

Article

Benefits and Limitations of Lean Tools in the Building Design Process: A Functional and Comparative Analysis

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Abstract: The design phase is critical in construction projects, as it directly impacts cost, quality, and execution efficiency. However, it suffers from structural deficiencies in communication, coordination, and early problem detection, leading to delays, cost overruns, and inefficiencies. While Lean Construction has been widely applied in execution phases, its adoption in design remains fragmented, lacking a clear framework for identifying and evaluating Lean tools in this context. This study aims to identify, classify, and evaluate Lean tools applicable to the building design phase, emphasizing their functionalities, benefits, and limitations. A systematic literature review and expert validation process led to the identification of 16 Lean tools and 26 design-related functionalities. Among these tools, Building Information Modeling (BIM), Last Planner System (LPS), and Agile Design Management (ADM) were identified as the most impactful, collectively addressing 88% of design functionalities. Expert insights revealed that ADM improves task control and decision-making clarity, LPS reduces uncertainty and enhances workflow reliability, and BIM strengthens coordination and early conflict detection. This study provides a structured perspective on Lean tool integration during design, highlighting their benefits and limitations and offering guidance for their implementation. The findings contribute to improving design efficiency, minimizing waste, and fostering collaboration in construction projects.

Keywords: lean design; BIM; last planner system; agile design management; construction efficiency



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1. Introduction

Despite the critical role of the design phase, it is often overlooked and underdeveloped in many construction projects [1]. This phase is frequently characterized by ineffective communication, insufficient or inadequate documentation, poor information management, and limited coordination among the disciplines involved [1–3]. Additionally, decision-making during this phase tends to be erratic, further exacerbating coordination and collaboration issues [1–3]. Most changes at this stage stem from a lack of communication between designers [4]. Furthermore, designers' inadequately conceptualizing the final product often leads to modifications during construction to meet client expectations, resulting in inefficiencies and increased costs [5].

Traditional project management techniques have proven ineffective in addressing the complexity inherent in design management, as they assume that work can be divided and managed independently [1]. In fact, addressing design and construction issues requires a team-based approach [6–9]. Previous research suggests that adopting a collaborative approach in the early design stages can mitigate many problems by promoting greater professional integration from the project's inception [10,11]. Therefore, it is crucial for stakeholders and designers to consider the impact of communication flow, trust in shared information, coordination, and effective collaboration among architects, contractors, and subcontractors [4].

Lean Construction was introduced in the Construction industry to improve workflows, meet client requirements, and eliminate waste with increasing global adoption [12]. Lean Construction maximizes client value by eliminating non-value-adding activities, creating a reliable workflow, and pursuing continuous improvement [4,12]. Although Lean Construction originates from Lean Production, its application in construction has required significant adaptations [12], leading to the development of specific tools and strategies [13]. Within this adaptation, Lean Design emerged as an approach focused on eliminating waste and non-value-adding activities in design processes [14,15].

To address the challenges of the design phase, Lean Design has proven to be a key methodology, facilitating early client involvement, maximizing value, and identifying stakeholder needs and objectives to minimize rework and unnecessary tasks [16]. Although Lean principles have been applied to design management since the late 1990s [17], many studies have only examined a subset of Lean practices without fully exploring their applications in building design [3]. While some research has documented the application of Lean management principles and specific tools in design management [18,19], the interactions between Lean tools such as the Last Planner System, Target Value Design, Set-Based Design, and Building Information Modeling (BIM) [14,20,21] have not been thoroughly investigated, nor have their combined benefits been extensively analyzed [4].

Currently, no studies explicitly identify Lean Design tools in building projects, nor do they systematically examine the functionalities, benefits, and limitations of Lean tools specifically applied to design. While this study provides a comprehensive identification and analysis of Lean tools for building design, it is limited by the number of expert responses obtained and the focus on tools with available literature and expert consensus. These constraints may affect the generalizability of certain findings and are discussed further in the concluding section. Therefore, this research aims to identify Lean tools in the building design process, compare their functionalities, and recognize their benefits and limitations within this phase. Therefore, this study not only addresses an underexplored area, Lean Design in building projects, but also contributes a systematic and validated framework that identifies, categorizes, and analyzes Lean tools specifically for the design phase. By integrating expert perspectives with literature findings, this research enhances both theoretical understanding and practical implementation, offering actionable insights for improving design performance in the construction industry. The hypothesis guiding this study is that a set of Lean tools, when systematically identified and functionally validated, can significantly improve the efficiency, coordination, and value generation in the building design phase. The novelty of this research lies in its integrated approach that combines literature review, expert validation, and functional analysis to identify and evaluate Lean tools specifically applied to building design. Unlike previous studies that examine tools individually or focus on construction stages, this study offers a structured and comparative framework tailored to the design phase, providing new insights into tool interactions, functional coverage, and practical applicability.

This research is structured as follows. Section 2 describes the research method applied in this article, comprising a set of activities for obtaining Lean design tools and their selection and validation by experts. In Section 3, the results are presented and discussed. Finally, the conclusions of this work are displayed in Section 4.

2. Research Method

The research method consists of three main stages: (1) Lean tools in the building design process, (2) functionalities of Lean tools in the building design process, and (3) benefits and limitations of Lean tools in the building design process. In the first stage, the identification of Lean tools was conducted through a systematic literature review using the Scopus database, which was selected due to its multidisciplinary coverage, its focus on peer-reviewed literature, and its international recognition as one of the most comprehensive and rigorous sources for academic studies in engineering and construction. In the second stage, a complementary literature review was carried out, specifically aimed at identifying the functionalities associated with each Lean tool within the building design process. This review enabled the establishment of relationships between the functionalities of each tool and the stages of the design process in order to understand how these tools add value. Finally, in the third stage, expert judgment and semi-structured interviews were conducted with professionals experienced in the design and management of building projects to identify and analyze the perceived benefits, as well as the practical limitations encountered in the application of Lean tools. Figure 1 provides an overview of the activities carried out in each stage, along with the methodological tools used and the resulting outputs.

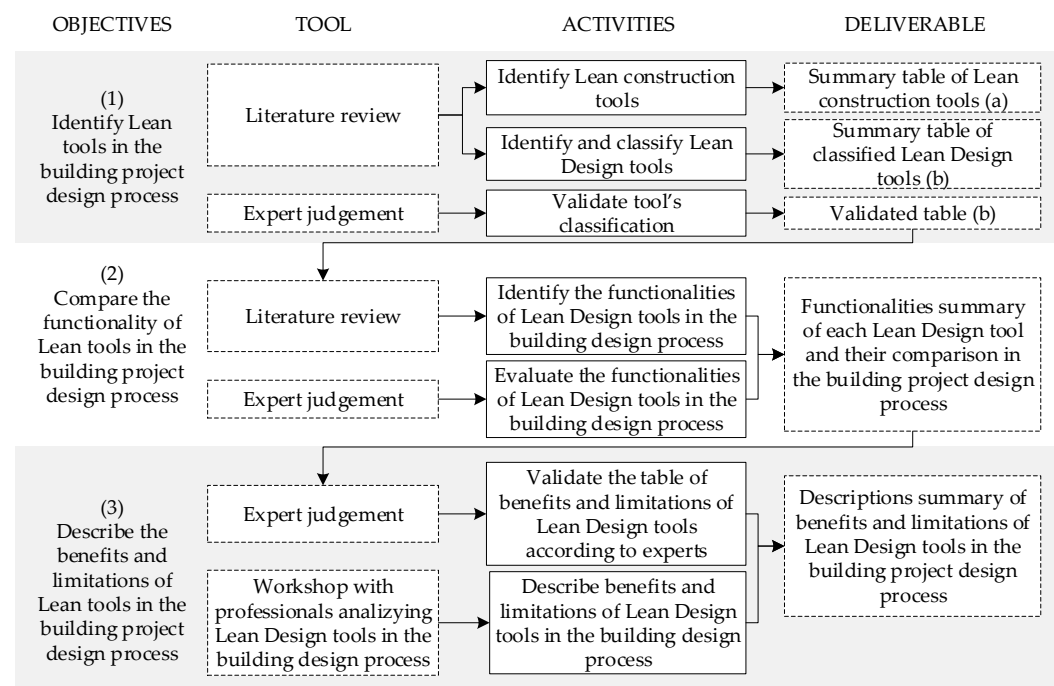


Figure 1. Research method.

The following explains each objective of the research method described in Figure 1.

2.1. Identifying Lean Tools in the Building Project Design Process

To identify Lean Construction tools applied during the design phase of building projects, a systematic literature review was conducted, following a methodological procedure structured in three main stages: search, filtering, and validation. First, an exhaustive search was carried out in the Scopus database, selected for its international recognition

and broad coverage in engineering and technology [22]. The search was guided by the keywords “Lean Construction” and “Tools”, resulting in a preliminary sample of 49 documents. Subsequently, two inclusion/exclusion criteria were applied. The first criterion consisted of a temporal filter, considering only documents published between 2013 and 2023, which reduced the sample to 43 articles. The second criterion involved a manual screening process, selecting only those documents that included explicit tables or listings of Lean tools applied to design. This stage narrowed the sample down to four articles. As a complement, conference papers from the International Group for Lean Construction (IGLC) were reviewed using the same filters, yielding one additional document. Lastly, the academic thesis titled “Integration of Overlapped Design and Construction Stages Through Location-Based Planning Tools” was incorporated, resulting in a final sample of six documents for in-depth analysis. This sample served as the foundation for identifying Lean Construction tools used during the design phase and evaluating their functionalities and limitations in the context of building projects.

