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A SYSTEMATIC LITERATURE REVIEW ON THE SYNERGISTIC APPLICATION OF BIM AND LEAN FOR SUSTAINABLE HOSPITAL DEVELOPMENT

EMAN EID ATTYA[1], MOHAMED ADEL SHEBL[2] AND RAGHDA ELSAYED HASSABALLAH[3]

[1] PROFESSOR OF ARCHITECTURE HISTORY AND THEORIES OF ARCHITECTURE, FACULTY OF ENGINEERING, SHEBIN EL-KOM, MENOUFIA UNIVERSITY.

[2] ASSISTANT PROFESSOR, DEPARTMENT OF ARCHITECTURAL ENGINEERING, FACULTY OF ENGINEERING, SHEBIN EL-KOM, MENOUFIA UNIVERSITY.

[3] MASTER OF ENGINEERING SCIENCES, FACULTY OF ENGINEERING SHEBIN EL-KOM, MENOUFIA UNIVERSITY, AND REGISTRATION OF RESEARCH POINT OF PHD IN MENOUFIA UNIVERSITY.

E-Mail: **raghda.ha.arc@gmail.com**

Abstract

Driven by the critical need for sustainable healthcare infrastructure, this research explores the synergistic integration of Building Information Modeling (BIM) and Lean principles to optimize hospital planning and design. This study examines how combining BIM and Lean methodologies enhances efficiency, reduces costs, and promotes environmental sustainability in hospital development. A rigorous systematic review of literature from Scopus, ScienceDirect and Google Scholar analyzed relevant studies on their application in healthcare facilities. Findings indicate that this integration significantly improves sustainable hospital development by enhancing spatial visualization, conflict resolution, and data-driven decision-making, while streamlining resource allocation and minimizing waste. This combined approach leads to superior design outcomes, lower capital expenditure, and resource-conscious, eco-friendly design. Acknowledging limitations, including reliance on English-language publications and the contextual variability of hospital planning, which may limit generalizability, the study emphasizes the need for standardized frameworks. Ultimately, the integration of BIM and Lean advances sustainable hospital infrastructure by fostering cost-effective, resource-efficient, and ecologically responsible design, aligning with sustainable development goals. This research establishes a foundational framework for developing prescriptive guidelines and best practices, optimizing project delivery protocols and enhancing operational efficacy within healthcare infrastructure projects.

Keywords

Construction Management, Healthcare Sector, Process Improvement, Environmental Impact

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مراجعة منهجية للأدبيات حول التطبيق التآزري لـ BIM والبناء الرشيد لتطوير المستشفيات المستدامة

الملخص

انطلاقًا من الحاجة الماسة إلى بنية تحتية مستدامة للرعاية الصحية، يستكشف هذا البحث التكامل التآزري بين نمذجة معلومات البناء (BIM) ومبادئ لين لتحسين تخطيط وتصميم المستشفيات. تدرس هذه الدراسة كيف يعزز الجمع بين منهجيات BIM ولين الكفاءة، ويقلل التكاليف، ويعزز الاستدامة البيئية في تطوير المستشفيات. أجرى البحث مراجعة منهجية دقيقة للأدبيات من قواعد بيانات Scopus و Google Scholar و ScienceDirect حيث تم تحليل الدراسات ذات الصلة بتطبيقها في مرافق الرعاية الصحية. لمعرفة الفجوة المعرفية والتي هي على الرغم من الاهتمام المتزايد بهذه المبادئ والأدوات، إلا أن الأبحاث التي تستكشف تأثير دمجها بشكل شامل في تصميم المستشفيات، وخاصة في سياق البلدان النامية، لا تزال محدودة.

تشير النتائج إلى أن هذا التكامل يحسن بشكل ملحوظ تطوير المستشفيات المستدامة من خلال تعزيز التصور المكاني، وحل النزاعات، واتخاذ القرارات القائمة على البيانات، مع تبسيط تخصيص الموارد وتقليل الهدر . يؤدي هذا النهج المدمج إلى نتائج تصميم فائقة، وإنفاق رأسمالي أقل، وتصميم واعٍ للموارد وصديق للبيئة.

مع التسليم بالقيود، بما في ذلك الاعتماد على المنشورات باللغة الإنجليزية والتباين السياقي لتخطيط المستشفيات، مما قد يحد من قابلية التعميم، تؤكد الدراسة على الحاجة إلى أطر عمل موحدة. في نهاية المطاف، يعزز تكامل BIM ولين البنية التحتية المستدامة للمستشفيات من خلال تعزيز التصميم الفعال من حيث التكلفة، والكفاءة في استخدام الموارد، والمسؤولية البيئية، بما يتماشى مع أهداف التنمية المستدامة. يضع هذا البحث إطارًا تأسيسيًا لتطوير إرشادات توجيهية وأفضل الممارسات، وتحسين بروتوكولات تسليم المشاريع وتعزيز الكفاءة التشغيلية داخل مشاريع البنية التحتية للرعاية الصحية.

1 INTRODUCTION

The pursuit of sustainable development goals within healthcare infrastructure necessitates the integration of innovative technologies and efficient methodologies. In this context, the convergence of Building Information Modeling (BIM) and Lean principles has emerged as a potentially transformative strategy to enhance hospital planning and design. Specifically, by capitalizing on BIM's collaborative functionalities [1] and Lean's waste-reduction paradigms [2], healthcare facilities can be optimized across critical dimensions of sustainability[3], cost-effectiveness, and operational efficiency.

Despite growing interest in these principles and tools, the research exploring their significant integration into hospital design, particularly in beneficiary communities, remains limited. This systematic literature review, based on PRISMA, bridges this gap by evaluating the available evidence on the effectiveness and outcomes of applying these principles and tools together in hospital design. This research aims to explore the synergistic relationship between BIM and Lean within hospital planning and design, and to rigorously evaluate the extent to which this integration facilitates the attainment of sustainable development goals in healthcare infrastructure projects. Through a comprehensive review of the extant literature, this study seeks to elucidate the benefits, challenges, and potential outcomes associated with the combined application of BIM technology and Lean methodologies in advancing sustainable healthcare facility development.

Building Information Modeling (BIM) is a critical methodology in design[4], providing precise 3D digital representations that foster collaboration and coordination among project stakeholders[5]. In healthcare settings, BIM enables medical staff and partners to virtually

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[1] Peter Johann Hareide and others, ‘Strategies for Optimization of Value in Hospital Buildings’, *Procedia - Social and Behavioral Sciences*, 226 (2016), 423–30 <https://doi.org/https://doi.org/10.1016/j.sbspro.2016.06.207>.

[2] Rodrigo F. Herrera and others, ‘An Assessment of Lean Design Management Practices in Construction Projects’, *Sustainability (Switzerland)*, 12.1 (2020) <https://doi.org/10.3390/su12010019>.

[3] Sara Bensalem, ‘Sustainable Healthcare Archi-Techure Designing a Healing Environment’, 2015.

[4] Yu Cheng Lin and others, ‘Integrated BIM, Game Engine and VR Technologies for Healthcare Design: A Case Study in Cancer Hospital’, *Advanced Engineering Informatics*, 36.February (2018), 130–45 <https://doi.org/10.1016/j.aei.2018.03.005>.

[5] Peter Johann Hareide and others, ‘Strategies for Optimization of Value in Hospital Buildings’, Procedia - Social and Behavioral Sciences, 226 (2016), 423–30 <https://doi.org/https://doi.org/10.1016/j.sbspro.2016.06.207>.

experience and evaluate spaces pre-construction, offering valuable early feedback6. This collaborative potential is further underscored by frameworks like Integrated Project Delivery (IPD)[7,8], utilized in regions such as New York, which leverage BIM as a central platform for interaction between architects, clinicians, and contractors to optimize designs for end-user needs and enhance healthcare delivery[9]. Integrating BIM with immersive technologies like Virtual Reality (VR)[10], as demonstrated in advanced design initiatives [4,10], allows for enhanced conceptual visualization and stimulates innovative ideas beyond the core design team. Consequently, BIM is integral to addressing traditional construction industry challenges related to project complexity and fragmented workflows, representing a necessary technological advancement for improving business processes and project outcomes[11].

