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LEAN-BIM SYNERGY IN THE CONSTRUCTION DESIGN PHASE: AUTO-GENERATION AND EVALUATION OF THERMAL ALTERNATIVES

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ABSTRACT

This study explores the integration of Lean principles with Building Information Modeling (BIM) to enhance decision-making in the relatively unexplored field of thermal design for construction projects. Recognizing the limitations of current design processes, characterized by insufficient alternatives and a lack of team collaboration, we introduce a new decision-making tool. This tool centers on a breakthrough framework and algorithm that bridge BIM with Lean techniques. It facilitates the automatic generation and evaluation of insulation material alternatives for residential buildings by integrating the Pleiades software database and Industry Foundation Classes (IFC) BIM data. Our study details an automated process for selecting insulation materials through an iterative, criteria-based approach that systematically identifies the three most viable solutions using Set-Based Design methods. It then selects the optimal one by examining and evaluating their criteria according to the project's needs based on energy efficiency, profitability, and sustainability through the Choosing By Advantages method. Additionally, by incorporating Big Room and BIM, our tool promotes enhanced communication and collaboration from the outset of the design phase, underscoring the significance of this integration in automating and optimizing thermal engineering projects.

KEYWORDS

Lean Construction, Set-based Design, Choosing By Advantages, Building Information Modeling, Big Room.

INTRODUCTION

In the construction industry, the design phase is the foundational stage where a project's trajectory toward efficiency and sustainability is determined (Bello et al. 2021). This phase is more than just the inception of architectural concepts, it is the period when the crucial elements of scope, cost, and time are precisely defined. Any discrepancies at this stage can have a significant effect, causing repercussions throughout the construction lifecycle (Yusof et al. 2015). Therefore, a meticulous focus on the design phase is not just prudent, it's imperative for the successful execution of any construction project (Herrera et al. 2021a; b).

In the last decade, several studies have highlighted the pivotal role of the synergy between Lean principles and BIM in enhancing the efficiency of construction projects, particularly during the design phase (Eldeep 2022; Herrera et al. 2021b; Sajedeh et al. 2016). Initially, it is crucial to understand the individual contributions of both Lean and BIM. Lean construction

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focuses on eliminating waste and optimizing processes, while BIM provides a detailed digital representation of the project, enabling better planning and visualization (El Mounla et al. 2023; Sacks et al. 2010).

When these two methodologies converge, they create an efficient tool for improving decision-making. Decision-making is a critical aspect of the design phase, as it sets the foundation for the entire project. Decisions made during this phase have far-reaching implications on cost, duration, and overall project quality. By integrating Lean's efficiency-driven approach with BIM's comprehensive, visual, and data-rich models, stakeholders can make more informed, precise, and timely decisions (El Mounla et al. 2023; TUDublin and Sheramn 2019).

However, traditional design practices often encounter challenges due to their linear and segregated nature, leading to communication breakdowns, resistance to change, and costly design alterations down the line (Castañeda et al. 2023; El Mounla et al. 2023). These outdated methods inhibit flexibility and can be detrimental to the project's overall adaptability and success. Moreover, after conducting the literature, review we found that applying Lean/BIM synergy in the thermal field has not yet been explored. The significance of decision-making in the design phase cannot be overstated, as these early-stage decisions have lasting implications on all subsequent phases of construction. Informed, strategic choices are essential, shaping the project's aesthetics, functionality, economic feasibility, and regulatory compliance (Lee et al. 2012a; Rempling et al. 2019).

Set-Based Design (SBD) and Choosing By Advantages (CBA) are integral methodologies in construction and engineering that streamline decision-making and enhance project outcomes. SBD involves exploring a broad spectrum of design options and methodically narrowing them down to the most suitable solutions by eliminating less feasible alternatives (Castañeda et al. 2023; Sahadevan and Varghese 2018, 2019). This approach ensures comprehensive consideration of all relevant criteria from the project's inception, avoiding the premature exclusion of viable options. In addition, CBA complements SBD by offering a structured decision-making process that focuses on the comparative advantages of each option, ensuring decisions are both transparent and value-driven (Lee et al. 2012b; Mathern et al. 2018; Parrish et al. 2007). This integration is evident in complex construction projects, such as steel fabrication, where SBD's broad exploration of design alternatives including material properties and construction methods pairs with CBA's evaluative approach focusing on benefits like durability and ease of installation. This synergy optimizes decision-making, balancing feasibility with value, as exemplified in the work of (Parrish and Tommelein 2009).