In the second stage, the application of these tools according to project type was analyzed. A complementary literature search was performed using the Scopus, Web of Science, and IGLC databases, selected for their relevance to natural sciences, engineering, and English-language scholarly publications [23]. The search was guided by the equation “Lean tools design and ‘n’”, where ‘n’ corresponds to the iteration of each previously identified Lean design tool (see Figure 2). The final selection of documents was based on two inclusion criteria: (1) a ten-year publication window and (2) a manual review to identify studies that demonstrated practical applications or explicitly suggested the implementation of Lean tools in design processes. This search yielded a final sample of 26 documents for detailed analysis.

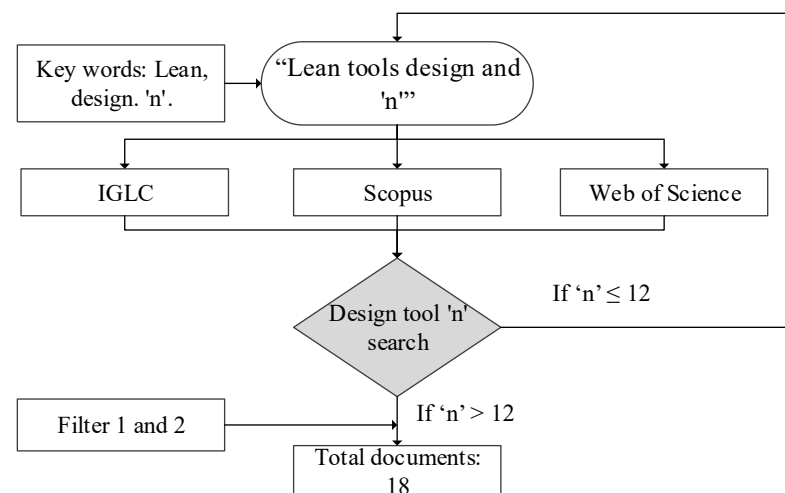


Figure 2. Complementary literature search flow.

Finally, an expert validation process was conducted to corroborate the relevance of the identified tools. A five-question survey was designed and distributed to 37 international experts in Lean Construction and building design. Given their geographical distribution, the validation was carried out online in two language versions: Spanish and English. The process was implemented in two phases: an initial pilot with three experts, followed by a broader application to 34 additional experts selected from the authors identified during the second literature review. As a result, 16 complete and valid responses were obtained and used to confirm the applicability of the Lean tools within the context of building design (see Table 1).

Table 1. Characterization of experts in the Lean Design tools validation process.

Id	Academic Degree	Professional Title	Research Line	Years of Experience	Role	Country of Residence
1	Ph.D.	Civil Engineer	Construction Management	>25	Professor/Consultant	Ecuador
2	Ph.D.	Civil Engineer	Situation Awareness in Construction	>25	Consultant	Finland
3	Master's	Civil Engineer	Lean-BIM	>25	Manager	Germany
4	Ph.D.	Civil Engineer	Lean Construction	>25	Professor	UK
5	Ph.D.	Architect	Target Value Delivery—Lean Design	>20	Professor/Consultant	Chile
6	Ph.D.	Civil Engineer	Construction Management and Technology	>20	Professor	Brazil
7	Ph.D.	Civil Engineer	Lean Construction	>15	Professor	South Africa
8	Ph.D.	Civil Engineer	Construction Management	>10	Professor	Colombia
9	Ph.D.	Construction Engineer	Last Planner System	>10	Professor	Chile
10	Ph.D.	Civil Engineer	Lean-BIM in Design	>10	Professor/Consultant	Chile
11	Ph.D.	Architect	Lean Construction	>10	Professor	Brazil
12	Ph.D.	Civil Engineer	Construction Technology	>10	Senior	Nigeria
13	Ph.D.	Civil Engineer	Lean-IPD	>10	Manager	Germany
14	Ph.D.	Civil Engineer	Lean Construction	>10	Manager	USA
15	Ph.D.	Civil Engineer	Lean-BIM-Roads	>5	Professor	Chile
16	Bachelor's	Civil Engineer	Construction Management	>5	Consultant	Peru

The five validation questions were designed to address aspects ranging from general to specific, aiming to assess the experts' level of knowledge and experience regarding Lean tools. These questions sought to determine the following: (i) The general knowledge experts had about the tool. (ii) Have they previously read about the tool? (iii) Did they know of any case studies where the tool had been applied? (iv) Have they implemented the tool in any building design process? (v) The extent to which they would recommend using the tool. Additionally, experts were asked to propose other Lean tools that could be applied to the building design process. Only tools suggested by at least two experts were considered, and four additional tools beyond those found in the literature review were identified.

Below are the detailed questions and instructions used in the validation process:

1. Which tools/methodologies do you know (have heard of, read about, applied, or know have been applied)? If you know of another, please specify.
2. Have you read about the application of this tool in the design phase of building projects?
3. Do you know of any cases where this tool has been applied in the design of building projects?
4. Have you applied this tool in the design phase of building projects?
5. On a scale of 1 to 7, how much would you recommend using this tool in the design phase of building projects? (1 = not recommended, 4 = neutral, 7 = highly recommended)?

To evaluate whether there were statistically significant differences in the level of knowledge and experience with various management tools in the construction sector, the non-parametric Friedman test was applied, as it is suitable for repeated measures with

dichotomous data (0 = no, 1 = yes). The analysis covered four dimensions: general recognition of the tool, prior reading or study, application in the third person (observation or supervision), and application in the first person (direct use). For each dimension, the Friedman test was used to assess global differences across eleven tools. When significant results were found ($p < 0.05$), post hoc pairwise comparisons were conducted using the Wilcoxon signed-rank test, with Bonferroni correction applied to control for Type I error. This approach enabled the identification of both overall and pairwise differences in tool familiarity and application among the experts. To statistically examine whether the experts evaluated the set of Lean and BIM-related tools differently, a non-parametric Kruskal–Wallis H test was applied, considering the ordinal nature of the data (scale from 1 to 7) and the unequal number of respondents per tool. This test allowed identifying global differences in the median evaluations across the tools. Following a statistically significant result ($p < 0.05$), pairwise comparisons were conducted using the Mann–Whitney U test, with Bonferroni correction to control for Type I error due to multiple testing. This two-step approach ensured a robust analysis of differences in tool assessments, considering both overall trends and potential significant contrasts between specific tools.

2.2. Identifying Lean Design Tool Functionalities

To identify the functionalities associated with Lean Design tools in the building design process, a third comprehensive literature review was conducted. This review incorporated four additional design tools recommended by experts during the validation process described in Section 2.1. The review followed the same methodological steps, search parameters, and inclusion/exclusion criteria previously established, resulting in the identification of four additional relevant documents. These were analyzed together with the 26 documents previously selected, forming a final sample of 30 scientific publications subjected to in-depth analysis. The initial definition of functionalities was based on Aslam et al. [24], which presented a set of tool functionalities oriented toward construction processes. From this reference, 21 functionalities applicable specifically to the design phase were selected and adapted. In addition, three functionalities were incorporated from the article *Optimizing Construction Design Process Using the Lean-Based Approach*, and two further functionalities emerged from the qualitative analysis of the complete sample. As a result, a total of 26 specific functionalities for Lean tools used in the building design process were defined. Each functionality was described and supported through the aforementioned sources, complemented by other relevant articles manually identified during the review process.

Subsequently, a functional classification of the tools was conducted based on the five classical principles of management: planning, organizing, directing, controlling, and staffing. This categorization was developed considering both the theoretical definition of each principle and the operational characteristics of the identified functionalities. However, the staffing category was excluded, as no functionality was found to be directly associated with this principle. Additionally, a global category was introduced to represent functionalities with cross-cutting relevance across multiple management domains. To ensure the validity of the defined functionalities and their classification, an expert judgment process was carried out. This process aimed to validate the applicability of each functionality within the context of building design, recognizing that some Lean tools may serve multiple purposes. The validation instrument was distributed to the 37 experts previously identified as authors of the reviewed articles. A total of 19 complete responses were received, which contributed to reinforcing the reliability of the analysis. The expert input also confirmed that a single tool may address several distinct functions. Table 2 provides a detailed characterization of the experts who participated in this validation stage.

Table 2. Characterization of experts in the Functionality validation process.

Id	Academic Degree	Professional Title	Research Line	Years of Experience	Role	Country of Residence
1	Ph.D.	Civil Engineer	Construction Management	>40	Consultant	Chile
2	Bachelor's	Architect	Design-Construction	>40	Professor	Peru
3	Bachelor's	Civil Engineer	Construction	>30	-	Finland
4	Ph.D.	Architect	TVD	>25	Consultant/ Professor	Chile
5	Master's	Civil Engineer	Lean Construction	>25	Consultant/ Professor	Peru
6	Ph.D.	Professor	Operational Management in Construction	>20	Professor	Finland
7	Ph.D.	Architect	Lean Construction	>20	Professor	UK
8	Ph.D.	Civil Engineer	Virtual Design and Construction	>20	Professor	Chile
9	Master's	Civil Engineer	Lean	>15	Consultant	UK
10	Master's	Civil Engineer	BIM-Lean	>15	Professor/ Consultant	Peru
11	Ph.D.	Civil Engineer	Lean in Construction	>10	Manager	USA
12	Ph.D.	Architect	Target Value Delivery—Lean Construction—BIM	>10	Professor	Brazil
13	Ph.D.	Civil Engineer	Lean Construction	>10	Professor	South Africa
14	Ph.D.	Architect	Lean Management in Design	>10	Professor/ Consultant	Brazil
15	Doctor	Civil Engineer	Lean-BIM-Roads	>5	Professor	Chile
16	Master's	Civil Engineer	BIM-Lean-GIS	>5	-	Colombia
17	Ph.D.	Civil Engineer	Technology and Management in AIC Industry	>5	Professor	Chile
18	Ph.D. (c)	Civil Engineer	Design and Planning of Road Infrastructure Projects	>5	Professor	Chile
19	Master's	Civil Engineer	BIM-Lean-GIS	>5	Consultant	Colombia

A cross-analysis was conducted between each functionality and the Lean tools, comparing the results with the experts' responses. As an acceptance criterion, it was established that at least 62.5% of the participants had to agree on each match, as this percentage reflects a moderate consensus among experts according to the literature [25]. This threshold was chosen to ensure that the functionalities were sufficiently supported by the participants' opinions, allowing for the feasibility of the validation process.