There is evidence of the application of lean management principles and some of its tools in the design management process[12]. A case study was presented that demonstrated a shift from traditional planning to the use of a last-mile planner (LPS) system in the design phase,

[6] Rachel C Okada, April E Simons, and Anoop Sattineni, ‘Owner-Requested Changes in the Design and Construction of Government Healthcare Facilities’, *Procedia Engineering*, 196 (2017), 592–606 <https://doi.org/https://doi.org/10.1016/j.proeng.2017.08.047>.
[7] The American Institute of Architects. Integrated Project Delivery: A Guide; The American Institute of Architects: Washington, DC, USA, 2007.
[8] Harrison A Mesa, Keith R Molenaar, and Luis F Alarcón, ‘Exploring Performance of the Integrated Project Delivery Process on Complex Building Projects’, *International Journal of Project Management*, 34.7 (2016), 1089–1101 <https://doi.org/https://doi.org/10.1016/j.ijproman.2016.05.007>.
[9] A. Khan and others, ‘Integration of Bim and Immersive Technologies for Aec: A Scientometric-swot Analysis and Critical Content Review’, *Buildings*, 11.3 (2021) <https://doi.org/10.3390/buildings11030126>.
[10] Yu Cheng Lin and others, ‘Integrated BIM, Game Engine and VR Technologies for Healthcare Design: A Case Study in Cancer Hospital’, *Advanced Engineering Informatics*, 36 (2018), 130–45 <https://doi.org/10.1016/j.aei.2018.03.005>.
[11] lzadi, H. 2013. integrating BIM and Lean in the design Phase investigating Collocated Design Meetings (iRoom). Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, P-1-52
[12] El. Reifi, M. H., & Emmitt, S. (2013). Perceptions of lean design management. Architectural Engineering and Design Management, 9(3), 195-208. https://doi.org/10.1080/17452007.2013.802979

which resulted in increased stakeholder satisfaction[13]. Another study[14] confirmed that the use of a last-mile planner and collaborative planning enhanced trust and commitment among team members, two essential elements for effective team performance[15].Integrated Project Delivery (IPD) has also emerged as a new project delivery system, providing greater collaboration and improved performance through supply chain integration [8]. Lean design combines several essential elements in the design phase, such as active client involvement, maximizing value, identifying the needs of all parties, simultaneous design execution, and deferring decisions, with the goal of reducing rework[16].

Many Lean tools can be used in lean design, such as target value design (TVD), set-based design (SBD), building information modeling (BIM), feature-based selection (CBA), and LPS[17]. A matrix linking lean construction principles to BIM functions is also proposed, opening up new research avenues[18]. A study found that applying Lean principles to construction project design improves efficiency and quality [6]. However, the application of these practices varies widely across projects, underscoring the need for tools to assess and improve their implementation.

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[13] Roar Fosse and Glenn Ballard, ‘Lean Design Management in Practice with the Last Planner System’, IGLC 2016 - 24th Annual Conference of the International Group for Lean Construction, 2016, 33–42.

[14] Conference Paper and Vegard Knotten, ‘Improving Design Management With Improving Design Management’, July, 2016.

[15] Fredrik Svalestuen and others, ‘Key Elements to an Effective Building Design Team’, *Procedia Computer Science*, 64.October (2015), 838–43 <https://doi.org/10.1016/j.procs.2015.08.636>.

[16] Rodrigo F. Herrera and others, ‘An Assessment of Lean Design Management Practices in Construction Projects’, *Sustainability (Switzerland)*, 12.1 (2020) <https://doi.org/10.3390/su12010019>.

[17] Paul A. Tilley, ‘Lean Design Management - A New Paradigm for Managing the Design and Documentation Process to Improve Quality?’, 13th International Group for Lean Construction Conference: Proceedings, January 2005, 2005, 283–95.

[18] Rafael and others, ‘Interaction of Lean and Building Information Modeling in Construction’, *Journal of Construction Engineering and Management*, 136.9 (2010), 968–80 <http://eprints.hud.ac.uk/id/eprint/25835/>.

The design and delivery of healthcare facilities present unique challenges characterized by complex programmatic requirements, intricate MEP systems, stringent regulatory standards, and the critical need to optimize operational efficiency and patient outcomes[19].

In this context, the integration of Building Information Modeling (BIM) [4] and Lean principles represents a significant paradigm shift, moving beyond traditional design and construction methodologies towards a more holistic, value-driven approach[20] .

BIM provides a robust digital platform for multi-dimensional modeling [21, 22] , data management[21], clash detection[22], and enhanced visualization, thereby facilitating better-informed decision-making and improved coordination among multidisciplinary teams[5]. Concurrently, Lean principles, originating from manufacturing but adapted for the Architecture, Engineering, and Construction (AEC) industry, focus on maximizing value for the end-user while systematically identifying and eliminating waste (Muda) in processes, materials, and time[2]. The synergistic application of BIM and Lean allows project stakeholders to collaboratively map value streams, optimize workflows, reduce non-value-added activities, and implement continuous improvement cycles directly within the information-rich BIM environment. This integration is therefore imperative for addressing the inherent complexities of healthcare projects[23], leading to demonstrably improved project predictability, reduced costs and schedules, enhanced facility quality, and ultimately, environments better suited to supporting efficient and safe patient care.

[19] https://www.e-zigurat.com/en/blog/benefits-of-bim

[20] https://www.taaltech.com/how-bim-is-driving-lean-construction-practices-in-the-industry/

[21] Anjar Primasetra, Dewi Larasati, and Surjamanto Wonorahardjo, ‘BIM Utilization in Improving Energy Efficiency Performance on Architectural Design Process: Challenges and Opportunities’, *IOP Conference Series: Earth and Environmental Science*, 1058.1 (2022) <https://doi.org/10.1088/1755-1315/1058/1/012018>.

[22] R. and Ghang L. Eastman, C., Teicholz, P. Sacks, BIM Handbook - A Guide to Building Information Modelling for Owners, Designers, Engineers, Contractors, and Facility Managers, Wiley and Sons, 2018.

[23] Joao Soliman-Junior and others, ‘The Relationship Between Requirements Subjectivity and Semantics for Healthcare Design Support Systems’, 2021, pp. 801–9 <https://doi.org/10.1007/978-3-030-51295-8_55>.

2 METHODOLOGY

While the integration of Building Information Modeling (BIM) and Lean principles has garnered increasing attention within the Architecture, Engineering, and Construction (AEC) industry, a comprehensive review of its application in optimizing hospital planning and design for sustainable outcomes appears to be lacking, particularly within the context of developing countries. To address this gap, this study employs a systematic literature review methodology, guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, to rigorously evaluate existing research. This approach facilitates the identification, appraisal, and synthesis of relevant studies, ensuring an

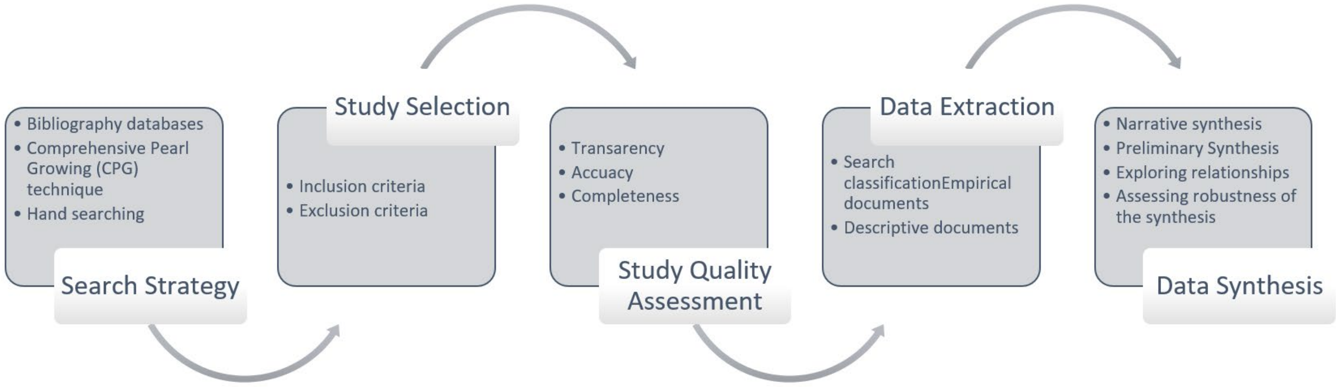

Figure 1 Research Protocol,
Source: Author, 2024

unbiased, explicit, and reproducible analysis of the evidence. The systematic review protocol encompasses five key stages: search strategy, study selection, quality assessment, data extraction, and data synthesis, designed to provide a balanced and impartial summary of findings while acknowledging potential limitations within the available evidence.