In addition to these two methods, the Big Room is another Lean method that serves as a collaborative hub. It aims to bring together architects, engineers, contractors, and clients, to collectively plan, design, and manage the construction process (Fosse et al. 2017). Integrating BIM into this method significantly enhances interaction and understanding among these stakeholders. For example, a case study on a complex construction project shows how the Big Room served as the central coordination point. The project team used BIM to develop a comprehensive 3D model of the building. This model, accessible in the Big Room, allowed stakeholders to visualize the project in real-time, identify potential design conflicts early, and make informed decisions collaboratively (Fosse et al. 2017).

The research problem addressed in this study focuses on enhancing the decision-making processes for thermal engineers during the residential building design phase, particularly in selecting optimal insulation materials to achieve energy efficiency, sustainability, and high performance. The core challenges include the limited application of SBD in construction projects, which is constrained by the time and resources required for complex decision-making. This complexity arises from the need to evaluate various materials against numerous criteria and the necessity for improved collaboration among stakeholders, including architects and engineers. Additionally, integrating advanced technologies to streamline these processes is essential. To address these issues, our solution proposes a decision-making tool that integrates Lean methods with BIM. The process begins by integrating BIM within the Big Room to enhance collaboration and communication, thereby facilitating the identification of project goals and improving the flow of information for decision-making. Then this tool employs SBD to systematically explore insulation material alternatives from the Pleiades database and IFC files, facilitating the automatic generation of the top three insulation options. Subsequently, CBA is applied to evaluate these options and select the best insulation material, considering environmental standards like France's Environmental Regulations 2020 (RE2020). This innovative approach not only promotes sustainability by prioritizing materials that meet stringent environmental criteria but also broadens the thermal engineer’s perspective by considering a wider range of high-performance materials. This improves the design phase’s efficiency and effectiveness in construction projects, contributing to the broader goal of energy-efficient and sustainable building practices.

METHODOLOGY

In our study, we combined three distinct research methodologies to ensure a comprehensive and robust analysis: the Construction Research Approach (CRA), Systematic Literature Review (SLR), and Semi-Structured Interviews (SSI). Central to our methodology, CRA is an innovative approach aimed at creating new constructs or solutions specifically designed to address practical problems in the real world. It not only facilitates the development of tangible interventions but also enriches the theoretical framework within the field by bridging the gap between theory and practice (Piirainen and Gonzalez 2013). This approach is pivotal in guiding our research toward making significant practical and theoretical contributions. Complementing CRA, the SLR method allows us to thoroughly review and synthesize existing research, ensuring our study is deeply grounded in current academic discourse. Additionally, SSI provides nuanced insights by exploring diverse perspectives and experiences related to our research problem. Together, these integrated approaches enhance the reliability and relevance of our findings, promoting a balanced understanding that advances both practical applications and theoretical knowledge (Lukka et al. 2003).

To understand the methodology applied in our study, table 1 illustrates a structured process for integrating these methods together to construct our decision making tool. The journey begins with a SLR method where research is conducted to identify gaps and limitations in existing research (Monla et al. 2023). This step is essential for understanding the problem space and setting the foundation for application. Subsequently, SSI is conducted to provide depth and context to the research topic by gathering qualitative insights. This method helps in understanding user needs and collecting more specific requirements (Attouri et al. 2022).

Following this, the process involves discussions with experts to further understand and refine the requirements based on their expert knowledge and to validate the findings from the interviews (Attouri et al. 2022). This ensures that the frameworks created are grounded in practical realities and expert insights. With this information, the decision-making tool is developed based on the information gathered from the previous steps. Once developed, the tool is then validated by experts to ensure that it meets the intended requirements and standards before being released.

The last phase, which involves testing in real case study and then comparing the results obtained with the theoretical framework, is planned as a future step to evaluate the effectiveness of the decision-making tool in a practical and theoretical settings. This will provide an opportunity to observe how well the application performs in the real world and to identify any areas for improvement. The work completed thus far includes identifying research gaps, engaging with users and experts, as well as developing and validating the tool, setting a strong foundation for the final testing and implementation phase.

Table 1 Methodology applied in our research: A sequential process CRA to deployment of an efficient decision-making tool.