2.3. Benefits and Limitations of Lean Tools in the Building Design Process

In Section 2.1, the application of Lean tools in the building project design process has been validated, involving 37 industry experts. These experts were asked to identify these tools' main benefits and challenges based on their professional experience. Additionally, a comparison was conducted between the perceptions of these experts and those of professionals in the field, specifically evaluating the Building Information Modeling (BIM), Last Planner System (LPS), and Agile Design Management (ADM) tools. Informal workshops were organized to gather insights from professionals, followed by individual interviews. The participants in these workshops were professionals with at least two years of experience in key roles within the building sector, such as structural engineers, specialty

engineers (MEP), architects, or project coordinators, who were considered designers according to the classification of [26]. A minimum of two participants was included for each profile, resulting in 15 participants (see Table 3).

Table 3. Characterization of interviewees.

Id	Profession	Position	Years of Experience
1	Architect	Architect	>30
2	Civil Engineer	Structural Engineer	>30
3	Architect	Architect	>20
4	Industrial Maintenance Technician	BIM Manager	>20
5	Civil Engineer	Structural Engineer	>18
6	Architect	Architect	>16
7	Civil Engineer	General Manager of Real Estate	>10
8	Civil Engineer	Structural Engineer	>6
9	Civil Engineer	Structural Engineer	>2
10	Civil Engineer	Structural Engineer	>2
11	Civil Engineer	Structural Engineer	>2
12	Civil Engineer	Specialty Engineer (MEP)	>2
13	Civil Engineer	Specialty Engineer (MEP)	>2
14	Civil Engineer	Project Coordinator	>2
15	Civil Engineer	Project Control Engineer	>2

At the beginning of each individual interview, professionals received introductory training on LPS, BIM, and ADM tools. They were then presented with the benefits and limitations of these tools, as detailed Section 3.3. During the interview, each participant reviewed and discussed these benefits and limitations, expressing their agreement or disagreement and justifying their opinion based on their specific area of expertise within the building design process. The interviews were recorded and transcribed for further analysis, ensuring that responses reflected a well-informed professional perspective grounded in the practical experience of each interviewee (informed consent in the interview in Supplementary File).

3. Results and Discussion

This chapter is divided into three sections. (1) Lean Construction Tools focuses on identifying Lean tools specifically aimed at design, known as Lean Design, within the context of building projects. (2) Lean Design and Its Functionalities analyzes Lean Design tools and their key functionalities, explaining their practical application in building design. (3) Benefits and Limitations of Lean Tools in Design examines how these tools contribute to optimizing the design process by reducing waste and improving efficiency, as well as the potential constraints or challenges that may arise when implementing them in the building design phase.

3.1. Lean Construction Tools

Table 4 presents the 48 Lean Construction tools obtained from the literature review and their detailed descriptions. These tools focus on improving the systems and processes that make up a project, aiming to minimize waste, increase productivity, and meet client requirements [27]. Lean Construction tools originated from Lean Production tools, which initially focused on production aspects and were later adapted for use in the construction industry [13]. However, various tools are mentioned in different articles without an official consensus, yet they are applicable in the construction industry. This occurs because no official list of these tools exists, and research in this area is ongoing.

Table 4. Lean construction tools based on literature review.

Tool	Description	Refs.
5S	Sort, Set in Order, Shine, Standardize, Sustain. A process for eliminating workplace waste using visual controls.	[1–3]
Concurrent Engineering	Parallel execution of multidisciplinary tasks to optimize engineering cycles for efficiency, quality, and functionality.	[1,4]
Check Sheet	A structured form is used to collect and analyze data on problem patterns, events, and causes.	[1]
Construction Process Analysis	Updated process and flow diagrams using symbols to identify problems and improve analysis.	[1,5]
Six Sigma	A methodology for improving quality by eliminating defects and reducing variability in processes.	[1,2]
Pareto Analysis	A bar chart analyzing the frequency of causes or problems in processes, highlighting their importance.	[28]
Failure Mode and Effects Analysis (FMEA)	A step-by-step approach to identifying, eliminating, and prioritizing failures in products or services.	[29–31]
Continuous Flow	Operating continuously and progressively, generating or processing through sequential steps.	[32,33]
FIFO line (First In, First Out)	A method to manage work requests based on flow order, from first to last.	[32]
Jidoka/Automation	Partial automation of the manufacturing process, allows operators to perform other tasks while machines run.	[32]
Kanban (Pull System)	An information control process regulating resource flow, ensuring timely parts and supply requests.	[28,32]
Kaizen	An approach focused on improving quality and efficiency by eliminating waste.	[32]
The Last Planner	The methodology ensures predictable workflow and reliable project outcomes by identifying obstacles in advance.	[34]
Poka-Yoke (Error Proofing)	A mechanism designed to detect and prevent errors in processes, aiming for zero defects.	[28,32]
First Run Studies	Executing tests to determine the best means, strategies, and sequencing for a process.	[35,36]
Bottleneck Analysis	Identifying process bottlenecks that limit productivity and improving their performance.	[28,37]
Visual Management	A technique to enhance efficiency and clarity in processes through visual signals.	[32,33,35]
Synchronize/Line Balancing	Leveling workload across all processes in a value stream to eliminate excess capacity and bottlenecks.	[32]
Work Structuring	Designing and operating processes based on supply chain, resource allocation, and assembly for quality results.	[35,38]
5 Whys	A problem-solving tool that repeatedly asks ‘why’ to find the root cause of a problem.	[35,38]
Fail-Safe for Quality	A method to detect defects and risks, similar to Poka-Yoke but focused on safety measures.	[35,36]
Daily Huddle Meetings	Daily team meetings promote communication, engagement, and problem-solving.	[35,36]
SMART Goals	Specific, measurable, achievable, relevant, and time-bound goals.	[37]

Table 4. *Cont.*

Tool	Description	Refs.
PDCA (Plan, Do, Check, Act)	An iterative approach: Plan, Do, Check, Act for continuous process improvement.	[37]
Work Standardization	Documented procedures capturing best practices, constantly updated.	[28,32]
Statistical Process Control	A quality control tool monitors and controls process outputs for optimal performance.	[32]
Just in Time (JIT)	A method reducing production flow times, supplier response, and waste.	
Team Preparation	Training process on waste reduction, continuous flow, and work standardization.	[32]
Muda Walk	Technique to identify waste by observing operations and highlighting improvement areas.	[28]
Value Stream Mapping	A technique to analyze, document, and visually improve process flow.	[28,37]
Root Cause Analysis	A problem-solving method that focuses on identifying and solving root causes instead of symptoms.	[37]
Set Based Design	A design methodology keeps options flexible as long as possible.	[39]
Prefabrication/Modular	Prefabricating building components in a controlled environment before on-site assembly.	[40,41]
Integrated Project Delivery	A methodology bringing key stakeholders together for project collaboration.	[42]
Building Information Modeling (BIM)	Software for intelligent building simulation and data-driven decision-making.	[43]
Theory of Constraints	A theory improving workflow by reducing constraints and ensuring steady material flow.	[36]
Target Value Design	A system reversing design practices where costs dictate design instead of vice versa.	[44]
Linguistic Action Perspective	Applying Speech Act Theory to project management, recognizing conversations as actions.	[45]
Choosing by Advantages	A structured decision-making system focusing on advantages to determine the best choice.	[46,47]
Gemba Walk	A Lean manufacturing practice emphasizing direct workplace observation.	[48]
A3 Report	A concise visual report for problem-solving, strategy development, and reporting.	[49]
Location-Based Scheduling	A scheduling method designing a continuous, uninterrupted production flow.	[50]
Flow line	A diagram illustrating production unit delivery over time, focusing on delivery rates.	[51]
Takt-time Planning	A unit of time defining production pace to meet demand while balancing workflow.	[52]
Integrated Concurrent Session	An integration event gathering stakeholders to accelerate design problem resolution.	[52]

Table 4. *Cont.*

Tool	Description	Refs.
Big Room	A project approach streamlining communication, improving decision-making, and reducing silos.	[53]
Total Productive Maintenance	A maintenance tool focusing on proactive and preventive equipment care.	[40,41]
Ishikawa Diagram	A tool for identifying and analyzing the root cause of a problem.	[54–56]

3.1.1. Lean Tools Applied to Design

Table 5 presents a set of 12 Lean Construction tools that have been used or recommended for application in the design phase, according to the literature review of 26 documents. The tools marked with an asterisk (*) indicate those whose implementation is suggested at this stage. A general description of each tool from the design perspective is provided, along with various cases in which they have been applied or their application has been proposed.

Table 5. Lean tools applied to design (* Application is suggested: Building Design (BD), Social Housing Designs (SHD), Hospital Building Design (HBD), Hydraulic Infrastructure Design (HID), Concrete Reinforcement Design (CRD), Subway Design (SD), Infrastructure Design (ID), Structural Design of a Building (SDB), Engineering Design (ED), Housing Design (HD), Design Stage (DS).).

