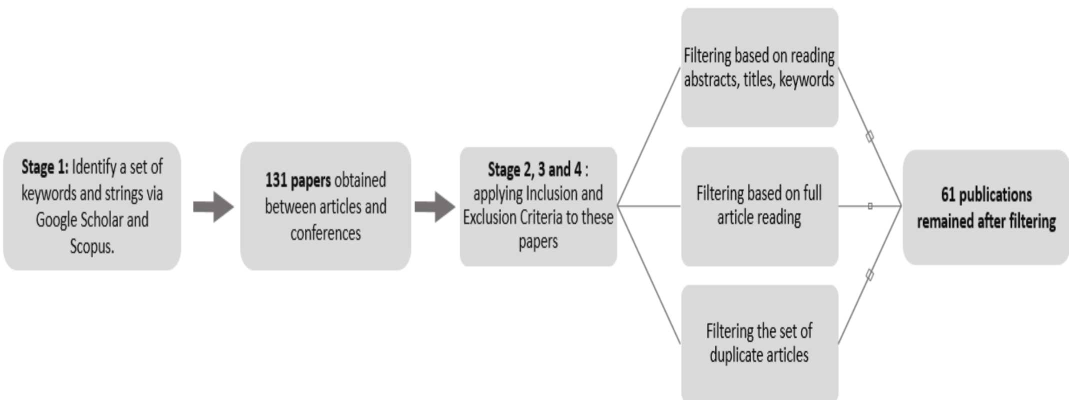


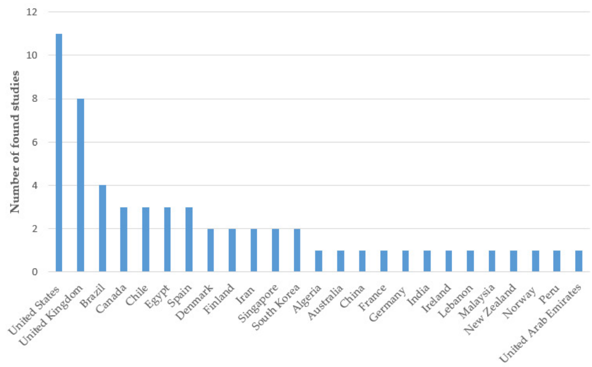
Figure 1. SLR stage iterations.

Table 1. Literature search keywords and strings.

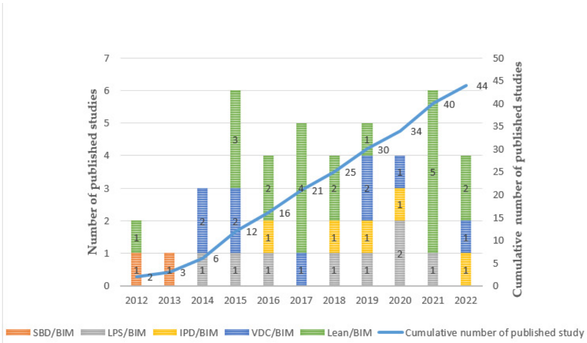
Operators	Keywords	Search Strings
• Allintitle • OR • AND	"Building Information Modelling"; Modeling"; "BIM"; "LPS"; "Last Planner System"; "Design"; "Lean"; "VDC"; "Virtual Design and Construction"; "SBD"; "Set-Based Design"; "IPD"; "Integrated Project Delivery".	•Allintitle: ("Building Information Modelling" OR "Building Information Modeling" OR "BIM") AND "Lean" AND "Design". •Allintitle: ("Building Information Modelling" OR "Building Information Modeling" OR "BIM") AND ("LPS" OR "Last Planner System"). •Allintitle: ("Building Information Modelling" OR "Building Information Modeling" OR "BIM") AND ("SBD" OR "Set-Based Design"). •Allintitle: ("Building Information Modelling" OR "Building Information Modeling" OR "BIM") AND ("VDC" OR "Virtual Design and Construction") AND "LEAN". •Allintitle: ("Building Information Modelling" OR "Building Information Modeling" OR "BIM") AND ("IPD" OR "Integrated Project Delivery") AND "LEAN".

After conducting the literature search through web search engines (Google Scholar and Scopus databases), 131 publications were identified. Initial relevance was assessed by examining the titles of each paper, and those deemed potentially relevant were further evaluated through several iterations. To ensure the review included recent literature, only publications between 2012 and 2022 were selected [29], which allowed us to retrieve and synthesize information from the past 10 years. Inclusion and exclusion criteria were then applied to the remaining publications by carefully reading the abstracts to determine their relevance to our research goal. Theses, books, summaries, editorials, and other document types were eliminated, leaving only articles and conference papers. Duplicates were removed, and non-English language papers were excluded. After this process, we were left with 44 papers. In addition, by using both the backward and forward search techniques, we employed two complementary approaches to identify relevant studies for inclusion in the review. In the backward search, we searched for studies that had already been published and cited in the references of potential candidates for the review, while in the forward search, we identified studies that had cited the studies being considered for inclusion in the review. As a result, we were able to identify and include 17 relevant articles to our research. This approach helped us reduce the likelihood of missing any important studies that could impact the findings of the review. In total, we included 61 papers from journals and conferences in our review [29].

Figure 2 displays the distribution of publications by country and year for the documents that were gathered through our research in the last 10 years, focusing on the fields of lean and BIM. We excluded any documents obtained through the backward and forward techniques, as they may be outdated (from the 2000s) or may cover different keywords and fields, but they may still contain valuable information that could benefit our search. The publications are related to the integration of lean methods and techniques into BIM during the design phase of a construction project. The United States is the country with the highest number of contributions, followed by the United Kingdom, with eleven and eight published papers, respectively. Moreover, it appears that the United States has published the most studies on integrating Lean and BIM during the design phase of a construction project. This can be attributed to several factors, such as the maturity of its construction industry, a highly regulated framework that demands efficient processes, the availability of technology, and a collaborative construction industry that promotes innovative practices. The combination of these factors has made the United States an ideal environment for researching and adopting Lean and BIM integration in construction projects.



(**a**)



(**b**)

Figure 2. Contribution of countries to the obtained articles (**a**) and their annual distribution from 2012 to 2022 (**b**).

On the other hand, part (b) of the figure shows a lack of papers related to our research topic before 2014. However, since then, several papers on various lean techniques integrated with BIM during the design phase of a construction project have been published. On average, approximately four papers per year were published between 2014 and 2022.

