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A CONCEPTUAL FRAMEWORK FOR SUSTAINABLE HOSPITAL DESIGN: SYNERGIZING QFD, LEAN DESIGN MANAGEMENT, AND BIM TO REALIZE SUSTAINABILITY BENCHMARKS IN THE DESIGN PHASE

Eman Eid Attya[1], Mohamed Adel Shebl[2] and Raghda Elsayed assabAllah[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

Acknowledging the urgent need for enhanced sustainability within the resource-intensive healthcare construction sector, this theoretical research introduces an integrated conceptual framework designed to promote holistic sustainability in hospital development. The proposed framework strategically synthesizes environmental stewardship, economic viability, and social equity considerations with the operational efficiencies of Lean Construction principles and the advanced information management capabilities of Building Information Modeling (BIM). To effectively capture and prioritize diverse stakeholder needs, Quality Function Deployment (QFD) is incorporated as a key mechanism for translating sustainability benchmarks into tangible design and management parameters. The study employs a rigorous literature review across the domains of construction management, healthcare sustainability, Lean thinking, and BIM implementation. The innovative application of QFD within this framework aims to delineate the synergistic relationships between sustainability targets, Lean methodologies focused on process optimization, and BIM functionalities enabling comprehensive project lifecycle management. This research contributes a robust theoretical model for practitioners and scholars seeking to embed sustainability within contemporary hospital construction management practices, with the overarching goals of optimizing resource utilization and minimizing waste. Although primarily conceptual, the anticipated impact of this framework lies in its potential to drive advancements in sustainable hospital building practices, thereby addressing growing healthcare demands while concurrently considering environmental, economic, and social imperatives. Context-specific recommendations are further articulated to facilitate the effective adoption of this framework within the Egyptian healthcare project landscape.

Keywords
Integrated Approach, Healthcare Construction, Design Optimization, User Requirements, Lifecycle Management

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إطار مفاهيمي شامل لتصميم مستشفيات مستدامة: دمج إدارة الجودة الشاملة (QFD)، وإدارة التصميم الرشيد ونمذجة معلومات البناء (BIM) لتحقيق معايير الإستدامة في مرحلة التصميم

ملخص البحث

إدراكًا للحاجة المُلِحّة لتعزيز الاستدامة في قطاع إنشاءات الرعاية الصحية كثيف الموارد، يُقدّم هذا البحث النظري إطارًا مفاهيميًا متكاملًا مُصمّمًا لتعزيز الاستدامة الشاملة في تطوير المستشفيات. يُركّز الإطار المُقترح استراتيجيًا على الإدارة البيئية، والجدوى الاقتصادية، واعتبارات العدالة الاجتماعية، مع الكفاءات التشغيلية لمبادئ البناء الرشيد، وقدرات إدارة المعلومات المُتقدّمة لنمذجة معلومات البناء (BIM). ولضمان فعّالية تحديد أولويات احتياجات أصحاب المصلحة المُتنوّعين، تمّ دمج نشر وظيفة الجودة (QFD) كآلية رئيسية لترجمة معايير الاستدامة إلى معايير تصميم وإدارة ملموسة. وتعتمد الدراسة على مراجعة دقيقة للأدبيات في مجالات إدارة البناء، واستدامة الرعاية الصحية، والتفكير الرشيد، وتطبيق نمذجة معلومات البناء. ويهدف التطبيق المُبتكر لنشر وظيفة الجودة ضمن هذا الإطار إلى تحديد العلاقات التآزرية بين أهداف الاستدامة، ومنهجيات البناء الرشيد التي تُركّز على تحسين العمليات، ووظائف نمذجة معلومات البناء التي تُتيح إدارة شاملة لدورة حياة المشروع. يُسهم هذا البحث في بناء نموذج نظري متين للممارسين والباحثين الساعين إلى دمج الاستدامة في ممارسات إدارة بناء المستشفيات المعاصرة، بهدفين رئيسيين هما تحسين استخدام الموارد وتقليل الهدر. ورغم أن هذا الإطار نظري في المقام الأول، إلا أن الأثر المتوقع له يكمن في قدرته على دفع عجلة التقدم في ممارسات بناء المستشفيات المستدامة، وبالتالي تلبية الاحتياجات المتزايدة للرعاية الصحية، مع مراعاة الضرورات البيئية والاقتصادية والاجتماعية في الوقت نفسه. كما يُقدم توصيات خاصة بكل سياق لتسهيل التطبيق الفعال لهذا الإطار في المشهد العام لمشاريع الرعاية الصحية في مصر.

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1. Introduction

The healthcare sector is currently undergoing a significant transformation, propelled by rapid technological advancements and an increasing awareness of the importance of sustainability. Amidst societies' pursuit of a more sustainable future, healthcare facilities stand out as entities with substantial environmental and social impacts, owing to their intricate nature and intensive resource consumption. Despite the prevailing notion of a conflict between the demands of modern healthcare and the principles of sustainability, research indicates that integrating sustainability into the design of these buildings not only conserves the environment but also extends to enhancing the patient experience and fostering the healing process. Indeed, the surrounding environment plays a pivotal role in patients' psychological well-being and the acceleration of their recovery.