Tool	Description	Applied Case
Target Value Design (TVD)	It is an approach that considers Architecture, Engineering, and Construction as a complex system with definition, design, and construction phases. This approach reverses conventional design practices by making costs guide the design instead of design determining the costs.	BD * [57–59], SHD * [60], HBD [61]
Set-based Design (SBD)	Designers generate design solutions that incorporate multiple criteria, considering the schedule and budget. These solutions are collaboratively improved until a satisfactory resolution is achieved, while progressively adapting to time and cost constraints.	HID * [62], BD [62]
Choosing by Advantage (CBA)	It is a proven and effective decision-making method that involves evaluating the advantages of each option and determining the best alternative.	BD [63], CRD * [47]
Agile Design Management	The implementation of an agile approach in design management involves the ability to embrace changes flexibly and continuously add value for both designers and clients.	DS [64], SD [65]
Design Structure Matrix (DSM)	It is a visual tool for modeling networks that represents system elements and their interactions, facilitating problem decomposition and integration.	(BD) [66], (ID) [67]
Last Planner System (LPS)	This tool increases process clarity, promotes collaboration, and facilitates communication among designers while strengthening workflow stability and reliability.	BD [66,68], SD [65], ID [67]
Building Information Modeling (BIM)	It refers to the development and use of software to simulate the creation and operation of a building. The result is a detailed building model enriched with intelligent and parameterized data, offering insights and analysis useful for decision-making and process improvement in construction.	(BD) [62,68], (SDB) [20]

Table 5. Cont.

Tool	Description	Applied Case
Linguistic Action Perspective (LAP)	This approach implies that conversations not only precede action but are actions themselves due to the commitments that arise. Conversations for action involve four fundamental speech acts: (1) request or offer, (2) promise or acceptance, (3) declaration of completion, and (4) declaration of satisfaction.	DS * [69]
Visual Management (VM)	Visual management refers to a set of practices that support communication through the use of various visual elements.	ED * [70] ID, [71]
Integrated Project Delivery (IPD)	It is a construction project execution method where key parties unite under a single agreement. This promotes continuous collaboration, reduces waste, improves efficiency, fosters team respect, and enhances project outcomes, including the benefits obtained.	HBD [61]
Value Stream Mapping (VSM)	It is a highly effective tool for optimizing process flow and reducing waste. Value Stream Mapping is an approach where a team maps the value stream in repetitive processes, leading team members to analyze where value is added and where it is not.	BD [62,72], HD [73]
Integrated Concurrent Engineering (ICE)	It involves collaboration among various actors, such as the design team, specialized engineers, and consultants. This process consists of three elements: performance metrics, BIM + simulation, and process design. This problem-solving technique accelerates solutions by considering multiple perspectives. Design reviews occur in a room where stakeholders discuss design aspects on large screens to speed up the process.	BD [62]

Among the most commonly used tools in the design phase, Building Information Modeling (BIM), Last Planner System (LPS), and Target Value Design (TVD) stand out. LPS has been adopted for planning and scheduling activities in engineering design projects, optimizing task organization, and improving deadline compliance [74]. BIM enables the creation of detailed 3D virtual models, fostering communication and collaboration among various design stakeholders [68]. TVD is used to maximize the cost-value relationship of the project from its early design stages, ensuring that decisions reflect a balance between value and resources [60]. These tools have gained recognition due to the strong body of research supporting their effectiveness in design.

A particularly illustrative case is the study [62]. The authors simultaneously used four tools: VSM, SBD, BIM, and ICE. This study demonstrates the positive interaction between Lean tools by applying principles such as consensus-based decision-making, consideration of alternatives, and visualization through BIM [58]. The results highlight the effectiveness of integrating multiple tools in the building design.

Additionally, some studies were identified where, although the tools were not directly applied, their implementation was recommended to optimize design. Other studies explored using Lean tools in engineering design beyond building projects. These findings reinforce the utility and effectiveness of the 12 identified tools in building design.

3.1.2. Validation of Lean Tools in the Building Design Process

Validation of the Proposed Lean Tools in the Building Design Process

Figure 3 illustrates the frequency of affirmative responses from experts regarding using or recommending Lean tools in the building design process. The *x*-axis presents the Lean tools identified in Section 3.2, corresponding to Lean Design, while the *y*-axis indicates

the frequency of affirmative responses expressed as a percentage. Each tool is represented by four bars that reflect different levels of familiarity and application: general knowledge, reading, second-person application, and first-person application. This structure provides a comparative view of experts' level of adoption and practical experience with each tool in the context of building design.

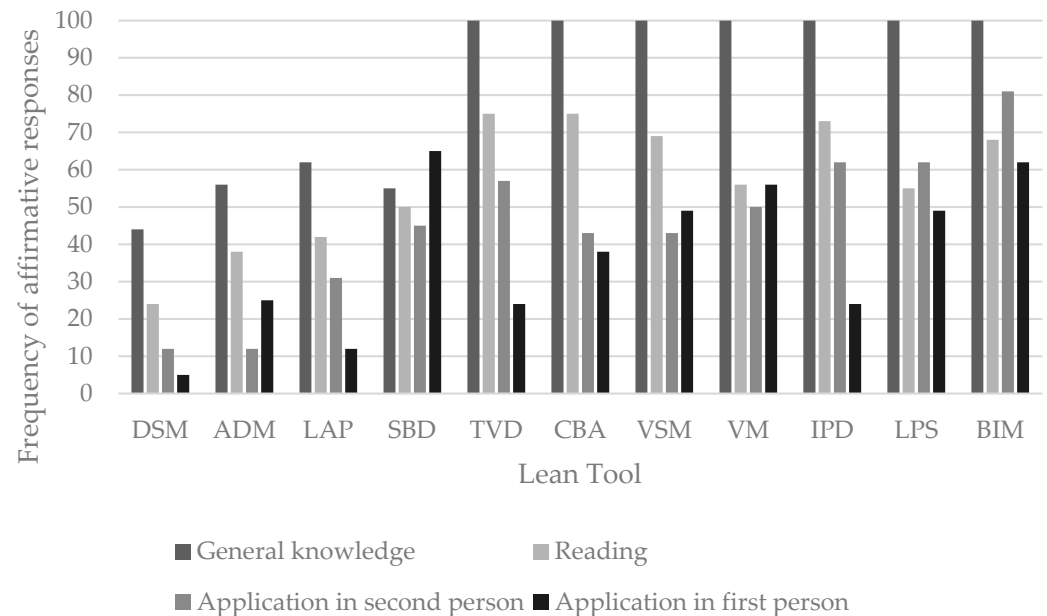


Figure 3. Validation of Lean tools applied to design.

Figure 3 reveals various trends regarding the level of knowledge and application of Lean tools in the building design process.

In terms of general recognition, tools such as BIM, LPS, VSM, IPD, CBA, and TVD are known by 100% of respondents, which may be attributed to their long-standing presence and the support of numerous studies in the construction field. Additionally, tools such as SBD, LAP, ADM, and DSM show a lower level of familiarity, likely due to their recent introduction or the complexity of their use.

Regarding theoretical familiarity, IPD, CBA, TVD, and SBD are the most frequently read about, with 75% of respondents reporting having studied them in depth. In contrast, ADM, DSM, and LAP have a lower reading frequency.

Concerning second-person practical experience, respondents demonstrate knowledge of applications for all tools, with BIM, VM, LPS, and TVD standing out with frequencies above 50%. This indicates that the respondents know cases where these tools have been implemented in building design projects, even if they have not participated directly.

Regarding first-person application, BIM stands out as the most used tool, with 63% of respondents reporting direct experience in its application within building design. Likewise, VSM and LPS are identified as relevant tools in this category. Notably, IPD is mentioned as a standard for applicability in various countries, aiming to standardize certain practices [75].

Although application frequencies vary for other tools, all have been used in building design, validating the 12 Lean tools in the design process described in Section 3.2. To statistically validate the observed differences in familiarity and application levels among the Lean tools, a Friedman test was conducted across four dimensions: general recognition, literature reading, application in the third person, and application in the first person. The results revealed statistically significant differences in all four dimensions ($p < 0.001$), indicating that not all tools are equally known or applied by the experts. Subsequently, Wilcoxon signed-rank post hoc tests with Bonferroni correction were applied to identify

specific differences between tool pairs. Although global significance was detected, pairwise comparisons did not yield statistically significant results after correction, suggesting that differences are more general than specific. These findings reinforce the uneven adoption of Lean tools in design and highlight the need for targeted dissemination and training efforts depending on the tool.

Recommendation Rating of Each Lean Design Tool

Figure 4 presents a box plot illustrating experts' recommendations on the 12 Lean tools in the building design process, evaluated on a scale from one to seven.

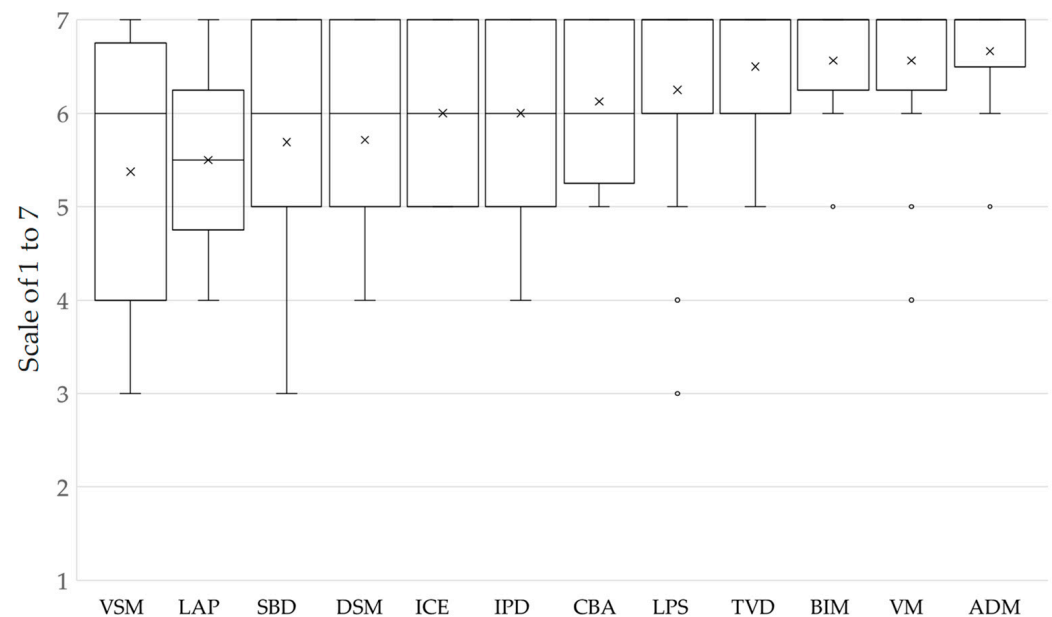


Figure 4. Box plot illustrating experts' recommendations on the 12 Lean tools in the building design process, evaluated on a scale from 1 to 7.