3. Results

In this section, an in-depth analysis was conducted on the articles acquired from Section 2. The first subsection (Section 3.1) focuses on the interaction between Lean principles and BIM functionalities, and their resulting benefits. The second subsection (Section 3.2) presents the application of Lean tools and other techniques to BIM, as well as their impact on every aspect of the design phase.

3.1. Interaction between Lean Principles and BIM Functionalities

Recent studies indicate that there are synergies between Lean principles and BIM functionalities that efficiently enhance construction projects' performance [15]. To delve deeper, Sacks identified 56 interactions between Lean/BIM that focus on the entire construction project life cycle [30]. However, we focused in our study only on the possible interaction in design phase. Table 2 below presents the main results from these matrices that are relevant to this phase, and arise from the combination of the Lean principles and BIM functionalities presented in Figure 3. In particular, these synergies give some benefits to the design stage of construction by: reducing rework, decreasing the design development life cycle, improving the predictability of investment, lifecycle time and cost scheduling, increasing the number of iterations for value improvement, and enhancing stakeholder engagement [6,31]. All of these can efficiently result a more economical, faster, and smoother construction process [12].

Table 2. Lean/BIM interactions during the design phase.

Lean/BIM Synergy in the Design Phase	References
Provide better and further information to all parties that, facilitate and support stakeholder's decision-making	[32]
Improve communication during the design stage by sharing models with the project team	[30]
Rapid turnaround for performance evaluations and cost estimations allows multiple design options to be evaluated	[33]
Design model coordination by integrating model viewers into a cooperative work environment allow design teams to bring multidisciplinary skills and knowledge to bear in a parallel action.	[34]
Applying performance criteria to the design ensures that it is suitable for the chosen task, improves the performance, and reduces the variability of the final product	[33]
Since all design aspects are presented in a 3D model, the customer can easily understand it. Requirements can be obtained and reported in a comprehensive way during the design phase.	[33,35]
Clash checking improves design quality and reduces rework in the field as a result of bad design.	[32,33]
A multidisciplinary design inspection allows the early identification of design errors.	[19,33]
Construction processes modeling in BIM 4 dimension provide a great benefit to visualize construction sequences for resolving constructability problems, also determining resource conflicts in space and time.	[36]

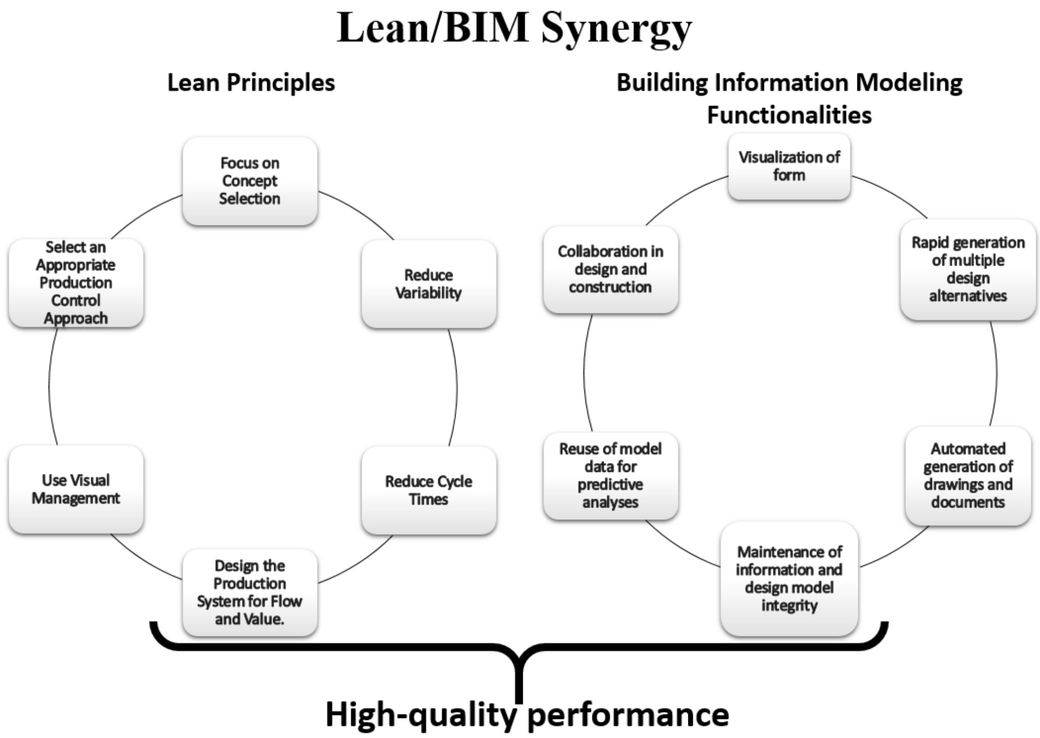


Figure 3. Lean principles and BIM functionalities synergy.

3.2. Lean Methods and Other Techniques Applied to BIM

This section describes the process of implementing Lean/BIM during the design stage. Several methods can be used to integrate Lean/BIM, including the Last Planner System (LPS), Virtual Design and Construction (VDC), Integrated Project Delivery (IPD), Big Room, Target Value Design (TVD), Set Based Design (SBD), and Choosing by Advantages (CBA). However, each method has a significant impact on one or more parts of the design phase. Figure 4 presents the main parts of the design phase with their various tasks, such as planning and control, decision-making, and team management. By optimizing the tasks in each part through the application of these methods with BIM, high-quality construction project performance can be achieved.

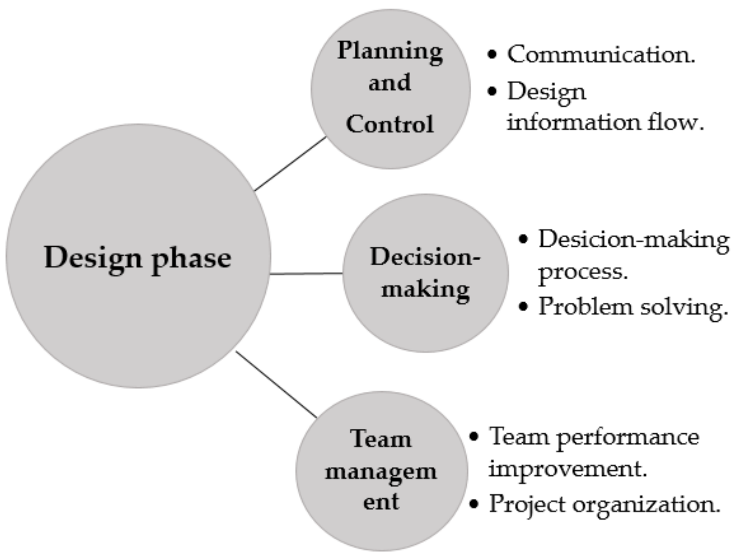


Figure 4. The main parts of the design phase with their different tasks.