CRA Steps	Description	Action
1	Choose a practical problem with theoretical basis, focusing on under-analyzed or challenging topics.	SLR method was used to identify gaps and limitations.
2	Form a long-term collaboration with target organizations, establishing a team, funding, data access, and result dissemination agreements.	SSI was applied to provide depth and context to the research topic.
3	Gain thorough practical and theoretical understanding of the subject, analyzing the organization's current situation and theoretical research field background.	
4	Design and develop a theoretical and practical solution, emphasizing innovation and prototype development.	A framework was created, and a tool is being built based on the information gathered from the previous steps.
5	Implement and test the solution within the partner organization, typically through pilot sites.	The developed tool will be reviewed by experts to ensure it meets the intended requirements and standards. The tool is then tested in a real case study and compared with theory.
6	Reflect on the solution's scope and transferability by evaluating the success of test markets and considering broader applications. Then, identify and analyze the study's theoretical contributions and their impact on existing theories.	

To delve into details in applying SLR method, the operation starts by searching for articles related to SBD in the design phase of a construction project. A total of 31 papers between journals and conferences are obtained after filtering through the steps presented in Figure 1 (Schiavi et al. 2022; Xiao and Watson 2019). The process begins at the top with the identification of a collection of keywords, which are then used to conduct a search through Google Scholar and Scopus, resulting in the gathering of 416 papers, encompassing both articles and conference papers.

Following this initial collection, the inclusion and exclusion criteria are applied. This involves filtering the papers by reading their abstracts and titles, which helps to assess their relevance to the research topic. The process also includes eliminating duplicate papers to ensure uniqueness in the review. Additionally, the criteria specify retaining only those papers that are written in English.

After this filtration stage, a thorough reading of the full papers is conducted for the remaining ones to further evaluate their suitability for the review. This in-depth reading helps confirm that each paper contributes valuable information to the research topic. At the end of this process, 31 papers are retained for in-depth analysis and synthesis, indicating a significant reduction from the initial 416 papers, thereby focusing the review on the most relevant and high-quality research available. A deep knowledge in the domain was recognized that aids in identifying gaps and limitations within the SBD.

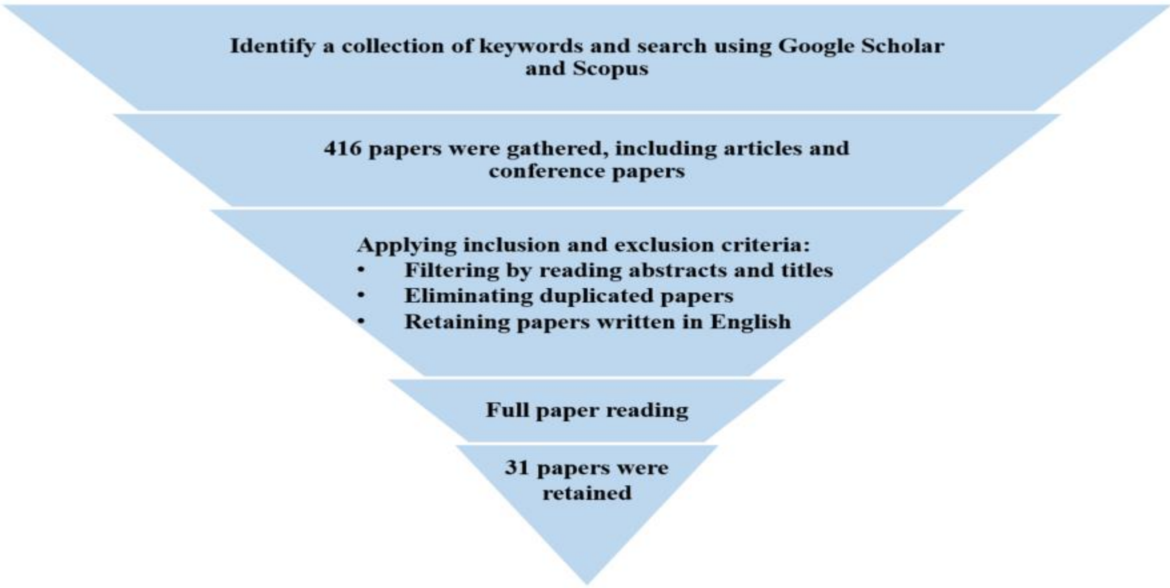

Figure 1 Systematic Literature Review procedure.

Critical limitations in applying SBD for thermal insulation selection in construction were identified: resource intensity, time-consuming analysis of all alternatives, decision complexity, information overload, integration challenges with tools like BIM, and difficulties aligning stakeholders. Therefore, our objective is to create a tool that simplifies the SBD process for thermal engineers by integrating Lean methods with BIM, thereby facilitating more efficient and effective decision-making in the design phase. Additionally, by automatically generating alternatives and selecting the best three solutions, we significantly decrease the time required for the procedure. Moreover, this approach aims to improve project outcomes by ensuring that the chosen insulation materials align with both project goals and environmental standards, such as France's 2020 Environmental Regulations (RE2020).