The Y-axis represents this recommendation scale, while the X-axis lists the names of each tool. This analysis is relevant for identifying the level of acceptance and preference that each tool has in the field of building design, allowing an understanding of which are considered more effective or applicable based on professionals' experience in the area.

Interpreting these recommendations provides valuable insights for research, guiding future implementations of Lean tools in design projects. It highlights those that may offer greater benefits or are better supported by the expertise and knowledge of the consulted experts.

Figure 4 shows a strong consensus among experts regarding recommending Lean tools in the building design process.

Among the highest-rated tools, Agile Design Management (ADM), Building Information Modeling (BIM), Visual Management (VM), and Target Value Design (TVD) stand out due to their low response dispersion, indicating a high level of agreement. ADM, with a standard deviation of 0.7, is positioned as the most recommended tool, followed by BIM and VM, with a standard deviation of 0.8. TVD ranks fourth in consensus, while the Last Planner System (LPS) holds the fifth position, consolidating all these as key tools in building design projects.

In contrast, some tools generated greater variability in expert opinions, reflected in a wider dispersion of their ratings. These include Value Stream Mapping (VSM), Linguistic Action Perspective (LAP), Set-Based Design (SBD), and Design Structure Matrix (DSM), whose ratings show greater diversity. This dispersion could be attributed to lower famil-

ilarity among experts, as shown in Figure 4, where LAP and DSM appear less known or used in the building design field. Additionally, this variability may be related to individual interpretations of their applicability and effectiveness in this context.

Finally, although some discrepancies are observed in the recommendation of tools such as LPS, BIM, VM, and ADM, where outlier ratings were identified, these tools—except for LPS—generally maintain a low dispersion in their evaluations. This suggests that, despite some divergent opinions, there is a high overall consensus on their utility and effectiveness. These differences in ratings may be influenced by the specific application context and the experts' prior experience in using each tool within the building design process. The results of the Kruskal–Wallis test indicated statistically significant differences in the evaluations of the various tools ($H = 41.39$, $p < 0.001$), confirming that not all tools were assessed equally by the experts. This global significance suggests a differentiated perception regarding the applicability or value of certain tools within the design process. While subsequent pairwise comparisons using the Mann–Whitney U test with Bonferroni correction did not yield statistically significant results after adjustment, consistent trends were observed. Tools such as Building Information Modeling (BIM) and Visual Management (VM) received systematically higher ratings among participants, frequently contrasting with lower-rated tools such as Value Stream Mapping (VSM) or Design Structure Matrix (DSM). These patterns suggest that, although pairwise differences did not reach corrected significance thresholds, BIM and VM may be perceived as more mature or valuable tools in current design practices.

Lean Design Tool Proposal

Experts proposed new Lean tools for the building design process, which were incorporated into the list of tools presented in Table 4, considering recommendations made by at least two experts. As a result, four additional tools were added: A3 Report, 5S, 5 Why, and Just In Time, expanding the set to 16 Lean tools for the building design process. The complete set of Lean Design tools now includes Target Value Design (TVD), Set-Based Design (SBD), Choosing by Advantage (CBA), Agile Design Management (ADM), Design Structure Matrix (DSM), Last Planner System (LPS), Building Information Modeling (BIM), Linguistic Action Perspective (LAP), Visual Management (VM), Integrated Concurrent Engineering (ICE), A3 Report, 5S, Just In Time (JIT), 5 Why, Integrated Project Delivery (IPD), and Value Stream Mapping (VSM). This expansion reflects the experts' insights into enhancing Lean methodologies within the design phase, integrating well-established and emerging tools to improve efficiency and effectiveness in building design projects.

3.2. Lean Design and Its Functionalities

3.2.1. Definition of Each Functionality

The literature review on the 33 documents selected according to Section 2.2 found no explicit evidence of Lean tool functionalities in the building design process. However, 34 functionalities were identified from the Lean Construction perspective and six from the design perspective. From these, 26 functionalities were selected and defined within the building design process, as shown in Table 6.

Table 6. Functionalities of Lean Tools in the Building Design Process.

Functionality	Definition	References
Global Collaborative Scheduling	Initial planning that details project milestones and phases, organized by function or area, covering the entire duration and guided by constraints and objectives.	[36–77]
Phase Collaborative Scheduling (Pull Planning)	A team planning technique that works backward from a target date, organizing tasks to release work requested by others, reducing waste, and focusing on value addition.	[36–77]
Lookahead Collaborative Scheduling	An intermediate planning process that adjusts budgets and schedules, optimizes resources and coordinates activities to effectively control project workflow.	[76,77]
Weekly Collaborative Scheduling	The most detailed planning phase before execution, conducted by various supervisors, promotes bidirectional communication and efficiency in projects.	[36–77]
Data Recording and Analysis	Involves examining collected data to extract valuable information, and identify patterns, trends, relationships, or significant conclusions from documents or records.	[77–79]
Constraint Analysis	Evaluates the necessary conditions for an activity to be executed, identifying the constraints that prevent its realization.	[74,77]
Visual Communication	Represents design as an information flow using images, graphics, and models to improve communication, reduce time and errors, and enhance collaboration among stakeholders.	[24,77]
Root Cause Problem Analysis	A problem-solving approach that seeks the root cause of a problem through repeated ‘why’ questioning to resolve its origin.	[76,77]
Design-Construction Coordination	Effectively integrates architectural and engineering design during construction to avoid issues, and costly changes, and ensure design feasibility in practice.	[24]
Progress Evaluation Against Schedule	Analysis of team progress according to the schedule, measured by evaluating the number of committed tasks completed divided by the total committed tasks and comparing it to the target progress.	[74,77]
Open, Transparent Communication Sharing Information with the Entire Team	Direct and honest exchange of information without blame, promoting problem-solving, cooperation, and trust in projects and organizations.	[75,77]
Stakeholder Involvement	Stakeholder involvement involves collaboration among clients, architects, engineers, contractors, and specialists to achieve common goals, prevent design changes, and improve the client’s technical understanding.	[24,77]
Optimization of Value/Cost Ratio for the Client	Identifying needs through regular dialogue, optimizing costs and schedules, avoiding scope changes, and ensuring client satisfaction.	[24,77]
Exploration of Alternative Solutions	The evaluation of options by a design team based on project requirements and preferences, promoting participation and considering diverse perspectives.	[75]
Effective Teamwork	Collaboration in a project team where members are committed to goals and values, led by the most qualified individuals, with defined roles and open communication.	[75,77]
Identification and Minimization of Non-Value-Added Activities	Recognizing necessary activities where some add value, and others do not, by mapping the value flow to eliminate or minimize non-value-adding activities.	[74,77]
Anticipation and Rapid Problem-Solving	Based on foreseeing problematic situations, identifying patterns or difficulties that may arise in the future, and, if they occur, quickly and effectively finding collaborative solutions.	[74,77]
Commitment Management	Ensures responsible fulfillment of agreements and tasks, ensuring efficiency and punctuality in work environments.	[74,76,77]

Table 6. *Cont.*

Functionality	Definition	References
Creation of New Workflows	Designing and implementing efficient procedures or systems for performing specific tasks or processes within an organization.	[62,77]
Complexity Reduction	Aims to simplify tasks, processes, and complex systems to make them more straightforward and understandable.	[66,77]
Customer Value Focus	Focuses on creating value by eliminating superfluous activities, promoting collaboration among stakeholders, defining value, and committing to the client to establish value goals.	[24]
Continuous Improvement	The constant pursuit of perfection through regular application of Lean concepts, measurement, analysis, and practice adjustments to optimize efficiency and customer satisfaction.	[24,77]
Reliable Information Flow (Consistent and Accurate)	Timely and accurate data delivery between teams, avoiding causes of design changes, ensuring reliability, and eliminating unnecessary or incorrect information.	[24]
Communication Instances	Different moments or events where interaction occurs within a work team, including the exchange of information.	[62,74]
Reduction of Workload on Individuals	Reduction in the number of tasks or activities assigned to an individual or a work team.	[67]
Prevention of Project Delays	Additional time periods are incorporated after processes with variable outcomes to serve as scheduling buffers and prevent project delays.	[77,80]

3.2.2. Functionalities According to Management Principles

Understanding managerial classifications to manage any organizational function or task [78]. Therefore, the functionalities were grouped according to the five management categories: planning, organizing, directing, controlling, and staffing [78], as presented in Table 7, with the last category excluded. This classification clarifies the usefulness of these functionalities within an organization from the building design perspective.

Table 7. Functionalities of Lean Design tools classified into 5 management functions.