Therefore, after conducting a thorough analysis of the literature, we created Table 3 to demonstrate the impact of each method and techniques on the different tasks in the design phase. Moreover, several Lean techniques can complement each other by combining and utilizing them simultaneously. For instance, using the LPS in the Integrated Concurrent Engineering (ICE) session (part of VDC) can enhance the flow of information between the design team [37]. Thus, Section 3.2.1 to Section 3.2.4 explain in detail how these methods improve work in the design phase.

Table 3. Lean techniques applied in the design phase matrix.

Methods	Planning and Control		Decision-Making		Team Management		Synergies
	Communication	Design Information Flow	Decision-Making Process	Problem Solving	Team Performance Improvement	Project Organization	
IPD	X		X		X	X	Big room, TVD and LPS
LPS	X	X	X			X	Big Room, VDC, IPD, SBD, CBA
VDC					X	X	Big Room, LPS
SBD			X	X			Big Room, LPS CBA, TVD
The Big Room	X	X			X		
CBA			X	X			Big Room, SBD, LPS, TVD
TVD				X	X	X	Big Room, IPD, SBD, CBA

3.2.1. Planning and Control

Planning the design process is essential in the design phase of a construction project [38]. This phase often suffers from poor performance and negative outcomes, such as unclear handoffs, a low volume of deliveries per week, lack of confidence in the allotted time to carry out the design work, and poor communication between stakeholders, which can result in the risk of not delivering tasks on schedule. However, applying Lean techniques and methods can help resolve these issues [39]. Therefore, the LPS is a Lean method that helps the design team to remedy uncertainties [40]. In addition, it reduces workflow variability and increases the reliability of task planning at the weekly work planning (WWP) level by ensuring a firm commitment of resources by the last planners, and by refining planned tasks to ensure their completion [41–43]. Moreover, LPS employs the pull system to optimize the planning of construction processes [40]. Some recent studies have investigated the potential benefits of implementing LPS with BIM technologies during the project design phase. This has resulted in an improved planning process, as BIM technical capabilities bring benefits to overall construction project efficiency and productivity [30,40]. The use of BIM has also been responsible for increasing the reliability of task planning, improving design workflow with WWP implementation, and finishing projects ahead of schedule. Moreover, their interaction improves project team performance control and transparency, which leads to a better understanding of the planned process [37,42,44,45].

3.2.2. Decision-Making

One of the most crucial processes during the design phase of a construction project is decision-making. During this stage, it is crucial to make timely decisions while adhering to the schedule to ensure a smooth workflow, and the decisions made should be of the highest quality from the outset to minimize waste [38,46]. In addition, the key criteria for decision-making during this phase are ensuring the project's quality and staying within the budget constraints [47]. To enhance the decision-making process during the design phase, a Lean tool such as CBA can have a significant impact. This method involves comparing the advantages of different alternatives and then assigning a degree of importance to each feature, relative to the least preferred feature [48,49]. In addition, another Lean technique that can improve decision-making is SBD. This approach enables the design team to consider a wide range of alternatives throughout the design process, and delay making a final decision until the last possible moment [50]. By doing so, the design team can avoid prematurely committing to a suboptimal design and potentially missing out on better options. Implementing SBD in construction projects has yielded promising results, including cost and time savings, and improved constructability [16]. Implementing SBD in construction projects has presented strong results, as well as big opportunities for improvements, including saving cost and time and increasing constructability [31]. Thus, adopting SBD with BIM can lead to more comprehensive and optimal solutions during advanced design processes. Recent research has investigated the implementation of SBD with BIM through two case studies, which showed that BIM can improve the flexibility of SBD by creating an environment that facilitates the integrated and systematic modeling of different design options, while also improving collaboration and information sharing [50]. Furthermore, their interaction can lead to more efficient and intelligent evaluation and the selection of a wide range of options, ultimately leading to the selection of the best solution [51].

3.2.3. Team Management

Managing or creating a cohesive team is essential to the design phase. A well-organized project is one where all parties work together cooperatively. Furthermore, a good relationship based on trust and respect among stakeholders can add significant value to the design phase [52]. In addition, integrating clients into the design phase by involving them in meetings alongside designers and contractors can improve the decision-making process, planning, control, and problem-solving capabilities of the team [38].

TVD is a critical Lean method that affects the team management phase by prioritizing customer value as the driver of design, resulting in waste reduction and increased owner satisfaction. The primary objective of TVD is to complete the project below market cost while achieving the desired outcomes [53]. Evidence suggests that TVD can lead to the completion of a project's initial scope below market cost. Additionally, TVD enables funds to be allocated across contractual and organizational boundaries to identify the best investment at the project level. This approach applies all relevant design criteria to assess, generate, and select product and process design options simultaneously [53].

Another method to enhance team management is through the implementation of a Big Room. This approach fosters a highly collaborative environment among stakeholders, where various designers work alongside each other in the same location. This results in significant information sharing and facilitates effective communication between the design team, leading to a reduction in the overall design duration for decision-making and planning [12,54,55].

In addition to TVD and Big Room, VDC is a digital and collaborative approach focused on the use of new technology related to Lean thinking with BIM. At Stanford University, VDC was created by the Center for Integrated Facility Engineering (CIFE) [37,56]. VDC with BIM can increase customer satisfaction through model visualization and clear expectations. It can also enhance team collaboration, resulting in better project outcomes, improved communication of project actions to owners, and better understanding of work scope and schedules by subcontractors and dealers [57,58]. Additionally, VDC can measure team performance and improve data sharing by allowing the design team to access the right information at the right time. The success of VDC depends on the talent, mentality, awareness, and organization of the team [59]. Several case studies have demonstrated the importance of the VDC approach using BIM at the design stage of a construction project, highlighting these features [37,59–61].