Review Questions:

This section aims to synthesize extant literature concerning the application of Building Information Modeling (BIM) and Lean methodologies within the context of healthcare facility development and sustainability. To guide this review, the following research questions were formulated:

- What is the influence of BIM and Lean integration on hospital building lifecycle sustainability?
- What evidence supports the application of BIM-enabled Lean design for enhanced sustainability in hospital buildings?
- What are the integration mechanisms, key challenges, and opportunities for BIM, rational design, and sustainability standards in hospital building projects?

2.1 Stage One: Search Strategy:

While the integration of Building Information Modeling (BIM) and Lean principles has garnered increasing attention within the Architecture, Engineering, and Construction (AEC) industry, a comprehensive review of its application in optimizing hospital planning and design for sustainable outcomes appears to be lacking, particularly within the context of developing countries.

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2.2 Stage Two: Study Selection (Screening)

The identification of relevant literature involved a systematic, multi-stage screening process aligned with PRISMA guidelines. Initially, all records retrieved from database searches were imported into Mendeley Desktop, where duplicate entries were identified and removed. Subsequently, the remaining unique records underwent a tiered screening process based on predefined criteria. The first stage involved evaluating titles, abstracts, and keywords for relevance to the research topic. Records deemed potentially relevant then proceeded to the second stage, which entailed a thorough full-text assessment to determine final eligibility.

This assessment focused on methodology, results, and conclusions. Throughout both screening stages, the following inclusion criteria were strictly applied: document type (conference proceedings, journal articles, and books), publication date (2018-2024), and language (English). Records failing to meet any of these criteria were excluded. The number of included and excluded articles at each stage of the screening process is documented in the PRISMA flow diagram.

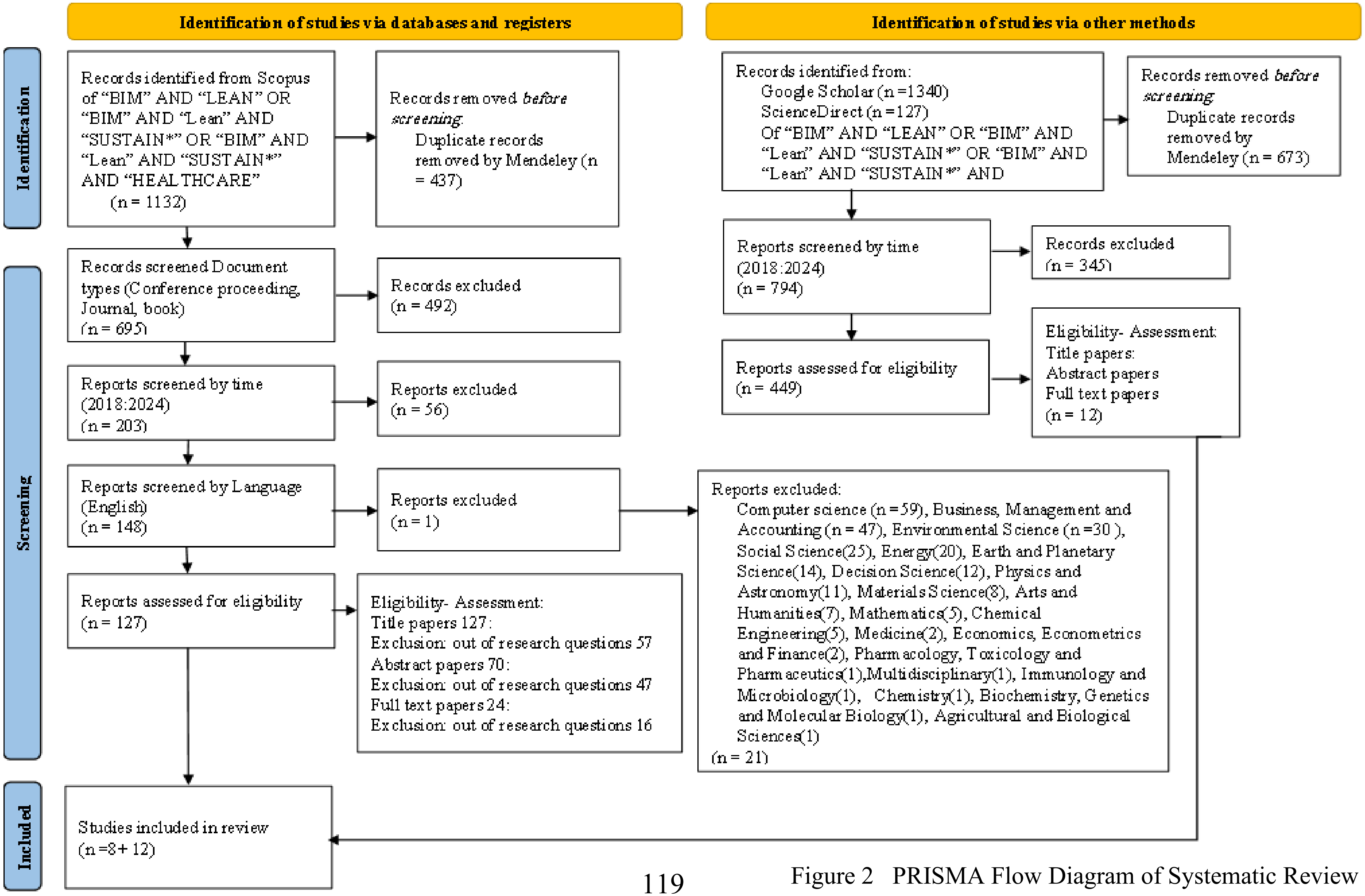

Figure 2 PRISMA Flow Diagram of Systematic Review Process (Source: Author's Compilation)

2.3 Stage Three: Study Quality Assessment

To ensure the methodological rigor and validity of the review, only studies published in peer-reviewed scientific journals and conference proceedings were included. The peer-review process inherent in these publications was considered a key mechanism for upholding stringent scientific standards and enhancing the reliability of the included research. Further quality assessment will be conducted using [Specify the quality assessment tool or criteria, e.g., "the Newcastle-Ottawa Scale" or "a modified version of the Cochrane Risk of Bias tool"] to evaluate the methodological quality of the included studies.

To ensure the methodological rigor and validity of this review, emphasis was placed on the inclusion of studies published in peer-reviewed scientific journals. The peer-review process, inherent to these publications, serves as a mechanism for upholding stringent scientific standards and enhancing the reliability of the included research.

2.4 Stage Four: Data Extraction

A mixed-methods approach was used for data extraction, incorporating both quantitative and qualitative techniques to analyze the existing research on BIM and Lean integration in sustainable hospital design.

Quantitative data was extracted through bibliometric analysis. This involved employing statistical methods to analyze academic publication trends, assess research performance, and identify patterns within the literature.

Qualitative data was extracted using content analysis to identify thematic insights related to the application of BIM and Lean in hospital projects. The interrelationships between keywords were visualized using VOS viewer diagrams (Figure 3), highlighting key research foci such as: (a)The application of Lean Construction methodologies in facility design and management, particularly in hospital settings. (b)The integration of BIM to enhance efficiency and sustainability. Extracted data included information on study methodologies, project characteristics, outcomes related to BIM and Lean implementation (e.g., energy efficiency, cost reduction, time savings), and identified barriers and facilitators. The extracted data will be synthesized to [State how the data will be synthesized - e.g., "to develop a conceptual framework" or "to identify best practices.