Planning	Organizing	Directing	Control	Global
Global collaborative scheduling	Design-construction coordination	Open and transparent communication	Data recording and analysis	Visual communication
Phase collaborative scheduling (Pull planning)	Complexity reduction	Identification and minimization of losses	Constraint analysis	Optimization of value/cost ratio for the client
Lookahead collaborative scheduling	Stakeholder involvement	Anticipation and rapid problem-solving	Root cause analysis of problems	Focus on value for the client
Weekly collaborative scheduling	Effective teamwork	Consistent and accurate information flow	Progress evaluation against the schedule	Continuous improvement
Exploration of alternative solutions	Commitment management	Reduction of team workload	-	Prevention of project delays
Creation of new workflows	Communication instances	-	-	-

In analyzing the functionalities of Lean tools within the building project design process, no functionality that corresponded to the “staffing” category was identified. Therefore, this category was excluded from Table 6. Instead, a new category called “global” was incorporated, which integrates the functions of planning, organizing, directing, and controlling, thus encompassing the fundamental principles of management. This characterization

provides a general overview of the functionalities, which are now grouped into five classifications, facilitating a comprehensive approach to evaluating the benefits and limitations of each Lean tool in the context of building design.

3.2.3. Functionality of Lean Tools in the Building Design Process

Table 8 presents a list of functionalities previously defined in Table 5 and the tools identified to address these functionalities. The table was developed using information from the literature review, complemented by expert opinions. In cases where 62.5% of the experts considered that one or more tools cover a specific functionality, it has been marked with an asterisk. This allows for an analysis of the functional coverage of Lean tools in building project design, supporting the evaluation process of their benefits and limitations.

Table 8. Lean Design tools functionalities (* expert judgment).

Functionality	Tools
Global collaborative scheduling	TVD [59], ADM [64], LPS [67,77] [*], BIM [*], VM [*]
Phase collaborative scheduling (Pull planning)	LPS [77] [*], BIM [*], LAP [*], VM [*], JIT [77]
Lookahead collaborative scheduling	LPS [77] [*], BIM [*], LAP [*], VM [*]
Weekly collaborative scheduling	ADM [*], LPS [71,77] [*], LAP [*], VM [*]
Exploration of alternative solutions	TVD [*], SBD [62,77] [*], CBA [63] [*]
Creation of new workflows	BIM [*], DSM [70], IPD [*], VSM [62], ICE [*], A3 Report [*]
Design-construction coordination	TVD [60,77] [*], SBD [77], ADM [*], LPS [67], BIM [62] [*], DSM [*], VM [*], IPD [61,77],
Complexity reduction	SBD [77], ADM [64] [*], LPS [68], BIM [68,77] [*], DSM [66] [*], VM [70] [*], IPD [77], VSM [62,77], ICE [*], A3 Report [*]
Stakeholder involvement	TVD [57,59,77] [*], SBD [62,77], CBA [47], ADM [64], LPS [67,77] [*], BIM [62] [*], LAP [*], VM [70], IPD [77] [*], VSM [62,73,77], ICE [*], JIT [77]
Effective teamwork	TVD [57,59] [*], SBD [77], CBA [63] [*], ADM [64] [*], LPS [67,68] [*], BIM [*], DSM [66], LAP [*], VM [70], IPD [61] [*], VSM [62], ICE [62], JIT [77]
Commitment management	SBD [62], ADM [*], LPS [67] [*], LAP [45,69] [*], VM [70], IPD [*],
Communication instances	TVD [*], SBD [62], CBA [63], ADM [64] [*], LPS [67] [*], BIM [62] [*], LAP [69] [*], VM [70] [*], IPD [*], VSM [62], ICE [62], A3 Report [*]
Open and transparent communication	SBD [77], CBA [63], ADM [64] [*], LPS [67] [*], BIM [77] [*], DSM [67], LAP [*], VM [*], IPD [61,77] [*], VSM [62,74,77], ICE [62] [*], A3 report [*], JIT [77]
Identification and minimization of losses	LPS [20] [*], BIM [62] [*], VM [70], VSM [62,74,77] [*], 5S [*], 5why [*], JIT [*]
Anticipation and rapid problem-solving	ADM [*], BIM [*], VM [77], IPD [*], ICE [*]
Consistent and accurate information flow	LPS [24], BIM [62] [*], DSM [66] [*]
Reduction of team workload	ADM [67], LPS [*], BIM [68], LAP [45,69], VSM [*], ICE [*],
Data recording and analysis	TVD [60,77], ADM [*], LPS [77] [*], BIM [20] [*], VM [70], VSM [74,77], A3 Report [79,81]
Constraint analysis	ADM [*], LPS [68,77] [*], BIM [*],
Root cause analysis of problems	LPS [68], A3 Report [*], 5 why [76] [*]

Table 8. Cont.

Functionality	Tools
Progress evaluation against the schedule	LPS [67] [*], LAP [45,69]
Visual communication	LPS [66], BIM [20,62] [*], DSM [66], VM [70] [*], VSM [62], ICE [62], A3 Report [81] [*], 5S [77]
Optimization of value/cost ratio for the client	TVD [57,77] [*], SBD [62] [*], BIM [77], IPD [61] [*]
Focus on value for the client	TVD [57,58] [*], SBD [62] [*], CBA [63], BIM [20], IPD [61,77] [*], ICE [*]
Continuous improvement	TVD [59], SBD [77], ADM [*], LPS [77] [*], BIM [*], LAP [*], VM [77], IPD [77], VSM [62] [*], A3 Report [*], 5S [*], 5 Why [*]
Prevention of project delays	ADM [*], LPS [77] [*], DSM [*], LAP [*]

To analyze Table 8 further, Table 9 is presented, which includes the tools used in building project design and the percentage of functionalities each tool covers based on the literature review and expert opinions. The percentage difference between both sources is also shown, allowing for identifying key discrepancies or alignments between theory and professional practice.

Table 9. Comparison of Lean Design tools functionalities.

Building Design Tools	Functionalities According to Literature (%)	Functionalities According to Experts (%)	Difference Between Literature and Experts (%)
Last Planner System (LPS)	65%	62%	4%
Building Information Modeling (BIM)	50%	62%	−12%
Agile Design Management (ADM)	27%	46%	−19%
Linguistic Action Perspective (LAP)	15%	42%	−27%
Visual Management (VM)	42%	38%	4%
Integrated Project Delivery (IPD)	31%	38%	−8%
A3 Report	12%	35%	−23%
Integrated Concurrent Engineering (ICE)	15%	31%	−15%
Target Value Design (TVD)	31%	27%	4%
Design Structure Matrix (DSM)	19%	19%	0%
5 Why	15%	15%	0%
Value Stream Mapping (VSM)	46%	12%	35%
Set-Based Design (SBD)	42%	12%	31%
Choosing by Advantage (CBA)	23%	12%	12%
5S	4%	8%	−4%
Just In Time (JIT)	4%	4%	0%

A comparison was made between the perception from the literature and expert opinions regarding the functionalities of Lean tools in the design of building projects. A notable consensus was identified between both sources in the evaluation of LPS and BIM, highlighting these tools as having the broadest functionality coverage. However, a slight discrepancy was observed in the case of LPS, with a 4% difference, and a larger one in BIM, with 12%, suggesting that experts attribute more functionalities to these tools than reported in the literature. Additionally, Agile Design Management exhibited a critical difference in opinion, as experts assigned it 19% more functionalities than documented in the literature, indicating a significant gap between theory and practice in its application.

One of the tools with the greatest discrepancy between literature and expert opinions is VSM. While the literature attributes it with 46% coverage of functionalities, experts

consider it to cover only 12%. This disparity is also evident in SBD, where studies indicate a 27% functionality coverage, but experts assign it 46%. Other differences, though less pronounced, were found in tools such as CBA, TVD, and VM, where the literature attributes them with greater functional coverage than perceived by specialists. Conversely, from the experts' perspective, tools like BIM, LAP, IPD, A3 Report, ICE, and 5S are considered more versatile and cover more functionalities than indicated in the literature.

Finally, some tools showed total consensus between both sources, notably the Design Structure Matrix (DSM), covering 19% of functionalities, 5 Whys with 15%, and JIT with 4%.

When analyzing the tools and their functionalities based on the five management principles, different levels of coverage were identified in each area. In the planning category, the most prominent tools were BIM, LPS, and VM, which covered four out of six identified functionalities. Regarding organization, BIM, ADM, IPD, LPS, and LAP stood out as the most relevant tools. LPS, BIM, and ICE demonstrated greater alignment with the required functionalities in the directing category. Once again, LPS, BIM, and ADM were identified as the main tools for control. Finally, in a global evaluation, tools such as TVD, ADM, BIM, LPS, LAP, IPD, and A3 Report demonstrated a strong capacity to meet administrative functionalities in building project design.

Table 10 presents the combinations of tools along with their respective percentages to identify which tool combinations achieve the highest functionality coverage from the experts' perspective.

Table 10. Combinations of tools based on functionalities.

Combinations	Covered Functionalities
LPS-BIM	88%
ADM-BIM	88%
BIM-LAP	81%
BIM-IPD	81%
LPS-A3 Report	81%
BIM-VM	77%
LPS-VM	77%
ADM-LPS	73%

Most research on Lean applied to design focuses on discussing tools individually, such as LPS, TVD, SBD, and BIM [14,20,21]. However, Table 8 presents a perspective where these tools can be combined efficiently. When tools complement each other, they can cover more functionalities, as seen in the cases of BIM-LPS or BIM-ADM.