IPD is one of the most essential methods that can influence team management in the design phase and provides an ideal platform for the interaction of Lean with BIM [31]. The American Institute of Architects (AIA) has presented IPD as a project delivery approach that integrates systems, stakeholders, business structures, and practices into a process that optimizes efficiency and reduces waste collaboratively [62]. IPD involves all multidisciplinary teams, increases collaboration in decision-making, provides a relational contracting approach, and shares benefits and risks between all parties [31]. Several studies demonstrate the importance of using IPD with BIM by highlighting their benefits for the design phase.

3.2.4. Tools Applied in the Design Phase

Based on the documents obtained in our research on Lean/BIM synergy, several tool applications were used to facilitate the integration of the Lean method with BIM during the design phase. Table 4 presents these tools and their impact on one or more parts of this phase. Most studies focused on using tools to improve the planning and control zone, particularly for the information flow part. Among the tools that were found to be useful in improving information flow are dRofus®, Solibri®, Level of Development (LOD), and Workplan software [4,63,64].

Table 4. Tools applied in the design phase matrix.

Tools	Planning and Control		Decision-Making		Team Management	
	Communication	**Design Information Flow**	**Decision-Making Process**	**Problem Solving**	**Team Performance Improvement**	**Project Organization**
D-Rofus		X				
Solibri		X				
SNA	X				X	
VE			X			
BDA			X	X		X
Work Plan software	X	X				
LOD		X				
CSM			X	X		

dRofus® and Solibri® are BIM-based tools that make it possible for different parts and requirements of a product model to be communicated using the Industry Foundation Classes (IFC) Open standard, to ensure that the design solution meets stakeholder requirements, depending on construction project types [65]. dRofus® focuses on modeling requirements that can be used to improve safety and indoor thermal comfort. On the other hand, Solibri® can encode requirements into logical rules by using checking software, such as Solibri Model Checker® [63]. Moreover, LOD is a tool that can be used to enhance BIM from the perspective of Transformation, Flow, and Value (TFV), in order to manage the design phase based on lean design management and TFV theory. It also facilitates the integration of design workflows into BIM projects [64]. Workplan software improves the LPS methodology by instructing the design team to check constraints, determine work packages, release weekly work plans, and allocate resources. Additionally, it improves communication among project stakeholders [4,66].

Social Network Analysis (SNA) is a tool that can enhance team performance and communication within a team, particularly in team management. It is used in studies of organizational behavior and in construction management to analyze the flow of communication and information between all parties for better integration of the design team and project management. By examining the relationships and interactions among team members, SNA can identify potential areas for improvement and facilitate effective communication and collaboration [67,68].

In addition, Big Data Analytics (BDA), Computer Simulation and Modeling (CSM), and Value Engineering (VE) have an impact on the decision-making process in construction. CSM is a tool that enhances decision-making and problem-solving by helping the design team to identify problems and provide suitable options with the lowest cost [69,70]. Furthermore, using BDA in conjunction with BIM can help to extract valuable insights related to modular element design parameters, and to evaluate design solutions, building maintenance, and performance. It is also a powerful tool that can improve team organizational performance [71]. VE is a tool that promotes function improvement or cost reduction in Lean Management and enhances value for clients [71–73].

4. Discussion

These lean techniques and methods play a crucial role in enhancing work performance during the design phase, specifically in planning and control, decision-making, and team management. The literature has indicated that the combination of these techniques with BIM yields significant advantages for construction projects. Each method employs one or more BIM functions to implement its features seamlessly and efficiently. For example, LPS leverages BIM's visualization capability to facilitate progress monitoring and animate the schedule [4,74]. BIM has revolutionized the design phase of construction projects by enabling greater collaboration and improved communication among the design team members. Despite the significant benefits that BIM offers, we found a lack of research that demonstrates the integration of specific lean methods and tools with BIM. Table 5 highlights some of the techniques that can be implemented through BIM. However, further research is required to explore the full potential of these lean methods in combination with BIM. Moreover, most of the literature found during our study consisted of case studies, and there was a dearth of papers related to the design phase compared to other phases of the construction project. To fully harness the potential of BIM and lean methods, more studies are needed to examine how they can be integrated at every stage of the construction project. However, we found that even methods that were not directly linked to BIM in the literature were indirectly connected to it. For example, VDC utilizes BIM in the Big Room, where collaboration between the design team and the visualization feature of BIM was demonstrated. This suggests that there is potential for BIM to be used in conjunction with various lean methods to further improve construction project outcomes.

Table 5. Interaction of techniques and methods with BIM.

Method and Techniques	Articles with BIM	Articles without BIM
IPD	X	
LPS	X	
VDC	X	
SBD	X	
The Big Room		X
CBA		X
TVD		X

Despite the significant benefits that can be obtained from integrating BIM with these methods, there are also limitations that hinder their application in construction projects. Table 6 illustrates the restrictions of each method used with BIM during the design phase, based on the available literature. The most common limitations identified for these techniques include resistance to change, lack of knowledge on how to use BIM with them, and insufficient application in real projects. In addition to these limitations, there may also be challenges related to the implementation of BIM and lean methods in the construction industry. For example, there may be issues related to data ownership, lack of standardization, and the need for specialized software and training. Moreover, the integration of BIM with lean methods may require significant changes in organizational culture and business processes, which can be difficult to achieve.

Further limitations are included in Table 6. For example, when applying SBD to the design phase, it can take a considerable amount of time to evaluate all possible alternatives. This can hinder the completion of the design stage, which may delay the project schedule. Similarly, the large amount of information in VDC can pose a challenge for designers in terms of structuring and utilizing this information effectively.

In our opinion, one of the main factors that could help to address these limitations is the digitization of these methods. By digitizing these approaches, it may be possible to streamline the processes and enable their efficient implementation through BIM. Digitization could also help to automate certain tasks, such as data analysis and visualization, which may save time and improve accuracy. Furthermore, by digitizing these methods and integrating them with BIM, it may be possible to generate new insights and information that would not be possible through traditional methods. For example, BIM can be used to analyze building performance data in real-time, which can inform design decisions and lead to improved building efficiency. Therefore, we believe that digitization is an essential factor in realizing the full potential of these lean methods in combination with BIM. By embracing digital technologies, the construction industry can move towards more efficient, sustainable, and collaborative project delivery. In addition, to overcome these limitations and challenges, it is crucial to increase awareness and education on the benefits of BIM and lean methods in construction projects. This can include providing training and support to industry professionals and promoting the use of standardized processes and tools. It is also important to continue research and development in this area to identify and address any remaining barriers to the adoption of BIM and lean methods in construction projects.