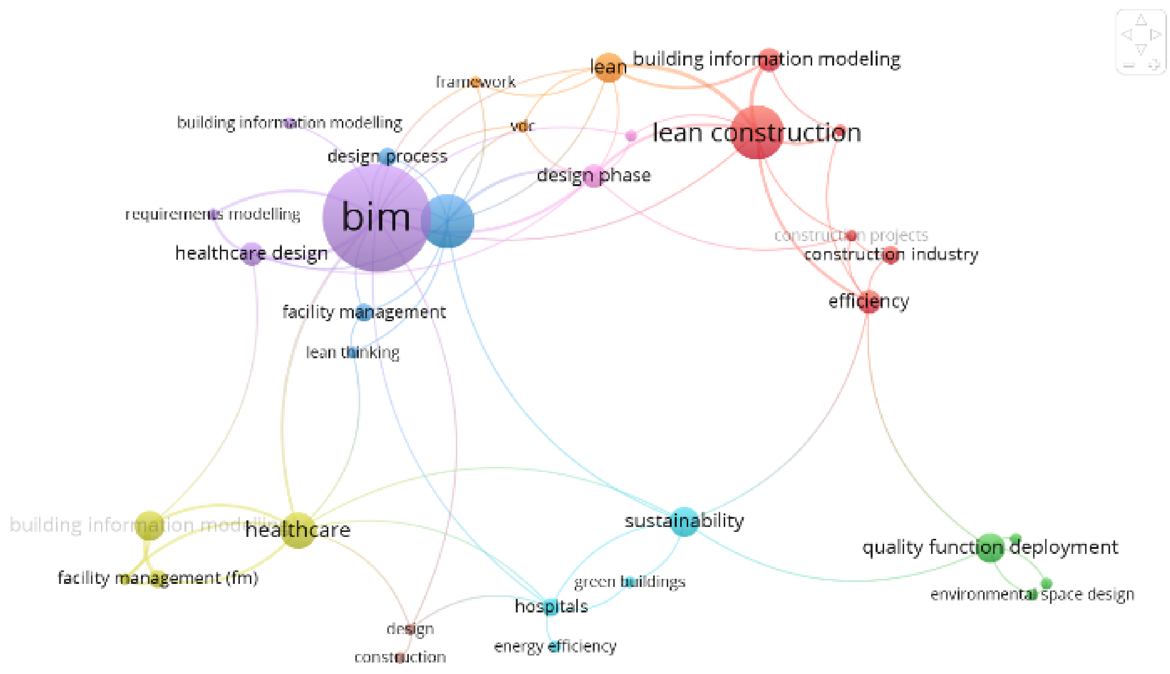

Figure 3the Vos viewer Network Visualization Illustrates the Interrelationships Between Keywords Identified Within The Research Corpus, Alongside A Research Gap Analysis

2.5 Stage Five: Data Synthesis

Each study included within this review underwent a comprehensive critical analysis. This process entailed a meticulous examination of all components of the research, aimed at identifying key aspects, conceptual relationships, proposed classifications, and comparative findings. This analytical approach facilitated a detailed evaluation of each study, enabling the identification of its strengths and limitations within the context of integrating BIM and Lean methodologies into sustainable hospital planning. Consequently, this methodological framework provides a robust foundation for a deeper understanding of the accumulated knowledge within this field.

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Table 1 Tools and techniques for data synthesis process

Tools and Techniques	Research questions	
	RQ1: What is the influence of BIM and Lean integration on hospital building lifecycle sustainability?	
Preliminary Synthesis	• Search process • Trend analysis •	Textual descriptions Summarizing the documents and beginning to extract information in a systematic way.
	• Type of publications	Presenting results in graphical form Categorizing sources (journals, conferences, etc.) to understand the nature of the research.
	• Range of disciplines	Several visual and graphical tools were used to explore the extracted studies.
	RQ2: What evidence supports the application of BIM-enabled Lean design for enhanced sustainability in hospital buildings	
	• Characteristics of reviewed studies	Tabulation Tabulation is a commonly used approach in all types of a systematic review to represent data visually. It has been used to develop an initial description of the included studies and to begin to identify patterns across them.
	• Keywords frequency	Translating data A word frequency tool was used to count keywords in extracted documents (one point for each utterance), generating "word clouds" that give greater prominence to repeated keywords
Exploring Relationships	• Grouping and clusters	Groupings and clusters Organizing the included studies into smaller groups to make the process more manageable.
	• Network analysis (VOS viewer)	Visualizing relationships between authors, keywords, or concepts to identify key connections and research clusters. VOS viewer is specifically used for this purpose.
Developing a conceptual model	RQ3: What are the integration mechanisms, key challenges, and opportunities for BIM, rational design, and sustainability standards in hospital building projects?	
	• Conceptual map	Idea webbing method is used for conceptualizing and representing the relationships being explored.

	• Content analysis	Systematically analyzing the content of documents (text, images, etc.) to quantify and interpret specific characteristics or patterns.

3 Results and Discussions

This section presents the findings of the study, addressing the research questions through a narrative synthesis approach. The analysis employed three key techniques: preliminary synthesis, exploration of relationships between concepts, and an assessment of the robustness of the synthesized evidence.

3.1 Developing a Preliminary Synthesis

It is always requiring a critical interrogation to establish an initial description of the included studies.

3.1.1 Research Process and results

The initial stage of the analysis involved a preliminary synthesis to establish a descriptive overview of the included studies. This step was crucial for summarizing the search strategy, study selection procedures, and data extraction outcomes, as illustrated in the PRISMA flow diagram (Figure 2).

To identify relevant studies, a systematic literature search was conducted, specifically designed to capture research on the integration of Building Information Modeling (BIM) and Lean principles within the context of sustainable hospital design and construction. A preliminary scoping exercise was undertaken to refine keywords and identify appropriate databases.

The primary electronic databases utilized for the search were Scopus, ScienceDirect, and Google Scholar. These databases were selected for their extensive coverage of the Architecture, Engineering, and Construction (AEC) literature, as well as their inclusion of healthcare-specific research. Scopus was particularly chosen for its recognized robustness within the construction field, as indicated by its CiteScore measurement (Elsevier).

To ensure a comprehensive search, the following search strings, incorporating Boolean operators, were employed: (i) TITLE-ABS-KEY ("Building Information Modeling" OR "BIM") AND ("Lean Construction" OR "Lean Principles") AND ("Sustainable Healthcare" OR "Sustainable Hospital Design"), (ii) TITLE-ABS-KEY ("BIM") AND

("Lean") AND ("Sustainable") AND ("Hospital" OR "Healthcare Facility"). The search was limited to peer-reviewed journal articles and conference proceedings published in English between 2018 and 2024. This timeframe was selected to capture contemporary research trends in the field.

In addition to the electronic database searches, a review of grey literature was conducted to identify relevant publications not indexed in the primary databases. This included publications from the International Group for Lean Construction (IGLC), documents from the United Nations (UN) website focusing on Sustainable Development Goals (SDGs) related to healthcare infrastructure, and articles from the Lean Construction Journal. Furthermore, the reference lists of included studies were hand-searched to identify any additional relevant sources. The execution and results of the search strategy are summarized in Figure 2.

3.1.2 Keyword Analysis

The analysis of keywords, as presented in Table 1 of the Appendix, facilitates the extraction of recurrent conceptual relationships within extant research. These relationships are as follows:

- Building Information Modeling (BIM): Constitutes a central node within the conceptual network, exhibiting strong interconnections with the majority of other concepts, thereby underscoring its pivotal role within the construction domain.
- Lean Construction: Demonstrates a close association with BIM, reflecting the increasing integration of these methodologies to enhance project efficiency.
- Healthcare Design: Represents a specialized field that leverages BIM and Lean Construction principles to optimize the quality of healthcare facilities.
- Sustainability: Exhibits linkages with both BIM and Lean Construction, indicating the contribution of these practices towards the achievement of sustainable building outcomes.
- Quality Function Deployment: Represents a tool employed to enhance design quality and address user requirements and is associated with BIM and Lean Construction methodologies.

3.1.3 Identifying Knowledge Gaps

Based on the aforementioned conceptual relationships, the following knowledge gaps have been identified:

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- Integration of BIM, Lean Construction, and Quality Function Deployment in Sustainable Hospital Design: While individual research exists for each of these concepts, a paucity of studies explores their integrated application within the specific context of hospital design, which constitutes the focus of this investigation.

Figure 4 Keyword frequency

- The Impact of Quality Function Deployment on BIM-Driven Design Decisions: Further research is warranted to elucidate how Quality Function Deployment can be effectively employed to accurately capture user requirements and translate them into actionable design parameters within a BIM environment.
- The Role of BIM in Achieving Hospital Sustainability: There is a need for more comprehensive research to determine how BIM can be strategically leveraged to attain sustainability goals in hospital design and construction. Moreover, the identification of key performance indicators for evaluating the environmental performance of these buildings is crucial.
- Project Lifecycle Cost Assessment: A need exists for methodologies to evaluate the long-term costs and benefits associated with the implementation of BIM and Lean Construction in hospital projects.
- Impact on User Experience: Further investigation is required to understand the impact of BIM and Lean Construction implementation on the user experience, encompassing both patients and staff.

3.1.4 Type of Publications:

- The analyzed resources predominantly consist of conference papers, accounting for 49.7% of the total. Following this, articles represent a substantial 37.2% of the selected publications. The remaining 13.1% is distributed among reviews, book chapters, books, editorials, and short surveys, each constituting a smaller fraction as shown in Figure 5.