Recognized for its balance of qualitative and quantitative analysis, SSI involved detailed discussions with experts in construction design from both academic and professional backgrounds (Attouri et al. 2022). The selection of the 25 experts for our project focused on their expertise in the AEC field, specifically in Lean and BIM methodologies. This process began by engaging academic researchers to validate our framework, which incorporates Lean methods like SBD, CBA, and the Big Room with BIM, tailored for applications in the thermal field. These researchers, chosen for their contributions to Construction Blogs, International Group for Lean Construction (IGLC) conferences, and other scientific publications, brought a wealth of knowledge, with experience ranging from five to twenty years. Meetings with them were conducted via Teams and face-to-face during scientific events like the IGLC 2023 conference in France and symposiums in Brest. Following this validation phase, we expanded our inquiry to include professionals such as architects and thermal engineers, conducting surveys to delve into the practical challenges and requirements of applying our framework in real-world scenarios. Specifically targeting French thermal engineers ensured the relevance of our findings to the French work environment, with selected experts also well-versed in BIM to closely align with our framework's focus. The insights obtained from these experts are pivotal, not only for completing but also for testing our decision tool in actual case studies, thereby refining our framework's accuracy, ensuring it aligns with industry best practices, and enhancing its potential to improve the design phase of construction projects. Through this rigorous validation and feedback process, our framework has gained credibility and applicability, demonstrating its effectiveness in thermal field applications. The feedback from experts was very positive, indicating that our work is essential and significant.

Table 2 Survey questions assessing the effectiveness of SBD in thermal engineering decision-making.

Number of questions	Questions
1	How effectively do you think the SBD aids decision-making for thermal engineers?
2	How would you rate the framework's ability to tackle the challenges faced in applying SBD in thermal engineering projects?
3	Do you find that the integration of CBA and the Big Room concept significantly improves SBD's application in thermal engineering?
4	How feasible do you consider the application of this framework in practical thermal engineering scenarios?

RESULTS AND DISCUSSION

LEAN METHODS COMBINATION BENEFITS

Table 3 illustrates the integration and impact of SBD, CBA, the Big Room concept, and BIM on the design process. SBD, as introduced by (Lane and Woodman 2000), focuses on delayed decision-making and considers multiple design alternatives to minimize rework and suboptimal outcomes, a concept further refined by (Ballard 2000) through positive and negative iterations. Complementing SBD, CBA, as outlined by (Arroyo and Long 2018), systematically evaluates options based on their advantages, aiding in making more informed decisions. The Big Room concept further enhances this process by fostering collaborative decision-making among all stakeholders in a shared space, ensuring a comprehensive approach to design. Additionally, the synergy of these methods optimizes efficiency, with SBD aligning production to actual demand, CBA prioritizing initiatives for discussion, and the Big Room facilitating multidisciplinary collaboration. Furthermore, BIM's role, emphasized by (Lee et al. 2012b; Lee and Cho 2012), is crucial in supporting SBD through enhanced 3D visualization and data management, enabling rapid evaluation of alternatives and maintaining accuracy throughout the design process. This synthesis is the result of a detailed analysis of the literature conducted in the state-of-the-art phase. It combines insights from various articles we have studied. The table effectively demonstrates how these methodologies, when used together, enhance the design process, making it more targeted, and effective.

Table 3 Lean methods processes and their combination benefits with BIM.

Combining CBA with SBD	Enhancing Decision-Making: Adds structure to SBD's decision-making process. Focusing on Value: Highlights the value and benefits in SBD's design choices. Facilitating Stakeholder Agreement: Helps align stakeholders during the SBD process. Aiding Iterative Refinement: Can be used at various SBD stages for refining design solutions. Resolving Conflicts: Provides clear rationale for choosing solution over another in SBD.
Combining Big Room with SBD and CBA	Fostering Collaboration: Brings stakeholders together for collective decision-making. Providing Immediate Feedback: Speeds up the SBD and CBA processes through instant input. Offering Diverse Insights: Enriches decision-making with varied expertise. Ensuring Transparency: Makes the rationale behind decisions clear to all stakeholders. Facilitating Conflict Resolution: Allows for immediate discussion and resolution of disagreements.
BIM with Lean methods	Enhanced Decision-Making: The combination of BIM, SBD, and CBA facilitates data-driven decisions, optimizing project outcomes by allowing thorough evaluation and comparison of multiple design options. Improved Collaboration: Integrating BIM with the Big Room concept promotes real-time communication and teamwork among all stakeholders, leading to a unified understanding and alignment of project goals. Increased Efficiency: This approach streamlines the design and construction process, reducing rework and modifications by ensuring well-informed, efficient decisions from the start.