Table 6. Limitations of applying these techniques with BIM during the design phase.

Limitations			
LPS	**SBD**	**VDC**	**IPD**
• There is a lack of application in real case projects. • Designers have generally shown resistance to adopting the LPS in the design phase.	• The design phase should be completed quickly. • Integrating the customer in the design phase prevents designers from testing the greatest number of concepts. • There is a lack of case studies.	• It is difficult to structure the information. • There is difficulty in developing an evaluation index, such as the performance indicator. • In practice, the classification system is not easy to use.	• There is a need for a systematic framework driven by AEC industry and government agencies to adopt IPD and BIM in the design phase. • There is a lack of knowledge, software interoperability, training, and advancement. • The skill and quality level of stakeholders in the AEC industry need to be increased.

On the other hand, in order to achieve optimal performance during the design stage, companies should implement these methods together. Figure 5 illustrates how all parties involved in the design phase of a construction project collaborate in a shared space where information is exchanged. This space is called the Big Room, and on its walls, LPS is used to plan tasks and create schedules. In addition, two screens display a BIM that enables 3D visualization of the building to enhance the information flow, planning process, and decision-making. The VDC process, which relies on technologies such as BIM, has applied one of its principles called ICE where all design teams were involved, well-prepared, and had clear goals. In addition, SBD and CBA can be applied in this room, where teams are empowered to collaboratively choose the best solution from all possible alternatives, while being well-organized and improved through the application of IPD and TVD. Another example of combining multiple methods in a construction project is the integration of SBD, CBA, and LPS. In the design phase, the team can start by utilizing set-based design to develop various design options and engaging all stakeholders, such as architects, engineers, contractors, and owners. Next, the team can employ CBA to assess each design option against specific criteria that reflect project objectives, budget, schedule, and regulatory or environmental requirements. Upon selecting the most suitable design option through CBA, the team can use LPS to create a comprehensive construction plan, including schedule, budget, resource allocation, and strategies for risk and constraint mitigation. Throughout the design phase, the team can use LPS to track progress and ensure the project is on track, with consistent communication and collaboration among all stakeholders to identify and address any issues that arise. By integrating these methods, the team can optimize the design and construction process, enhance communication and collaboration, and deliver a successful project that meets project objectives.

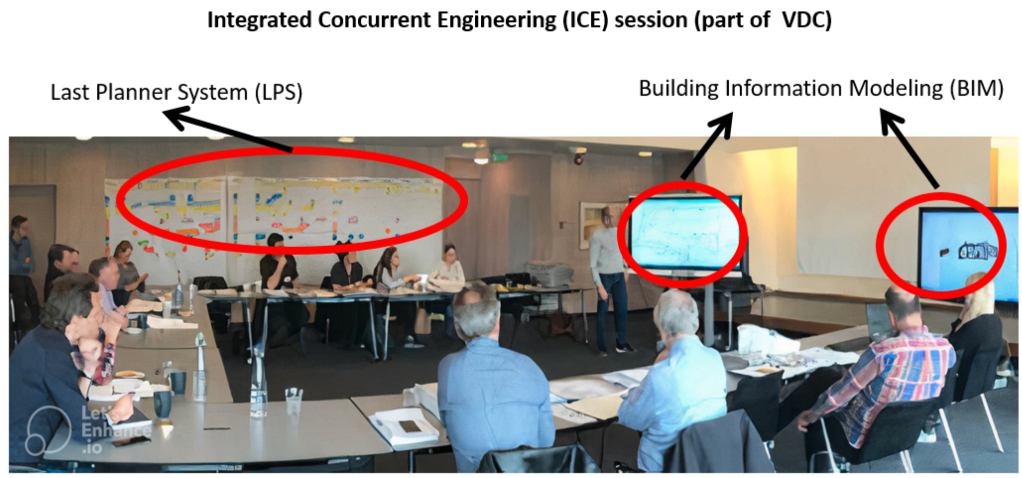


Figure 5. ICE session in the Big Room, adapted from [37], Roar Fosse: IGLC 2017.

In our opinion, there needs to be a focus on automating the LPS, which plays an essential role in the planning part and controls the progress of tasks in the design phase. This collaborative planning method focuses on reducing data variability, controlling workflows, and fostering collaboration in planning. Its effectiveness can be significantly enhanced by integrating it with BIM, particularly in the 3D visualization of elements. Moreover, automating LPS will facilitate the implementation of other methods by scheduling the process and providing the required information, thus optimizing the workflow for their application.

5. Conclusions and Future Research Directions

In this article, we conducted a comprehensive literature review on the interaction of Lean and BIM in the design phase. A structured research methodology was used to identify Lean tools and methods that can be deployed with BIM to optimize the design phase. Analysis of the results allowed us to identify improvements that can be made in the areas of planning and control, decision-making, and team management. During these stages, design teams could use one or more Lean methods with the features of the BIM model to reveal non-value-added activities and improve the construction process. The idea is to move from a logic of designing before testing to a logic of testing before designing. In Lean design, anticipating all phases becomes necessary. The decisions made must take into account, among other things, the management of changes requested by the client, the operation of the structure, construction methods, supply chain configuration, and commercial agreement structure. Despite the promising results highlighted by researchers, limitations still hinder the use of Lean and BIM by designers, preventing them from reaching their full potential. These limitations could encourage scientists to conduct further research to develop optimization solutions. Experimentation with these solutions through real projects is essential to validate or improve them.