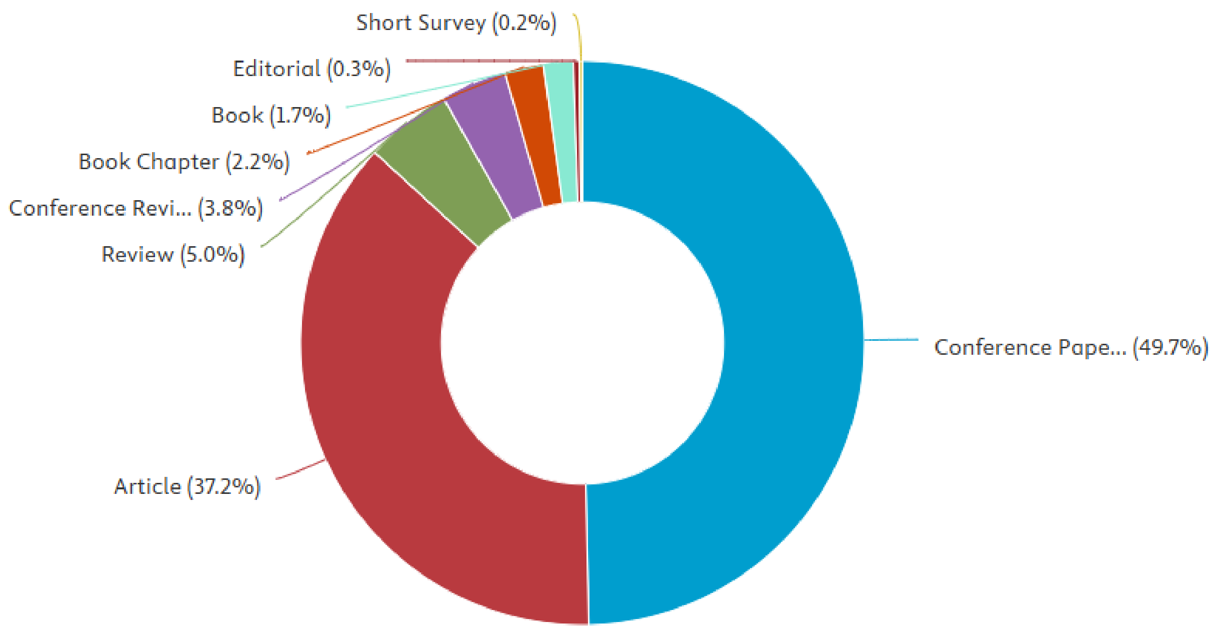

Figure 5 Selected resources classified by type of publications

The presented pie chart (Figure 6) delineates the distribution of research focus concerning the nexus of Building Information Modeling (BIM), sustainable design, and lean construction within the healthcare sector. The data reveals a primary concentration on the intersection of BIM and design (25%), succeeded by the tripartite combination of BIM, healthcare, and design (35%). This distribution underscores a significant research interest in the application of BIM to enhance the design processes of healthcare facilities. Furthermore, a 10% allocation of research attention is evident in the interplay of BIM with lean construction, design, and construction, suggesting an emerging emphasis on achieving enhanced efficiencies in construction workflows. Cumulatively, the proportional representation indicates a burgeoning scholarly interest in the

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integrated application of these concepts to elevate the quality and efficiency of healthcare projects.

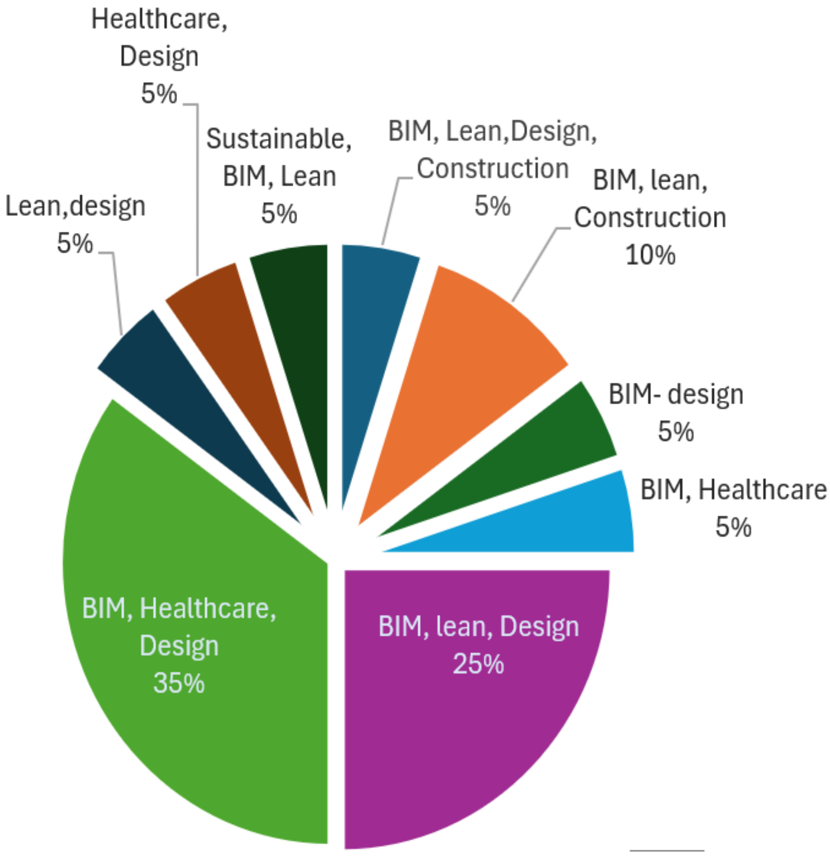

Figure 6 The Presented Chart Quantifies The Percentage Of Recurrence For Key Terms Identified Within Previous Search Queries

Analysis of the depicted data yields the following key inferences:

- Prevalence of the Keyword Combination "BIM, Healthcare, Design": The substantial proportion (35%) associated with this combination signifies a prominent research focus on investigating the implementation of Building Information Modeling (BIM) during the design stage of healthcare projects. This trend reflects the increasing recognition of BIM's potential to optimize design quality and cost-effectiveness within this domain.

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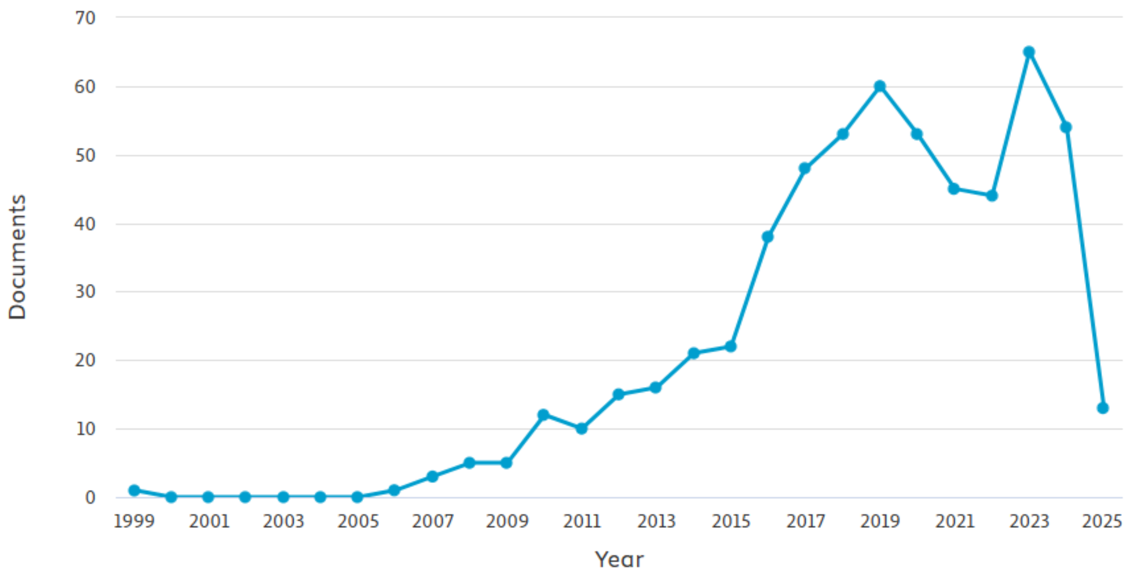

Figure٧ Trend analysis: number of publications about SYNERGIZING QFD, LEAN DESIGN, BIM and sustainability, healthcare

- Emphasis on the Design Phase: The recurrent appearance of the term "Design" across multiple clusters underscores the critical importance attributed to the design phase in the application of sustainable construction principles and BIM methodologies.

- Integration of Lean Construction Principles: The presence of "Lean" across various clusters indicates scholarly interest in exploring the integration of lean construction principles to improve operational efficiency and minimize waste in construction projects, particularly within the hospital sector.

- Multifaceted Application of BIM: The identification of clusters such as "BIM, Design, Construction" and "BIM, Lean, Construction" demonstrates scholarly inquiry into the application of BIM across diverse project phases, spanning from conceptualization to implementation.