OUTCOMES OF SEMI-STRUCTURED INTERVIEWS AND THE DEVELOPMENT OF A DECISION-MAKING TOOL

On the other hand, our SSI, reinforce existing literature while also uncovering new insights specific to the thermal field. These interviews highlighted key motivators for adopting SBD and CBA in thermal projects. These motivators include reducing waste, boosting productivity, shortening project durations, and enhancing decision-making processes. Additionally, the concept of the Big Room, where project stakeholders collaborate closely, emerged as a significant factor in improving project outcomes. In light of these findings, our initial step was to create a framework, which we then refined into a decision-making tool improving the thermal field. This tool, incorporating principles of SBD and CBA, along with the collaborative approach of Big Room and BIM, aims to enhance decision-making in thermal design projects. It is designed to enable better decision-making at the beginning of the design process, resulting in a more efficient assessment of thermal solutions and strategies. By integrating these methodologies, the tool specifically addresses the distinct challenges and demands of thermal engineering. This enables professionals to make well-informed, effective decisions that are align with project objectives and sustainability criteria, while also featuring automated processes to further streamline its use.

Figure 2 demonstrates a comparison between the traditional thermal engineering process and our improved method, which applies our framework. Initially, thermal engineers would manually define parameters, select two solutions, simulate them using thermal software, and then choose the best option.

Our framework applies the Big Room concept, where, using BIM, the thermal engineer, architect, client, and other engineers can identify the project's goals and make suitable decisions. For example, they use the 3D visualization provided by BIM to identify solutions and solve problems. This approach improves communication and collaboration, enabling the team to make the right decisions necessary for advancing the design phase. Then, through coding, SBD is applied to explore all possible alternatives from the Pleiades database and information obtained from IFC files to automatically generating the top three insulation materials that meet the project's objectives and have the best performance. These three solutions are then integrated directly into three different IFC files and connected to Pleiades software for thermal simulation of the building. Subsequently, CBA is used to evaluate and select the best insulation material from these options after analyzing the results from Pleiades. This tool enhances sustainability by selecting insulation materials that meet environmental standards, such as RE2020. Additionally, by testing all possible alternatives, it provides a broader vision for the thermal engineer, aiding in the selection of better insulation materials that may offer superior performance. By applying Lean methods in conjunction with BIM, we create more innovative and efficient thermal design solutions, thus elevating the overall effectiveness of the design phase in construction projects, a key factor in achieving energy efficiency and sustainability in buildings.