Author Contributions: Conceptualization, K.E.M., D.B. and K.B.; methodology, K.E.M.; software, K.E.M.; validation, K.B. and D.B.; formal analysis, K.E.M.; investigation, K.E.M.; resources, K.B.; data curation, K.E.M.; writing—original draft preparation, K.E.M.; writing—review and editing, K.E.M., D.B. and K.B.; visualization, K.B.; supervision, B.M.; project administration, B.M.; funding acquisition, B.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available in the article.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

LPS	Last Planner® System
VDC	Virtual Design and Construction
IPD	Integrated Project Delivery
SBD	Set-Based Design
TVD	Target Value Design
ICE	Integrated Concurrent Engineering
BIM	Building Information Modeling
LOD	Level Of Development
VE	Value Engineering
CSM	Computer Simulation and Modeling
SLR	Systematic Literature Review
AEC	Architecture, Engineering and Construction
CBA	Choosing By Advantages
WWP	Weekly Work Planning
CIFE	Center for Integrated Facility Engineering
TFV	Transformation, Flow and Value
SNA	Social Network Analysis
BDA	Big Data Analytics

References

1. Changali, S.; Mohammad, A.; Nieuwland, M.V. The Construction Productivity Imperative. McKinsey Productivity Sciences Center. 2015. Available online: https://www.mckinsey.com/~/media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/The%20construction%20productivity%20imperative/The%20construction%20productivity%20imperative.pdf (accessed on 6 February 2023).
2. Bello, S.A.; Oyedele, L.O.; Akinade, O.O.; Bilal, M.; Delgado, J.M.D.; Akanbi, L.A.; Ajayi, A.O.; Owolabi, H.A. Cloud Computing in Construction Industry: Use Cases, Benefits and Challenges. *Autom. Constr.* **2021**, *122*, 103441. [CrossRef]
3. Zavadskas, E.K.; Turskis, Z.; Tamošaitiene, J. Risk Assessment of Construction Projects. *J. Civ. Eng. Manag.* **2010**, *16*, 33–46. [CrossRef]
4. Sbiti, M.; Beddiar, K.; Beladjine, D.; Perrault, R.; Mazari, B. Toward BIM and LPS Data Integration for Lean Site Project Management: A State-of-the-Art Review and Recommendations. *Buildings* **2021**, *11*, 196. [CrossRef]
5. Yusof, I.H.M.; An, M.; Barghi, M.H. Integration of Lean Construction Considerations into Design Process of Construction Projects. *Management* **2015**, *885*, 894.
6. Herrera, R.F.; Mourgues, C.; Alarcón, L.F.; Pellicer, E. Analyzing the Association between Lean Design Management Practices and BIM Uses in the Design of Construction Projects. *J. Constr. Eng. Manag.* **2021**, *147*, 04021010. [CrossRef]
7. Aziz, R.F.; Hafez, S.M. Applying Lean Thinking in Construction and Performance Improvement. *Alex. Eng. J.* **2013**, *52*, 679–695. [CrossRef]
8. Love, P.E.; Edwards, D.J. Forensic Project Management: The Underlying Causes of Rework in Construction Projects. *Civ. Eng. Environ. Syst.* **2004**, *21*, 207–228. [CrossRef]
9. Love, P.E. Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects. *J. Constr. Eng. Manag.* **2002**, *128*, 18–29. [CrossRef]
10. Hwang, B.-G.; Thomas, S.R.; Haas, C.T.; Caldas, C.H. Measuring the Impact of Rework on Construction Cost Performance. *J. Constr. Eng. Manag.* **2009**, *135*, 187–198. [CrossRef]
11. Akinci, B.; Boukamp, F.; Gordon, C.; Huber, D.; Lyons, C.; Park, K. A Formalism for Utilization of Sensor Systems and Integrated Project Models for Active Construction Quality Control. *Autom. Constr.* **2006**, *15*, 124–138. [CrossRef]
12. Tauriainen, M.; Marttinen, P.; Dave, B.; Koskela, L. The Effects of BIM and Lean Construction on Design Management Practices. *Procedia Eng.* **2016**, *164*, 567–574. [CrossRef]
13. Josephson, P.-E.; Hammarlund, Y. The Causes and Costs of Defects in Construction: A Study of Seven Building Projects. *Autom. Constr.* **1999**, *8*, 681–687.16. [CrossRef]
14. Andújar-Montoya, M.D.; Galiano-Garrigós, A.; Rizo-Maestre, C.; Echarri-Iribarren, V. Bim and Lean Construction Interactions: A State-of-the-Art Review. *WIT Trans. Built Environ.* **2019**, *192*, 1–13.
15. Sajedeh, M.; Fleming, A.; Talebi, S.; Underwood, J. Development of an Experimental Waste Framework Based on BIM/Lean Concept in Construction Design. In Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA, 18–24 July 2016.
16. Liker, J.K. *Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*; McGraw-Hill Education: New York, NY, USA, 2004; ISBN 0-07-139231-9.