Figure 8 illustrates the distribution of research methodologies employed in the reviewed literature. The findings reveal considerable heterogeneity in methodological approaches, with a discernible dominance of certain methods. Specifically, case study methodology constituted the most prevalent approach, representing approximately 45% of the analyzed studies. This prevalence suggests a significant scholarly interest in in-depth analysis of specific instances and the contextual understanding of complex phenomena within the research domain. Systematic literature reviews represented the second most common methodology, accounting for approximately 15% of the reviewed studies, thereby underscoring the importance attributed to the synthesis and critical evaluation of existing scholarly work in this field.

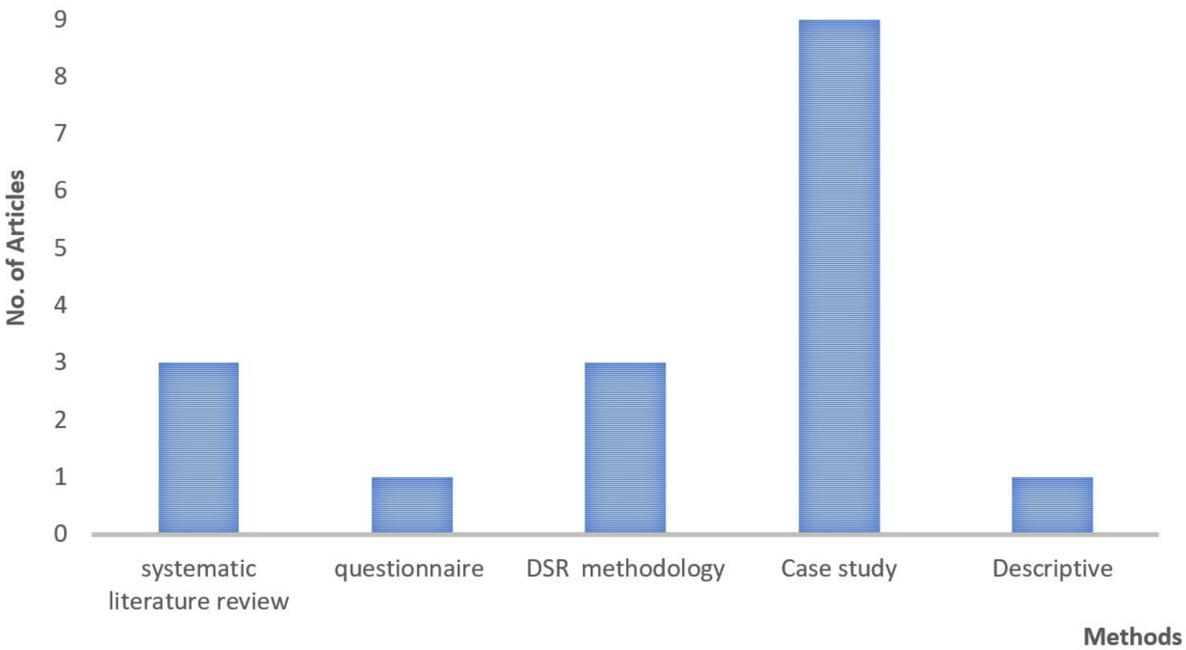

Figure 8 Literature-Based Methodological Approaches

Further analysis indicates that questionnaire-based surveys and descriptive methodologies were utilized in approximately 5% of the studies each, suggesting a comparatively limited application of these approaches within the examined body of research. Notably, a data-driven approach (DSR) was employed in approximately 15% of the studies, indicating a growing scholarly engagement with the utilization and analysis of large datasets in relevant research endeavors.

The analysis of category distribution reveals several key insights into the thematic clusters present in the reviewed literature:

Dominant Thematic Foci: The categories "BIM, lean, Design" and "BIM, Healthcare. Design" exhibits the highest frequency of occurrence, indicating a predominant emphasis in current research on the integration of Building Information Modeling (BIM) with Lean methodologies within the context of design processes, and specifically within healthcare design.

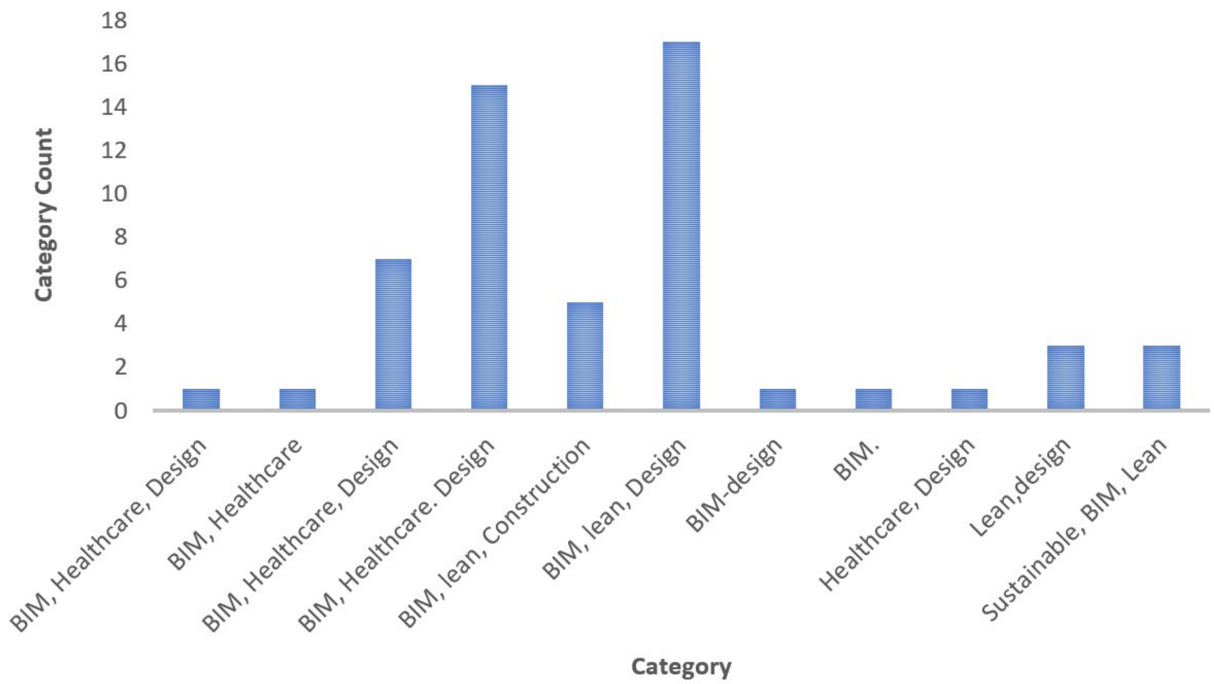

Figure 9 Category Distribution' Visually Represents the Groupings and Clusters

Centrality of BIM: Building Information Modeling (BIM) emerges as a central construct across multiple categories, underscoring its pivotal role in contemporary scholarly investigations related to construction, design, and healthcare environments.

Discrete Areas of Scholarly Interest: The data demonstrates distinct clusters of scholarly interest, notably around healthcare design (in conjunction with BIM) and Lean design principles, suggesting these as salient domains of inquiry within the field.

Emergent or Less Explored Themes: The presence of less frequent categories points to niche or emergent areas of investigation, potentially representing topics that have received comparatively limited attention or are indicative of nascent trends in the literature.

In the Eligibility phase, studies that passed the Screening phase were assessed for their relevance to the research question. Those that did not meet the predefined criteria for inclusion were excluded. The chart indicates that a large proportion of these excluded studies were categorized under "Engineering" (50.0%), followed by "Computer Science" (11.4%) and "Business, Management..." (8.7%) (Figure 9). This suggests that while the initial search strategy (Identification) captured a significant number of studies in these fields, many lacked sufficient relevance to the specific focus of the review, as defined by the research questions and eligibility criteria.