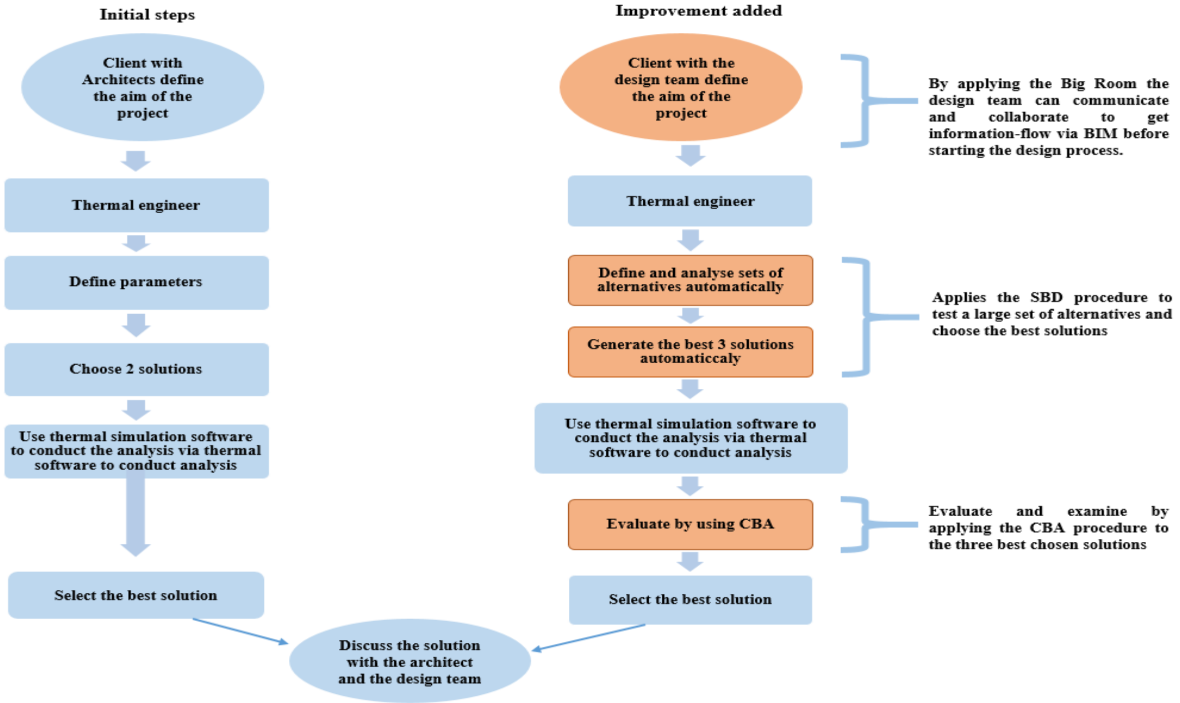

Figure 2 Traditional framework (left) versus Proposed framework (right) (with the orange rectangle indicating the additional value our framework provides).

AUTOMATING PROCESSES USING THE R STUDIO PROGRAM

To delve into the specifics of our work and the creation of the automation process, figure 3 illustrates a flowchart that outlines the procedural code for a thermal engineering application. The process initiates with the crucial step of "Identifying parameters", involving a strategic combination of data from both the Pleiades software and IFC BIM models. This integration of two distinct data sources is essential for accurately identifying relevant attributes and uncovering potential correlations. By leveraging the strengths of Pleiades and IFC BIM, we aim to develop a comprehensive understanding of the parameters that will guide the "Generation of sets of alternatives" for insulation materials. This approach ensures a thorough and nuanced analysis, setting a strong foundation for the subsequent stages of the process. Once these sets are created, the "Start the process" step initiates, where insulation material is selected based on the engineer's criteria.

If the chosen material "Complies with the requirements" such as thermic conductivity, CO2 emission, density… the process returns to generating alternatives, indicating an iterative approach to find the optimal solution. In case of non-compliance, the alternative is discarded, and the results are stored in a database. This phase includes a crucial decision point, "Last alternative?" If the answer is "Yes" the process progresses to "calculating scores for each alternative based on their criteria" followed by a generating of "top 3 solutions".

The flowchart also illustrates a client-server model through the App block, featuring a User Interface (UI) component that interacts with the server to process 'Input' and deliver 'Output'. This suggests that user inputs through the UI initiate server-side processes, which in turn provide outputs back to the client. The "request-response" mechanism between the client and server indicates that the decision-making tool, facilitating dynamic interaction as the server processes data and returns results for display or further analysis. Integrating a decision-making tool is a key part of automating the workflow, thus enhancing the decision-making process in thermal engineering projects.