17. Aslam, M.; Gao, Z.; Smith, G. Optimizing Construction Design Process Using The Lean Based Approach. *Lean Constr. J.* **2020**, *30*, 176–204.
18. Fakhimi, A.H.; Sardroud, J.M.; Azhar, S. How Can Lean, IPD and BIM Work Together? In Proceedings of the International Symposium on Automation and Robotics in Construction (ISARC), Auburn, AL, USA, 18–21 July 2016; Volume 33, p. 1.
19. Olofsson, T.; Lee, G.; Eastman, C.; Reed, D. Benefits and Lessons Learned of Implementing Building Virtual Design and Construction (VDC) Technologies for Coordination of Mechanical, Electrical, and Plumbing. *J. Inf. Technol. Constr.* **2008**, *13*, 324–342.
20. Azhar, S. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadersh. Manag. Eng.* **2011**, *11*, 241–252. [CrossRef]
21. Keit, F.; Kathryn, E.C. The Business Value of Bim in North America. In *SmartMarket Report*; MCGraw Hill Construction: New York, NY, USA, 2012; Volume 72.
22. Eldeep, A. Benefits of Integration Between Lean and Bim in the Design and Construction Phase; Lessons Learned. *SVU-Int. J. Eng. Sci. Appl.* **2022**, *3*, 21–28. [CrossRef]
23. Zhang, X.; Azhar, S.; Nadeem, A.; Khalfan, M. Using Building Information Modelling to Achieve Lean Principles by Improving Efficiency of Work Teams. *Int. J. Constr. Manag.* **2018**, *18*, 293–300. [CrossRef]
24. Sheramn, B. *To What Extent Can Lean Construction Processes and Principles Be Utilised in the Design Stage of a BIM Project in the Irish Design and Construction Industry*; Capstone Project from the MSc in aBIMM; Technological University Dublin: Dublin, Ireland, 2019; Volume 22.
25. MacDonald, J. Systematic Approaches to a Successful Literature Review. *J. Can. Health Libr. Assoc. J. L'association Bibliothèques St. Can.* **2013**, *34*, 46–47. [CrossRef]
26. Dos Santos, A.C.C.; Delamaro, M.E.; Nunes, F.L. The Relationship between Requirements Engineering and Virtual Reality Systems: A Systematic Literature Review. In Proceedings of the 2013 XV Symposium on Virtual and Augmented Reality, Cuiaba, Brazil, 28–31 May 2013; pp. 53–62.
27. Palmarini, R.; Erkoyuncu, J.A.; Roy, R.; Torabmostaedi, H. A Systematic Review of Augmented Reality Applications in Maintenance. *Robot. Comput. Integr. Manuf.* **2018**, *49*, 215–228. [CrossRef]
28. Schiavi, B.; Havard, V.; Beddiar, K.; Baudry, D. BIM Data Flow Architecture with AR/VR Technologies: Use Cases in Architecture, Engineering and Construction. *Autom. Constr.* **2022**, *134*, 104054. [CrossRef]
29. Xiao, Y.; Watson, M. Guidance on Conducting a Systematic Literature Review. *J. Plan. Educ. Res.* **2019**, *39*, 93–112. [CrossRef]
30. Sacks, R.; Koskela, L.; Dave, B.A.; Owen, R. Interaction of Lean and Building Information Modeling in Construction. *J. Constr. Eng. Manag.* **2010**, *136*, 968–980. [CrossRef]
31. Dave, B.; Koskela, L.; Kiviniemi, A.; Tzortzopoulos, P.; Owen, R. *Implementing Lean in Construction: Lean Construction and BIM [CIRIA Guide C725]*; CIRIA—Construction Industry Research and Information Association: London, UK, 2013.
32. Dehlin, S.; Olofsson, T. An Evaluation Model for ICT Investments in Construction Projects. *Electron. J. Inf. Technol. Constr.* **2008**, *13*, 343–361.
33. Eastman, C.M.; Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*; John Wiley & Sons: Hoboken, NJ, USA, 2011; ISBN 0-470-54137-7.
34. Liston, K.; Fischer, M.; Winograd, T. Focused Sharing of Information for Multidisciplinary Decision Making by Project Teams. *J. Inf. Technol. Constr.* **2003**, *6*, 69–82.
35. Manning, R.; Messner, J.I. Case Studies in BIM Implementation for Programming of Healthcare Facilities. *Electron. J. Inf. Technol. Constr.* **2008**, *13*, 246–257.
36. Li, H.; Chan, N.; Huang, T.; Guo, H.L.; Lu, W.; Skitmore, M. Optimizing Construction Planning Schedules by Virtual Prototyping Enabled Resource Analysis. *Autom. Constr.* **2009**, *18*, 912–918. [CrossRef]
37. Fosse, R.; Ballard, G.; Fischer, M. Virtual Design and Construction: Aligning BIM and Lean in Practice. In Proceedings of the 25th Annual Conference of the International Group for Lean Construction, Heraklion, Greece, 9–12 July 2017.
38. Knotten, V.; Lædre, O.; Hansen, G.K. Building Design Management—Key Success Factors. *Archit. Eng. Des. Manag.* **2017**, *13*, 479–493. [CrossRef]
39. Chiu, S.; Cousins, B. Last Planner System® in Design. *Lean Constr. J.* **2020**, *22*, 78–99.
40. Heigermoser, D.; de Soto, B.G.; Abbott, E.L.S.; Chua, D.K.H. BIM-Based Last Planner System Tool for Improving Construction Project Management. *Autom. Constr.* **2019**, *104*, 246–254. [CrossRef]
41. AlSehaimi, A.O.; Fazenda, P.T.; Koskela, L. Improving Construction Management Practice with the Last Planner System: A Case Study. *Eng. Constr. Archit. Manag.* **2014**, *21*, 51–64. [CrossRef]
42. Khan, S.; Tzortzopoulos, P. Effects of the Interactions between LPS and BIM on Workflow in Two Building Design Projects. In Proceedings of the 22nd Annual Conference of the International Group for Lean Construction, Oslo, Norway, 25–27 June 2014; Kalsaas, B.T., Koskela, L., Saurin, T.A., Eds.; IGLC and Akademika Forlag: Oslo, Norway, 2014; Volume 2, pp. 933–944.
43. Sbiti, M.; Beladjine, D.; Beddiar, K.; Mazari, B. Leveraging Quantity Surveying Data and BIM to Automate Mechanical and Electrical (M & E) Construction Planning. *Appl. Sci.* **2022**, *12*, 4546.
44. Amany, A.; Taghizade, K.; Noorzai, E. Investigating Conflicts of Expert Contractors Using the Last Planner System in Building Information Modeling Process. *J. Eng. Des. Technol.* **2020**, *18*, 1381–1402. [CrossRef]