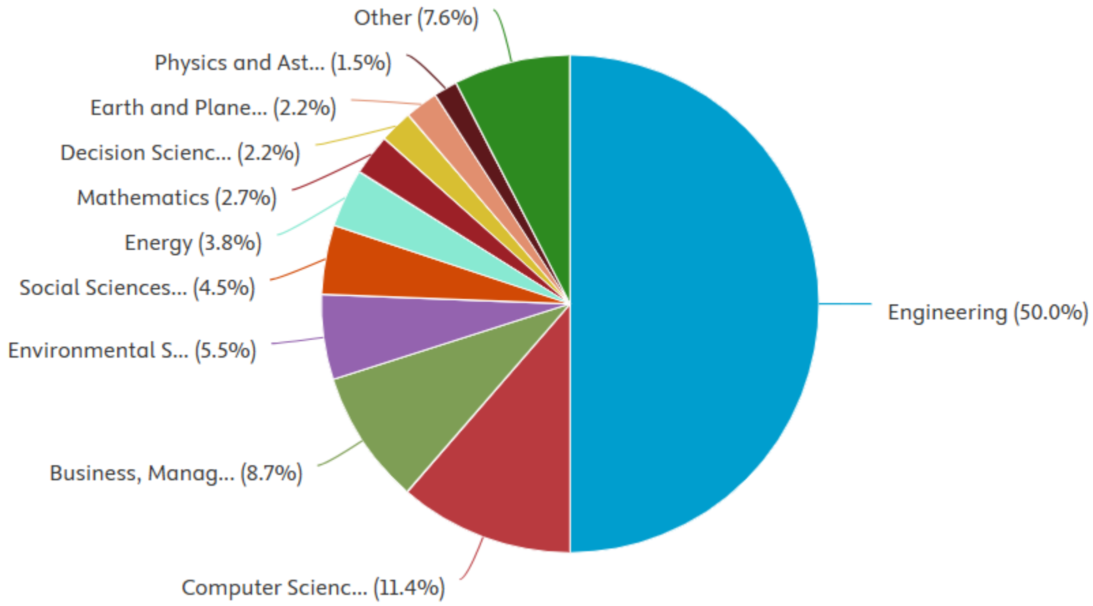

Figure 10 Journals classified by discipline- A total of (147)

3.2 Exploring Relationships between Studies:

This section details the methodology employed to analyze the collected evidence documents related to hospital building projects. The analytical process involves several techniques, including the organization of studies using groupings and clusters, and the development of conceptual maps. These methods facilitate the exploration of relationships between different research findings, the identification of recurring patterns, and the derivation of comprehensive conclusions regarding the integration of Lean, BIM, and sustainability in healthcare construction.

3.2.1 Groupings and Clusters: Lean, BIM, and Sustainability in Healthcare Buildings

In synthesizing the literature, an initial grouping of studies reveals distinct clusters based on their focus, which then allows for a more nuanced exploration of the relationships between Lean construction, Building Information Modeling (BIM), and sustainability within healthcare building projects.

Cluster 1: BIM and Lean Integration

A prominent cluster focuses on the integration of BIM and Lean methodologies.

- Several studies within this cluster explore the general synergies between BIM and Lean. For example, Uvarova et al. (2023) examine the use of digital tools and technologies in Lean construction to enhance efficiency. Eldeep (2022) discusses the benefits of integrating Lean and BIM across project phases. Gómez-Sánchez et al. (2019) analyze the integration of Lean practices and BIM through a case study. Rahman et al. (2022) developed a conceptual BIM-Lean relationship assessment framework.

- A sub-cluster emphasizes the design phase. EL Mounla et al. (2023) provide an updated review of BIM and Lean interaction specifically in the design phase. Aziz et al. (2024) explore BIM's role as a Lean tool to reduce waste during design. AlBalkhy et al. (2023) offer guidelines for fitting design methods based on Lean principles. Herrera et al. (2019) assess Lean design management practices.

Cluster 2: BIM and Sustainability

Another cluster focuses on the intersection of BIM and sustainability.

- Studies in this cluster investigate how BIM can be used to achieve sustainability goals. Primasetra et al. (2022) explore BIM's utilization in improving energy efficiency during architectural design. Patel et al. (2023) proposes a methodological approach integrating BIM, Green Building Methods, and Lean for sustainable construction.

Cluster 3: BIM in Healthcare Design and Management

A third cluster addresses the broader applications of BIM in healthcare.

- This cluster includes studies examining BIM's role in various aspects of healthcare facility projects. Lin et al. (2018) developed a VR/BIM system for healthcare design. Caixeta et al. (2021) explore a physical-digital model for co-design. Thomson et al. (2019) discuss BIM's applications in healthcare precinct design and facilities management. Wang et al. (2021) explore BIM in smart hospital management. Soliman-Junior et al. (2018) focus on modeling user requirements with BIM.

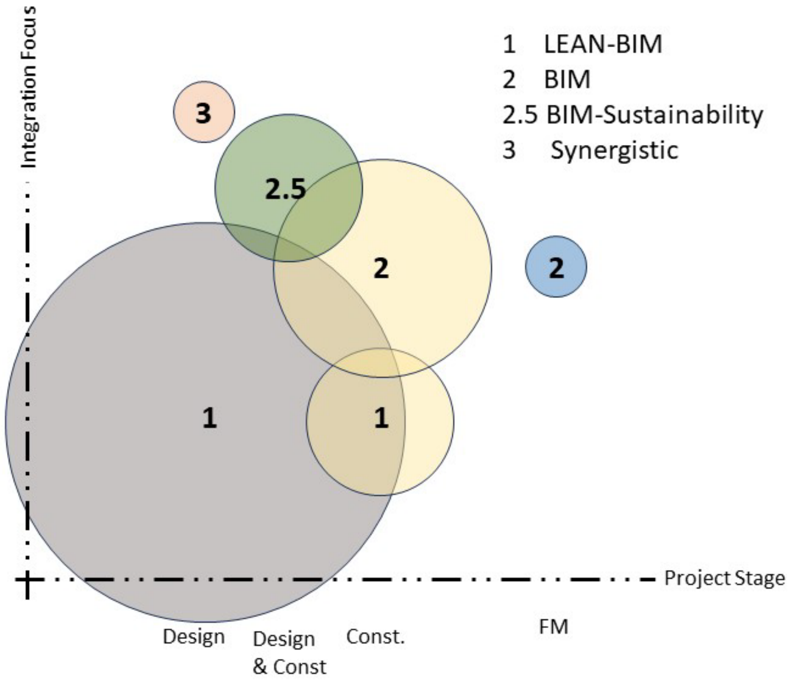

Figure 11 Grouping and clusters

Evolving Synthesis: Stage-Specific Synergies

As the synthesis evolves through the analysis of these clusters, it becomes apparent that the application of Lean, BIM, and sustainability is stage-specific, with notable synergies:

- **Design Phase:** BIM facilitates design coordination and incorporates sustainability analysis, while Lean principles optimize design workflows.
- **Construction Phase:** BIM aids in coordination and waste reduction, and Lean improves on-site efficiency.
- **Facilities Management:** BIM supports efficient building operations and management.

This clustering approach highlights the multifaceted relationships between Lean, BIM, and sustainability and provides a structured understanding of their application in healthcare building projects.

This analytical technique focuses on the integration and convergence of BIM, Lean principles, and sustainability within the context of healthcare buildings. It involves the examination of evidence through groupings, clusters, and conceptual maps. The primary aim is to explore the interrelationships between these concepts, identify emergent patterns, and derive meaningful conclusions.

3.2.2 THE CONCEPTUAL MAP:

It is used to illustrate the key themes and relationships identified within the reviewed studies on Lean, BIM, and Sustainable Healthcare. A preliminary analysis reveals several interconnected themes, including Technology, Design Process, Lean Construction, Healthcare, and Sustainability. These themes are further influenced by overarching concepts such as Practices, Principles, Frameworks, and Interactions, highlighting the multifaceted nature of research in this domain. The visualization emphasizes the interplay between these elements in shaping efficient and sustainable healthcare environments as shown in Figure 12