The literature suggests that to increase productivity in the design phase, it is essential to strengthen the following five key areas: creating a consistent and reliable information flow [67,82], optimizing value generation [83,84], fostering effective collaboration among stakeholders [67,79], achieving perfection through continuous improvement [85], and integrating design with construction [24]. These improvements can be achieved through various Lean practices and tools specifically designed for this purpose [24]. Based on the conducted analysis, it is concluded that the tools that can significantly enhance these five areas are BIM, LPS, and ADM, given their impact on optimizing building project design.

During the design phase, it is crucial to use one or more Lean tools that, when combined with the BIM model, help optimize key areas such as planning, control, decision-making, and team management [86]. This is achieved by identifying non-value-added activities and improving processes for later construction stages [86]. In this context, BIM offers a broad range of functionalities that can generate highly efficient results in the design phase when combined with complementary tools.

For instance, automating LPS, which plays a key role in planning and progress control, could enhance its effectiveness when integrated with BIM, particularly through 3D visualization of elements. Implementing additional methods within the system would provide the necessary information to optimize workflow holistically [86]. Additionally, the importance of combining complementary tools becomes evident, as this maximizes their impact on the design process.

3.3. Benefits and Limitations of Lean Tools in Design

Table 11 presents a series of benefits and limitations associated with BIM, LPS, and Agile Design Management (ADM) in the building design process. These tools have been evaluated based on their functionalities from the perspective of experts, who highlight their ability to optimize various design stages while identifying their potential limitations in specific contexts.

Table 11. Benefits and limitations of Lean tools in the building design process.

Tools	Benefits	Disadvantages and/or Limitations
Agile Design Management	+ Since everything is divided into small packages, there is more control over[-2ex] the tasks. + Small packages allow for improving the detail of each task. + Small packages help to visualize and eliminate errors. + Transparency in the design work. + Its principles help optimize the design process through iterations, continuous reviews, and collaboration.	- It requires a change in mentality to work with small packages. - People need to be trained due to a lack of knowledge about the tool. - It is necessary to have a team that is open to integrating new processes and resources.
Last Planner System (LPS)	+ Delivers reliable equipment performance information. + Encourages interaction, cooperation, and collaboration among the work team. + It can improve project planning. + The team obtains results in a timely manner + Quality work is obtained from the team. + Allows tracking of the execution of each milestone. + Allows tracking of the team's commitments. + Allows for greater monitoring and control of the project. + Can improve scheduling, allowing deadlines to be met in a timely fashion + It can improve cost control through indicators. + Detects problems early. - Efficient use of resources by optimizing the planning process.	- Requires cultural changes in the team. - A manual process for merging and data collection must be performed. - Difficulty in implementing the methodology and adapting projects to it. - The tool is limited to specific stages, such as on-site management. - Contains many levels of planning - Discipline and knowledge are required to apply the methodology
Building Information Models (BIM)	+ Can improve the team's accuracy and consistency	- Cost, technology, training, education, and infrastructure challenges.

These approaches, whether ADM, LPS, or BIM, share several fundamental principles. One key aspect is their ability to identify problems early during the design and planning stages, allowing them to be addressed before they become significant obstacles. Additionally, each tool emphasizes the importance of collaboration and teamwork, highlighting that exchanging ideas and cooperation among team members is essential for improving project efficiency and quality.

One of the main limitations of adopting Lean tools in building design projects is resistance to change and a lack of knowledge about these methodologies, which requires a shift in mindset among personnel. Effective implementation demands training in these tools and an adaptation process to facilitate their integration into workflows. This challenge is not exclusive to a particular tool but applies to all.

Moreover, some tools require specific technical skills, such as proficiency in specialized software, which necessitates additional training or external courses, limiting their adoption in cases where experience or resources are lacking. Another common disadvantage is the need to effectively adapt each tool to the characteristics of the project, which can pose significant challenges, especially in terms of time and other resources required for proper implementation.

3.3.1. Benefits and Limitations of Agile Design Management

To contrast the experts' opinions reflected in Table 11, a series of interviews were conducted with building design professionals, including architects, structural engineers, specialty engineers (MEP), and representatives from the real estate sector. The specialty engineers (MEP) agreed to highlight several advantages of Agile Design Management (ADM) presented in Table 11, particularly the efficiency in breaking down tasks into smaller packages, allowing for more detailed and faster work while fostering collaboration. However, some professionals questioned the claim that this tool ensures the complete elimination of errors. Regarding the disadvantages, they noted the need for a mindset shift and training, noting that this transformation depends on individuals and the tool itself. Additionally, they recognized time and resource constraints as limitations for implementing ADM, including team training and the required collaborative infrastructure.

Architects agreed that breaking down work into smaller packages enables greater control and detail in design tasks, facilitating the identification and correction of errors. However, there were discrepancies regarding whether this subdivision truly helps visualize and eliminate all errors, as the human factor may cause some to go unnoticed. They also noted that while Agile Design Management (ADM) does not fully guarantee transparency, it does promote better coordination among team members. They acknowledged the need for a progressive mindset shift and training to effectively implement this tool, especially in large offices with significant staff and departments. Furthermore, they emphasized the importance of balancing the overall and detailed views of the process, highlighting the need for a coordinator to oversee the proper execution of tasks and ensure the successful implementation of ADM.

Most real estate professionals recognized the benefits of ADM, emphasizing the usefulness of breaking down tasks into smaller packages for greater control and a higher level of detail. However, they warned that the effectiveness of this strategy depends on how specifically these packages are defined. While they agreed that working with smaller packages facilitates the identification and correction of errors, they also pointed out that it does not guarantee their elimination, as they consider human error a constant in the process. Concerns were raised regarding the transparency of the design process, as it is difficult to control all aspects of these packages, potentially compromising transparency. There was no consensus on whether iterations optimize the design process, as some perceived them as

potentially limiting or slowing progress; however, all agreed that ADM promotes better team collaboration. Regarding disadvantages, they acknowledged the need for a mindset shift, training, and openness to new processes and resources. They also emphasized that the time and resources required for training and mindset changes represent critical challenges, especially regarding costs and personnel availability.

Structural engineers agreed on the presented benefits and pointed out that the effectiveness of breaking tasks into smaller packages largely depends on the specific nature of each task. They highlighted that this subdivision does not always allow for effective identification and correction of errors, as some may go unnoticed if different people are responsible for different tasks, increasing the likelihood of human errors. There were differing views on whether the necessary mindset shift to work with smaller packages is an inherent tool limitation or depends more on individuals' willingness. There was general agreement on the need for training and teams to be open to new processes and resources.

Additionally, these professionals expressed concerns about the potential loss of the team's overall focus when working with small packages, as this could lead each person to focus solely on their task, disconnecting from the project's common goal. In this regard, they emphasized the importance of maintaining a global vision to apply task division successfully. They also noted that excessive subdivision could make it difficult to associate packages with the necessary resources, affecting the efficiency and flow of the design process.

Professionals from various fields agreed that ADM offers significant advantages, including breaking tasks or deliverables into smaller packages for greater control, detail, and clarity. They also highlighted that this tool can improve collaboration and coordination within the work team. These advantages align with the findings of Demir and Thesis [67], who emphasize benefits such as interdisciplinary coordination, collaboration, control through small packages, and problem communication when detecting errors. This demonstrates a consensus on the advantages of ADM among experts, professionals, and the literature.

However, most professionals do not believe the tool guarantees the complete elimination of errors due to the inevitability of human errors in the process. There was also general agreement on the disadvantages of ADM, particularly regarding the training and resources that companies or work teams must allocate for its effective implementation. Additionally, they repeatedly pointed out resistance to change as a significant barrier due to workers' low tolerance for modifications in their work methods [87,88]. To address this resistance, they stressed the importance of building trust, maintaining effective communication, and exercising clear leadership [87–89].

3.3.2. Benefits and Limitations of Last Planner System

MEP professionals collectively recognize the key advantages of LPS highlighted in Table 11, particularly valuing its ability to facilitate precise planning that leads to real and timely results while reducing costs through effective time management. They also agree on the importance of defining phases and deliverables from the early stages of the project, contributing to maintaining order and clarity in the design process. Regarding disadvantages, they acknowledge that a mindset shift is necessary to successfully adopt LPS and emphasize the need to improve the data integration process, which is currently performed manually. They also stress the importance of gradually adapting projects to the tool for effective and sustainable implementation.

Architects recognize several key advantages of LPS, especially its usefulness in improving control and anticipating planning issues. However, there are discrepancies regarding certain advantages attributed to this tool, such as the reliability of information on team per-

formance, effective cost control through indicators, and the timely delivery of results; some professionals believe that LPS does not necessarily guarantee these aspects. Regarding disadvantages, they agree on the need for a mindset shift, the incorporation of planning levels, and the discipline required for effective implementation. There are differing opinions on whether the manual data integration process is a disadvantage; some consider it beneficial as it allows for planning review and error detection. They also reject that LPS only applies on-site, as they have also used it in the design phase. Finally, they highlight the importance of having a coordinator to lead and oversee planning to ensure that the mentioned benefits are effectively achieved.

In the real estate sector, professionals involved in adopting LPS show a consensus on its benefits, although they differ in their perception of the tool's implementation. Regarding advantages, all recognize LPS's potential to improve project management, though some question its ability to provide reliable information on team performance or guarantee timely results. While some professionals emphasize the need for a mindset shift and manual processes for data collection, others believe that implementation should be less complicated with proper training and expert guidance. There is agreement on the importance of coordination and discipline in executing the system, though opinions vary regarding the complexity of its adoption.

When analyzing LPS, structural engineers express diverse opinions regarding its ability to ensure work quality and meet deadlines, as these results are not always consistently achieved. While some consider that this methodology does not guarantee quality or precise timelines due to the influence of external variables and reliance on the people involved, others highlight its advantages, such as tracking team commitments and optimizing planning. There is a consensus on the need for training and discipline for an effective LPS implementation, although opinions differ regarding the difficulty of integrating this methodology into different types of projects.