45. Kerosuo, H.; Mäki, T.; Codinhoto, R.; Koskela, L.; Miettinen, R. In Time at Last: Adaption of Last Planner Tools for the Design Phase of a Building Project. In Proceedings of the 20th Annual Conference of the International Group of Lean Construction: Are We Near a Tipping Point? San Diego, CA, USA, 18–20 July 2012; pp. 1031–1041.
46. Emmitt, S.; Ruikar, K. *Collaborative Design Management*; Routledge: London, UK, 2013; ISBN 0-203-81912-8.
47. Schöttle, A.; Arroyo, P.; Christensen, R. Demonstrating the Value of an Effective Collaborative Decision-Making Process in the Design Phase. In Proceedings of the 26th Annual Conference of the International. Group for Lean Construction, Chennai, India, 18–20 July 2018; pp. 18–20.
48. Suhr, J. *The Choosing by Advantages Decisionmaking System*; Greenwood Publishing Group: Westport, CT, USA, 1999; ISBN 1-56720-217-9.
49. Parrish, K.; Tommelein, I. Making Design Decisions Using Choosing by Advantages. In Proceedings of the 17th Annual Conference of the International Group for Lean Construction, IGLC17, Taipei, Taiwan, 15–17 July 2009; pp. 501–510.
50. Lee, S.-I.; Bae, J.-S.; Cho, Y.S. Efficiency Analysis of Set-Based Design with Structural Building Information Modeling (S-BIM) on High-Rise Building Structures. *Autom. Constr.* **2012**, *23*, 20–32. [CrossRef]
51. Bavafa, M.; Kiviniemi, A.; Weekes, L. Optimised Strategy by Utilising BIM and Set-Based Design: Reinforced Concrete Slabs. In Proceedings of the CIB W078 2012 Conference, Beirut, Lebanon, 17–19 October 2012.
52. Fundli, I.S.; Drevland, F. Collaborative Design Management—A Case Study. In Proceedings of the 22nd Annual Conference of the International Group for Lean Construction 2014 (IGLC 2014), Oslo, Norway, 25–27 June 2014; pp. 627–638.
53. Zimina, D.; Ballard, G.; Pasquire, C. Target Value Design: Using Collaboration and a Lean Approach to Reduce Construction Cost. *Constr. Manag. Econ.* **2012**, *30*, 383–398. [CrossRef]
54. Kerosuo, H. BIM-Based Collaboration across Organizational and Disciplinary Boundaries through Knotworking. *Procedia Econ. Financ.* **2015**, *21*, 201–208. [CrossRef]
55. Kerosuo, H.; Mäki, T.; Korpela, J. Knotworking-A Novel BIM-Based Collaboration Practice in Building Design Projects. In Proceedings of the 5th International Conference on Construction Engineering and Project Management ICCEPM, Anaheim, CA, USA, 9–11 January 2013.
56. Kunz, J.; Fisher, M. *Virtual Design Cases & Studies*; Working Paper 097; Center for Integrated Facility Engineering: Stanford, CA, USA, 2012.
57. Ghaffarianhoseini, A.; Tookey, J.; Ghaffarianhoseini, A.; Naismith, N.; Azhar, S.; Efimova, O.; Raahemifar, K. Building Information Modelling (BIM) Uptake: Clear Benefits, Understanding Its Implementation, Risks and Challenges. *Renew. Sustain. Energy Rev.* **2017**, *75*, 1046–1053. [CrossRef]
58. Volk, R.; Stengel, J.; Schultmann, F. Building Information Modeling (BIM) for Existing Buildings—Literature Review and Future Needs. *Autom. Constr.* **2014**, *38*, 109–127. [CrossRef]
59. Andersen, M.T.; Findsen, A.-L. Exploring the Benefits of Structured Information with the Use of Virtual Design and Construction Principles in a BIM Life-Cycle Approach. *Archit. Eng. Des. Manag.* **2019**, *15*, 83–100. [CrossRef]
60. Adel, M.; Cheng, Z.; Lei, Z. Integration of Building Information Modeling (BIM) and Virtual Design and Construction (VDC) with Stick-Built Construction to Implement Digital Construction: A Canadian General Contractor's Perspective. *Buildings* **2022**, *12*, 1337. [CrossRef]
61. Kang, T.W.; Woo, J.Y. The Development Direction for a VDC Support System Based on BIM. *KSCE J. Civ. Eng.* **2015**, *19*, 1573–1584. [CrossRef]
62. Trach, R.; Pawluk, K.; Lendo-Siwicka, M. The Assessment of the Effect of BIM and IPD on Construction Projects in Ukraine. *Int. J. Constr. Manag.* **2022**, *22*, 1844–1851. [CrossRef]
63. Junior, J.S.; Baldauf, J.P.; Formoso, C.T.; Tzortzopoulos, P. Using Bim and Lean for Modelling Requirements in the Design of Healthcare Projects. In Proceedings of the 26th Annual Conference of the International Group for Lean Construction (IGLC), Chennai, India, 16–22 July 2018; pp. 16–22.
64. Sepasgozar, S.M.; Hui, F.K.P.; Shirowzhan, S.; Foroozanfar, M.; Yang, L.; Aye, L. Lean Practices Using Building Information Modeling (Bim) and Digital Twinning for Sustainable Construction. *Sustainability* **2020**, *13*, 161. [CrossRef]
65. Kim, T.W.; Kim, Y.; Cha, S.H.; Fischer, M. Automated Updating of Space Design Requirements Connecting User Activities and Space Types. *Autom. Constr.* **2015**, *50*, 102–110. [CrossRef]
66. Choo, H.J.; Tommelein, I.D.; Ballard, G.; Zabelle, T.R. WorkPlan: Constraint-Based Database for Work Package Scheduling. *J. Constr. Eng. Manag.* **1999**, *125*, 151–160. [CrossRef]
67. Al Hattab, M.; Hamzeh, F. Using Social Network Theory and Simulation to Compare Traditional versus BIM–Lean Practice for Design Error Management. *Autom. Constr.* **2015**, *52*, 59–69. [CrossRef]
68. Herrera, R.F.; Mourgues, C.; Alarcón, L.F.; Pellicer, E. Comparing Team Interactions in Traditional and BIM-Lean Design Management. *Buildings* **2021**, *11*, 447. [CrossRef]
69. AbouRizk, S.; Halpin, D.; Mohamed, Y.; Hermann, U. Research in Modeling and Simulation for Improving Construction Engineering Operations. *J. Constr. Eng. Manag.* **2011**, *137*, 843–852. [CrossRef]
70. Wickramasekara, A.N.; Gonzalez, V.; O'Sullivan, M.; Walker, C.; Poshdar, M.; Ying, F. Exploring the Integration of Last Planner® System, Bim, and Construction Simulation. In Proceedings of the Annual Conference of the International. Group for Lean Construction, Berkeley, CA, USA, 6–10 July 2020.
71. Demirdöğen, G.; Diren, N.S.; Aladağ, H.; Işık, Z. Lean Based Maturity Framework Integrating Value, BIM and Big Data Analytics: Evidence from AEC Industry. *Sustainability* **2021**, *13*, 10029. [CrossRef]

72. Park, C.-S.; Kim, H.-J.; Park, H.-T.; Goh, J.-H.; Pedro, A. BIM-Based Idea Bank for Managing Value Engineering Ideas. *Int. J. Proj. Manag.* **2017**, *35*, 699–713. [CrossRef]
73. Ekanayake, E.; Sandanayake, Y.G. LiVE Approach: Lean Integrated Value Engineering for Construction Industry. *Built Environ. Proj. Asset Manag.* **2017**, *7*, 518–533. [CrossRef]
74. Ahuja, R.; Sawhney, A.; Arif, M. Developing Organizational Capabilities to Deliver Lean and Green Project Outcomes Using BIM. *Eng. Constr. Archit. Manag.* **2018**, *25*, 1255–1276. [CrossRef]