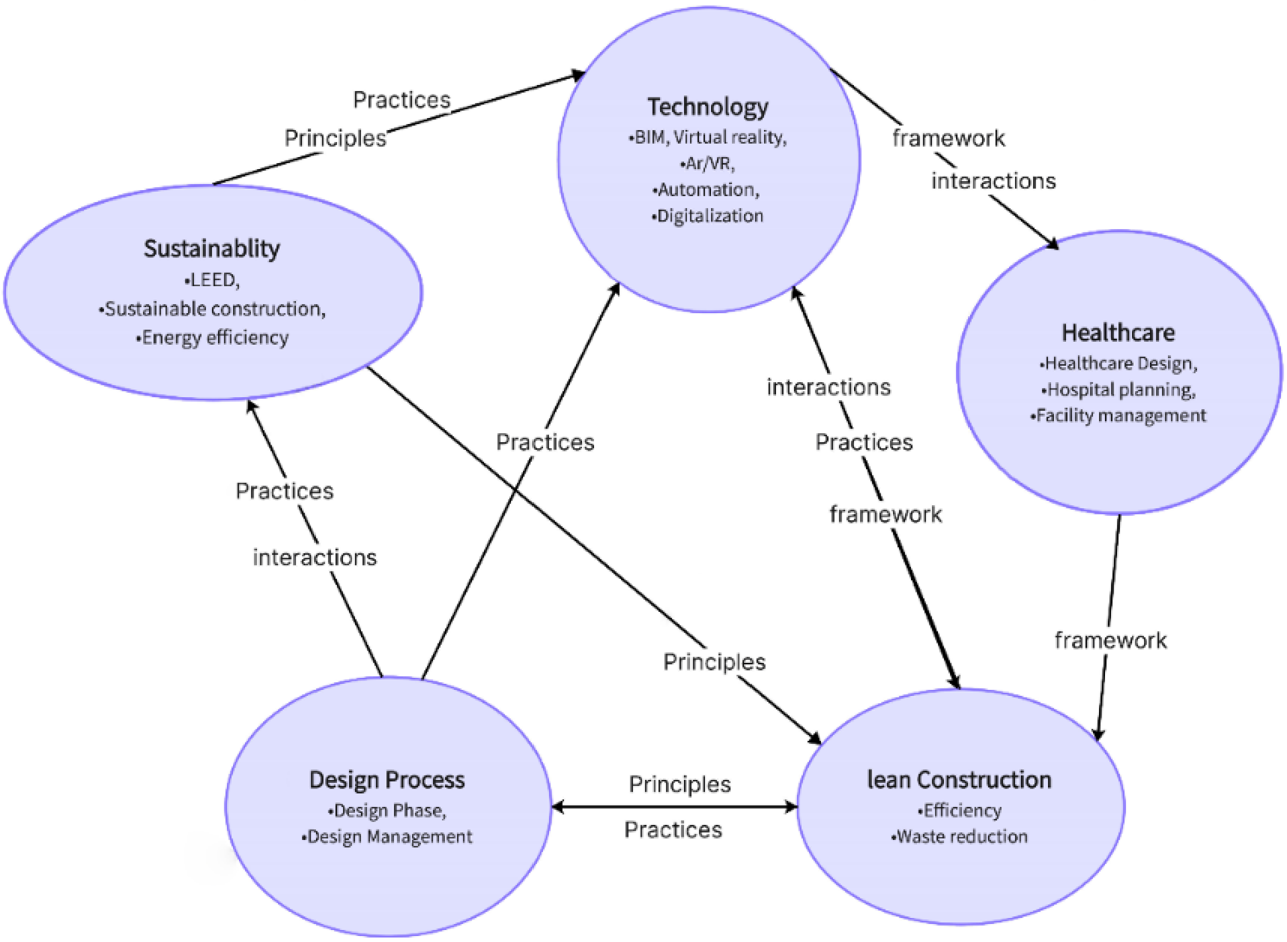

Figure 12 Conceptual Map

Assessing Robustness of the Synthesis

To assess the robustness of the synthesis, this discussion section addresses factors inherent in the narrative synthesis methodology that may influence the generalizability of the review's results (Busse et al., 2002).

3.2.3 Overall completeness and applicability of evidence:

The included studies sufficiently address the objectives of this review and provide an answer to the three interrelated research questions, though there is an existing gap in the literature regarding the comprehensive, longitudinal assessment of fully integrated BIM and Lean systems within operational hospital settings. The evidence demonstrates that the synergistic integration of BIM and Lean principles holds substantial promise for optimizing various facets of hospital planning and design. Specifically, the convergence of these methodologies enhances spatial visualization, facilitates conflict resolution, and enables data-driven decision-making, thereby streamlining resource allocation and minimizing waste. However, the applicability of these findings is primarily concentrated in the design and construction phases, with fewer studies examining the long-term operational impacts. Further research is needed to explore the contextual factors influencing BIM and Lean integration, and to develop standardized frameworks for broader implementation across diverse healthcare settings.

3.2.4 Quality of the evidence:

Assessing the quality of evidence involved considering limitations in the primary studies, as recommended by GRADE. While there is potential for bias in the included studies, this review employed quality assessment criteria to mitigate its influence on the overall findings. These criteria prioritized transparency, accuracy, and completeness. It is important to note that, as described by Whiting et al. (2016), a systematic review can achieve a low risk of bias even when the included studies have a higher risk of bias, provided that the review adequately addresses and accounts for those individual biases.

3.2.5 Potential biases in the review process:

The six-year timeframe of this study, concluding in October 2024, presents a potential for bias due to the increasing volume of relevant evidence emerging towards the end of this period. Studies published after this cutoff were not included, potentially overlooking significant recent findings. Furthermore, the exclusive focus on healthcare buildings limits the generalizability of the findings to other building types. While conducting simultaneous searches across three major databases aimed to enhance the comprehensiveness of the review and mitigate the limitations of individual databases, the process was resource-intensive, particularly in the meticulous task of identifying and removing duplicate entries. These constraints underscore important considerations for future research in this area

4 Discussion and Future Enhancements

The findings of this review have several important implications, particularly for advancing sustainable hospital development. The consistent emphasis on BIM's role in supporting Lean principles suggests that technology plays a crucial role in enabling more efficient and collaborative hospital projects, which directly contributes to sustainability goals. Lean principles focus on minimizing waste in resources, time, and effort; when combined with BIM's ability to accurately simulate and visualize building performance, the potential for sustainable outcomes is significantly enhanced.

This synergy aligns with broader theories of technology adoption in the AEC industry, such as the Technology Acceptance Model (TAM), which posits that perceived usefulness and ease of use drive technology adoption. The reviewed studies indicate that BIM is perceived as useful for waste reduction and collaboration, which encourages its use in Lean workflows, ultimately leading to more sustainable practices.

However, the variability in BIM and Lean implementation across different case studies highlights the influence of contextual factors on achieving sustainability. Cultural differences, for example, can affect collaboration and communication practices, which are critical for both BIM and Lean success in driving sustainable outcomes. Regulatory environments, such as building codes and sustainability standards (e.g., LEED), can also shape how BIM and Lean are applied.

For instance, stricter sustainability regulations may drive a greater emphasis on BIM's energy modeling capabilities within a Lean framework to optimize building performance and reduce environmental impact. These contextual variations underscore the need for adaptable implementation strategies to maximize the sustainability benefits of BIM-Lean integration.

Future research should address several areas to further explore and enhance the link between BIM, Lean, and sustainability. Longitudinal studies are needed to assess the long-term impact of integrated BIM-Lean approaches on hospital sustainability, including energy consumption, carbon footprint, and lifecycle costs. More research is also required to develop standardized frameworks and guidelines that can help practitioners effectively implement BIM and Lean for sustainability across diverse contexts. Additionally, there is a need for studies that explore the perspectives of various stakeholders, such as healthcare professionals and patients, on how BIM-Lean integration affects the sustainability of hospital environments and their well-being.

Finally, comparative studies across different countries or regions could provide valuable insights into the influence of cultural and regulatory factors on the success of BIM-Lean strategies in achieving global sustainability goals within healthcare infrastructure.

5 CONCLUSION:

The findings of this systematic review underscore the burgeoning recognition within academia of the pivotal role that BIM, integrated with sustainable design and lean construction principles, can play in the planning and design stages of healthcare buildings. The pronounced research focus on the "Design" phase across various intersections emphatically highlights the critical importance of leveraging these tools early in the project lifecycle. By strategically implementing BIM during planning and design, stakeholders can foster enhanced collaboration, improve information management, optimize spatial layouts, simulate building performance, and ultimately make more informed decisions that contribute to resource efficiency and reduced environmental impact.

The significance of this integrated approach extends beyond individual project benefits. In the context of sustainable development, particularly in a rapidly developing nation like Egypt, the adoption of BIM-enabled sustainable design and lean construction practices in healthcare infrastructure is of paramount importance. These vital buildings, serving critical societal needs, necessitate resource-efficient designs that minimize their environmental footprint throughout their lifecycle, from material selection to operational energy consumption. Furthermore, lean principles embedded within the design and construction processes can lead to significant cost savings and reduced project timelines, allowing for more efficient allocation of resources to meet the growing healthcare demands.

6 Future Enhancements:

While the current research landscape demonstrates a strong initial focus, several avenues for future research and development warrant consideration to further advance the effective integration of BIM, sustainability, and lean principles in healthcare building projects, particularly within the Egyptian context:

Quantitative Impact Assessment: Future research should prioritize quantitative studies that rigorously measure the actual impact of BIM-enabled sustainable design and lean construction on key performance indicators (KPIs) such as energy consumption, waste generation, project costs, and construction timelines in healthcare projects

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