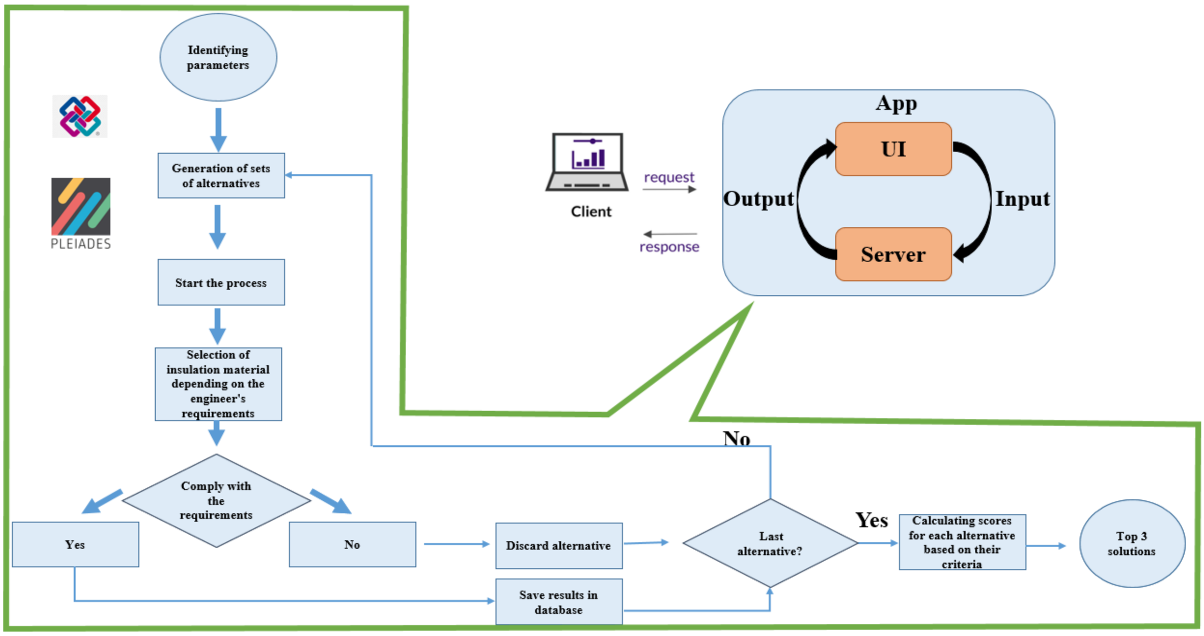

Figure 3 Architecture of decision-making tool for Lean-integrated thermal design process.

In our study, we have demonstrated the feasibility of enhancing the design phase by applying Lean principles with BIM, leading to significant improvements in the thermal engineering process for building design. The results, as illustrated in the figures above, show a clear distinction between the traditional approach and our research framework. Our method leverages automated parameter definition and a comprehensive evaluation of insulation material alternatives, leading to a more effective selection process. This approach, enhanced by the use of a decision-making tool, aligns with digital construction methodologies and provides a structured, streamlined method for thermal engineering. The key improvement is in the decision-making process, where thermal engineers can now evaluate a broader range of options using SBD and CBA techniques, ensuring the selection of the most optimal solution based on multi-criteria analysis. This not only improves the accuracy and consistency of the design process but also significantly reduces manual efforts and time spent on repetitive tasks. The integration of Lean principles with BIM technology in our framework represents a forward step in addressing the challenges of energy efficiency and sustainability in building design, show casing the potential for innovative solutions in the field of thermal engineering.

CONCLUSION AND FURTHER WORKS

In conclusion, this research has established a novel framework that synergizes Lean principles with BIM to optimize the design phase in construction, with a specific focus on thermal engineering. Grounded in comprehensive literature reviews and validated through surveys and semi-structured interviews with industry experts, the framework introduces automation in the generation and evaluation of design alternatives and then choosing the best 3 solutions automatically. This automation, facilitated through a decision-making tool, has demonstrated its effectiveness through its constituent elements in enhancing decision-making, reducing costs, and increasing the value of construction projects. Future work for this article involves completing the coding of the decision-making tool and then testing it in real-case studies. Additionally, applying this tool to other aspects of thermal design will add significant value, especially for HVAC systems, which present challenges in decision-making. This process will ultimately ensure the tool's effectiveness in practical applications.

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REFERENCES

Arroyo, P., and D. Long. 2018. “Collaborative Design Decisions.” 463–472. Chennai, India.

Attouri, E., Z. Lafhaj, L. Ducoulombier, and B. Linéatte. 2022. “The current use of industrialized construction techniques in France: Benefits, limits and future expectations.” *Clean. Eng. Technol.*, 7: 100436. Elsevier.

Ballard, G. 2000. “Positive vs negative iteration in design.” *Proc. Eighth Annu. Conf. Int. Group Lean Constr. IGLC-6 Brighton UK*, 17–19.

Bello, S. A., L. O. Oyedele, O. O. Akinade, M. Bilal, J. M. D. Delgado, L. A. Akanbi, A. O. Ajayi, and H. A. Owolabi. 2021. “Cloud computing in construction industry: Use cases, benefits and challenges.” *Autom. Constr.*, 122: 103441. Elsevier.

Castañeda, K., R. F. Herrera, O. Sánchez, and G. Mejía. 2023. “set-based design in construction projects: benefits, difficulties and trends.” *Prod. Dev.*

El Mounla, K., D. Beladjine, K. Beddiar, and B. Mazari. 2023. “Lean-BIM Approach for Improving the Performance of a Construction Project in the Design Phase.” *Buildings*, 13 (3): 654. MDPI.

Eldeep, A. 2022. “Benefits of Integration Between Lean and Bim in the Design and Construction Phase; Lessons Learned.” *SVU-Int. J. Eng. Sci. Appl.*, 3 (1): 21–28. South Valley University, Faculty of Engineering.

Fosse, R., G. Ballard, and M. Fischer. 2017. “Virtual design and construction: Aligning BIM and lean in practice.” 25th Annual Conference of the International Group for Lean Construction ….

Herrera, R. F., C. Mourgues, L. F. Alarcón, and E. Pellicer. 2021a. “Analyzing the association between lean design management practices and BIM uses in the design of construction projects.” *J. Constr. Eng. Manag.*, 147 (4): 1–11. American Society of Civil Engineers.