Among professionals from the five consulted fields, several advantages of LPS are recognized, such as commitment control, milestone tracking, and overall project management, facilitating proper progress monitoring. Most professionals emphasize LPS's ability to detect issues early, though they point out that it does not allow for predicting all potential problems. However, there are discrepancies regarding the reliability of information on team performance and the feasibility of certain aspects, such as the manual data integration process. Despite these differences, all agree on the importance of gradually adapting projects to this methodology for a successful and sustainable implementation.

The key advantages highlighted by experts are supported by the literature, which defines LPS as a tool that helps design teams reduce uncertainty [90], achieving this through structured planning and constant process monitoring. Additionally, LPS decreases workflow variability [71,91,92] due to the continuous control exercised throughout the planning phase. Furthermore, this tool improves the reliability of task scheduling at the weekly level, ensuring firm resource commitments from the last planners and refining tasks to guarantee their completion [71,91,92].

However, discrepancies emerged among professionals regarding the supposed limitation of LPS to on-site applications, as not all agree with this restriction. The literature points to a lack of LPS implementation in real design cases, as some designers resist adopting the tool in this phase [86]. This point was debated among professionals, who noted that resistance to change is common, especially when companies do not perceive clear value in the tool during the design phase, as many believe its use is exclusive to the construction phase.

3.3.3. Benefits and Limitations of BIM

MEP professionals agree that BIM is valuable for preventing errors and improving information management in building projects. However, there are discrepancies regarding BIM's ability to achieve a complete digital twin and its impact on visual communication. Some question whether automation enhances team consistency or significantly saves time, although they acknowledge its capacity to reduce miscoordination between specialties and detect issues early.

Architects doubt whether BIM improves team consistency and whether automation represents an effective time-saving solution, as they believe human error remains a constant factor. Nonetheless, they appreciate that BIM allows all team members to work on the same model, reducing miscoordination between specialties, though they emphasize that effective communication remains essential. They also agree that BIM facilitates early detection of clashes, though they admit that not all issues can be identified at this stage, as some tend to arise during construction. Regarding disadvantages, most professionals recognize the challenges associated with the costs and infrastructure required for BIM implementation but highlight that it represents a valuable long-term investment. A key insight is that they do not consider proper 3D model management as a disadvantage, arguing that the presence of a BIM coordinator mitigates this difficulty by ensuring model control and accuracy throughout the process.

Real estate professionals largely agree on the advantages of BIM but point out some critical aspects. One of these is that the methodology does not directly improve team consistency, as this depends on each individual's work pace. Additionally, while they appreciate BIM's automation, they warn that it can make detecting and correcting certain errors more difficult, as users may become overly dependent on the software. They note that coordination between specialties is not always achieved, especially if users are not sufficiently proficient with the software. They also identify two areas of conflict. The first is resistance to change, which tends to arise when management or decision-makers do not perceive the value of implementing BIM. However, workers will adopt the methodology if it becomes a company requirement. The second is the notion that an internal BIM team is necessary, which they consider unnecessary, as this service is frequently outsourced today.

Structural engineers agree with many of BIM's advantages, which are mentioned in Table 11. They recognize that the tool reduces miscoordination, allows for early clash detection, and is an effective visual resource for communication. However, there are discrepancies regarding whether BIM improves consistency or automatically unifies criteria, and some believe that cost savings depend on the company's level of maturity in using BIM. Regarding disadvantages, there is consensus on the need for a BIM manager or coordinator and the challenge of integrating structural design software with BIM platforms. They also agree that specialized training and a uniform level of knowledge within the team are required to ensure effective use of the tool.

Professionals from various sectors agree on several aspects regarding BIM's advantages and disadvantages, which are presented in Table 11. Most recognize its ability to reduce miscoordination between specialties and detect issues early in projects. However, there are discrepancies regarding whether BIM improves team consistency or saves time through automation. There is a consensus that BIM presents significant implementation challenges, as it requires training, resources, and a gradual shift in team mindset. The literature supports BIM's impact on the design phase of construction projects, emphasizing its ability to foster collaboration and improve communication among design team members [86]. This confirms the collaboration- and communication-related advantages mentioned in Table 11, supported by experts, professionals, and previous

studies. However, the limitations noted by [86], such as resistance to change, lack of knowledge about the tool's use, the need for specialized software, and the required technical training, align with the disadvantages highlighted by experts and acknowledged by most professionals.

4. Conclusions

This study presents 12 Lean tools applied in the building design process, identified through a literature review. The collected evidence demonstrates the application or recommendation of these tools in building design projects. Experts confirmed the use of these tools during this stage of the process. Among both sources, tools such as LPS, BIM, VM, and ADM stand out, as they show the highest evidence of application in specific cases and the lowest variability in recommendations. Experts proposed four additional tools, increasing the total number of Lean tools identified for the building design process to 16.

Each tool was analyzed to determine if it fulfilled at least one function in the design phase. A comparison between the literature and expert opinions on the number of functions each tool can cover showed that the most valued tools were BIM and LPS, with unanimous agreement from both sources. The tools with the greatest positive discrepancies between the literature and expert opinions were ADM and LAP. At the same time, VSM and SBD showed the greatest negative discrepancies, raising questions about their functionalities. When evaluating functionalities based on the classification of the five management principles, the most significant tools from an organizational perspective, according to experts, were BIM, LPS, and ADM. This is because these tools encompass a broad range of planning, organization, direction, and control functions.

The tools that best complement each other in terms of the number of functions they can cover are BIM and LPS. This duo has great potential, as LPS is essential for design planning and control, and if automated and combined with BIM, it could enhance workflow with 3D visualizations and optimize project processes [86]. Another notable duo is ADM-BIM, as Agile Design Management covers functionalities similar to the Last Planner System. Together, these two duos cover 88% of the identified functions. Based on this analysis, the best tools for use in the building design process are the Last Planner System, Agile Design Management, and Building Information Modeling, as they contribute to maximizing value, focusing on the client, and improving information flow [21]. The benefits and limitations of LPS, BIM, and ADM were assessed. The findings suggest that professionals support Agile Design Management, particularly regarding breaking tasks into smaller packages to enhance control and clarity, ultimately improving collaboration. These findings align with Demir and Theis [67]. However, limitations to implementing the tool include the need for training, resources, and resistance to change.

As supported by experts, the key advantages of LPS align with the literature: it reduces uncertainty [90] through precise planning and monitoring. It decreases workflow variability [71,91,92] due to continuous control in planning. It also ensures reliability in weekly planning and resource commitment [71,91,92], refining tasks to guarantee completion. The literature highlights a lack of LPS application in real design cases due to designers' resistance during this phase [87]. Professionals agree that resistance to change is a key barrier, especially when companies fail to perceive the tool's value at this stage, mistakenly considering it relevant only for the construction phase.

Experts and professionals agree that Building Information Modeling enhances coordination, early problem detection in projects, information management, visualization, and control. They all recognize the implementation challenges, such as the need for training and team mindset shifts. The literature supports BIM's positive impact on

collaboration and communication in design projects [86], consistent with expert and professional opinions. The limitations identified by [86], such as resistance to change and the need for specialized training, align with those mentioned by experts and most professionals. The sustainability of this research lies in its methodological replicability and potential for future extension. The systematic identification, validation, and functional mapping of Lean tools provide a foundation that can be adapted to other design contexts and project types. Moreover, the insights obtained through expert involvement and tool interaction analysis offer a long-term reference for practitioners and academics seeking to implement or refine Lean Design strategies. This study opens avenues for future research, including longitudinal case studies to evaluate the actual impact of tool combinations over time, the integration of digital platforms for Lean Design monitoring, and the exploration of Lean-BIM-Agile synergies in diverse construction environments.

This study presents several limitations that should be acknowledged. First, the analysis of the relationship between Lean tools and their associated functionalities was based on binary mappings validated through expert consensus rather than continuous numerical ratings. As a result, advanced multivariate techniques, such as Principal Component Analysis (PCA), factor analysis, or Structural Equation Modeling (SEM), could not be applied within the current methodological framework. Future research should consider the development of a structured survey instrument that captures quantitative assessments of the degree to which each tool supports specific functionalities, allowing the use of dimensionality reduction methods and statistical modeling to strengthen explanatory power. Second, although four new Lean tools were incorporated based on expert recommendations, no evidence regarding their specific benefits or drawbacks was found in the literature or mentioned by the consulted experts. Additionally, not all benefits and limitations reported in the literature for the twelve previously known Lean tools were validated during the expert consultation phase, which may limit the completeness of the functional assessment. Third, the qualitative validation component was constrained by a reduced number of participants. Although the original plan involved interviewing five professionals per design role, only fifteen design professionals were ultimately consulted through semi-structured interviews. This smaller-than-expected sample may affect the generalizability of the findings and highlights the need for broader practitioner engagement in future validation studies. Furthermore, although the study included participants from diverse professional backgrounds, it did not statistically examine whether roles such as architects, engineers, or consultants perceive the advantages and disadvantages of Lean tools differently. Future research could apply inferential techniques, such as Chi-square tests or logistic regression models, to analyze whether professional profile significantly influences the perception and adoption of tools like BIM, LPS, or ADM. Incorporating this type of analysis would enrich the understanding of sociotechnical barriers and accelerators in the practical implementation of Lean-based design management. Finally, this study did not explore in depth the interaction between complementary tools, such as BIM-LPS or BIM-ADM, in practical design environments. Future research should investigate these interactions through longitudinal case studies or pilot implementations to evaluate their combined impact on collaboration, decision-making, and value generation in the building design process.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app15095137/s1>, Supplementary Material. Informed consent to participate in an interview for the development of a research project.

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