Herrera, R. F., C. Mourgues, L. F. Alarcón, and E. Pellicer. 2021b. “Comparing Team Interactions in Traditional and BIM-Lean Design Management.” *Buildings*, 11 (10): 447. https://doi.org/10.3390/buildings11100447.

Lane, R., and G. Woodman. 2000. "Wicked Problems, Righteous Solutions–Back to the Future on Large Complex Projects." *Int. Group Lean Constr. Eighth Annu. Conf. IGEC Brighton Engl. July*. Citeseer.

Lee, J.-S., H.-S. Lee, M.-S. Park, and S.-H. Ji. 2012a. "A decision support system for super tall building development: DSS FRAMEWORK FOR SUPER TALL BUILDING DEVELOPMENT." *Struct. Des. Tall Spec. Build.*, n/a-n/a. https://doi.org/10.1002/tal.1002.

Lee, S.-I., J.-S. Bae, and Y. S. Cho. 2012b. "Efficiency analysis of Set-based Design with structural building information modeling (S-BIM) on high-rise building structures." *Autom. Constr.*, 23: 20–32. Elsevier.

Lee, S.-I., and Y.-S. Cho. 2012. "An application of lean design of structural floor system using structural building information modeling (s-bim)." *Adv. Sci. Lett.*, 13 (1): 158–164. American Scientific Publishers.

Lukka, K., L. OJALA, and O. HILMOLA. 2003. "Case study research in logistics." *Publ. Turku Sch. Econ. Bus. Adm. Ser. B*, 1 (2003): 83–101.

Mathern, A., R. Rempling, D. Tarazona Ramos, and S. Luis Fernández. 2018. "Applying a Set-based Parametric Design Method to Structural Design of Bridges." S5-215. Nantes, France.

Monla, Z., A. Assila, D. Beladjine, and M. Zghal. 2023. "Maturity Evaluation Methods for BIM-based AR/VR in Construction Industry: A Literature Review." *IEEE Access*. IEEE.

Parrish, K., and I. Tommelein. 2009. "Making design decisions using choosing by advantages." *17th Annu. Conf. Int. Group Lean Constr. IGLC17*, 501–510.

Parrish, K., J.-M. Wong, I. D. Tommelein, and B. Stojadinovic. 2007. "Exploration of set-based design for reinforced concrete structures." *15th Annu. Conf. Int. Group Lean Constr. IGLS*, 18–20.

Piirainen, K. A., and R. A. Gonzalez. 2013. "Seeking constructive synergy: design science and the constructive research approach." *Des. Sci. Intersect. Phys. Virtual Des. 8th Int. Conf. DESRIST 2013 Hels. Finl. June 11-12 2013 Proc. 8*, 59–72. Springer.

Rempling, R., A. Mathern, D. Tarazona Ramos, and S. Luis Fernández. 2019. "Automatic structural design by a set-based parametric design method." *Autom. Constr.*, 108: 102936. https://doi.org/10.1016/j.autcon.2019.102936.

Sacks, R., L. Koskela, B. A. Dave, and R. Owen. 2010. "Interaction of lean and building information modeling in construction." *J. Constr. Eng. Manag.*, 136 (9): 968–980. American Society of Civil Engineers.

Sahadevan, V., and K. Varghese. 2018. "Stakeholder value evolution, capture and assessment in aec project design." 26th Annual Conference of the International Group for Lean Construction ….

Sahadevan, V., and K. Varghese. 2019. "AHP and CBA Application to Layout Design: A Case of Classroom Layout Assessment." 1333–1344. Dublin, Ireland.

Sajedeh, M., A. Fleming, S. Talebi, and J. Underwood. 2016. "Development of an experimental waste framework based on BIM/lean concept in construction design."

Schiavi, B., V. Havard, K. Beddiar, and D. Baudry. 2022. "BIM data flow architecture with AR/VR technologies: Use cases in architecture, engineering and construction." *Autom. Constr.*, 134: 104054. Elsevier.

TUDublin, B., and B. Sheramn. 2019. "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." 22.

Xiao, Y., and M. Watson. 2019. "Guidance on conducting a systematic literature review." *J. Plan. Educ. Res.*, 39 (1): 93–112. SAGE Publications Sage CA: Los Angeles, CA.

Yusof, I. H. M., M. An, and M. H. Barghi. 2015. "Integration of lean construction considerations into design process of construction projects." *Management*, 885: 894.