In this context, the construction sector, including hospital construction, assumes paramount importance in addressing global environmental challenges. The urgent need to shift this sector towards "green" practices through waste reduction, maximization of resource efficiency, and the adoption of sustainable building solutions renders green hospitals an integral component of the comprehensive solution to these challenges

To facilitate the realization of these ambitious objectives in the design and construction of contemporary hospitals, Building Information Modeling (BIM) technology emerges as a fundamental tool. By providing an accurate three-dimensional digital model of the project, BIM enables effective collaboration and coordination among all stakeholders. Furthermore, it allows for realistic simulations of the hospital design, offering a valuable opportunity for medical staff and stakeholders to experience the spaces and provide their feedback prior to the commencement of construction activities.

The role of BIM is particularly amplified when adopting the Integrated Project Delivery (IPD) approach, which fosters close collaboration among all participants, positioning BIM as a crucial platform for seamless communication and effective interaction. Studies, such as the case of the cancer center in Taiwan, have demonstrated how the integration of BIM with virtual reality technologies can enhance stakeholders' comprehension of the design and mitigate communication gaps with design teams. Consequently, BIM stands as a pivotal instrument for optimizing hospital design and construction by providing detailed models and fostering collaboration among working teams. Nevertheless, the construction sector encounters challenges in simulating complex projects, necessitating the adoption of a "re-engineering" culture and the leveraging of technologies such as BIM to enhance processes.

The lifecycle of a hospital building comprises multiple phases, with the design stage serving as a cornerstone where critical decisions are made that determine the long-term performance and efficiency of the facility. Investing in meticulous planning and design significantly mitigates the costs associated with subsequent modifications during the construction and operational phases. To achieve success in this stage, effective collaboration among diverse work teams is paramount. Consequently, the efficient management of the design process, encompassing planning, organization, and supervision, is essential to ensure the realization of project objectives. Recent years have witnessed the development of tools and systems aimed at enhancing design management efficiency, including information and communication technologies such as BIM. However, the effectiveness of the design process is not solely reliant on technology; social factors, such as communication and cooperation, play a crucial role in its success.

Lean Management principles and their associated tools have emerged as promising solutions for improving the design management process. Case studies have illustrated how the application of the Last Planner System (LPS) in the design phase can enhance stakeholder satisfaction. Furthermore, other research has underscored that the use of LPS and collaborative planning fosters trust and commitment among team members, which are fundamental elements for effective team performance. Additionally, the Integrated Project Delivery (IPD) model has emerged as a novel system seeking to improve collaboration and performance in projects through supply chain integration. Lean Design incorporates essential elements such as client engagement, value maximization, and concurrent design execution, with the aim of minimizing waste and rework. Several Lean tools can be applied in Lean Design, including Target Value Design (TVD), Set-Based Design (SBD), BIM, Choosing By Advantages (CBA), and LPS. A matrix linking Lean Construction principles and BIM functionalities has been proposed, opening new avenues for research. Studies have concluded that the application of Lean principles in the design of construction projects enhances efficiency and quality; however, the level of implementation varies across projects, necessitating the need for tools to assess and improve this application.

In a similar vein, Quality Function Deployment (QFD) stands as a robust tool for systematically linking customer requirements to design specifications, with the overarching goal of achieving customer satisfaction. QFD has been successfully implemented across diverse fields, including the construction sector, to enhance project quality and meet user needs. Furthermore, QFD has been employed in the design of sustainable buildings and green hospitals to address user requirements while considering environmental aspects. Comparisons between QFD-driven design and intuitive design have demonstrated the superiority of QFD in achieving higher energy efficiency. Case studies further illustrate how QFD can be applied using the House of Quality (HoQ) matrix to ensure the fulfillment of user needs in various building types.

Against this backdrop, the integration of Building Information Modeling (BIM) and Lean methodologies emerges as a promising trend for enhancing the planning and design of healthcare projects. With the growing awareness of the significance of Lean construction and sustainability, the amalgamation of these approaches becomes an imperative for achieving a balance between environmental, economic, and social demands. BIM plays a crucial role in realizing the objectives of Lean construction by generating detailed three-dimensional models and integrating engineering and operational data. This integration enables engineers and designers to evaluate designs with greater precision and identify potential issues early on, thereby reducing costs, time, and effort. Specifically in hospital design, the incorporation of BIM contributes to improved design quality, increased energy efficiency, cost reduction, enhanced health and safety for patients and staff, and the facilitation of operational and maintenance processes.

This research proposes an integrated BIM-Lean-Green System for Healthcare Construction and Facility design (BLS-HCAF) as an innovative approach to re-engineer the building and construction industry, with a particular emphasis on optimizing design processes in the early stages. This approach seeks to achieve an effective synergy between Lean methodologies and Building Information Modeling (BIM) to address the existing research gap and maximize potential benefits. Furthermore, it aims to foster workflow optimization, achieve added value, enhance transparency, and improve communication and effective coordination among stakeholders, while also promoting environmental stewardship in sustainable healthcare projects.

2. METHODOLOGY

Research (DSR) as its constructive research strategy, aiming to address real-world challenges. This methodology has demonstrated its efficacy and broad applicability across diverse domains such as healthcare, information management, and engineering. DSR provides a systematic structure for the development of innovative tools, frameworks, and models that contribute to resolving complex problems encountered by various industries, including the building and construction sector.

Within the context of this research, the Design Science Research process model proposed by Peffers et al. is employed, comprising six fundamental stages. These stages encompass: the identification of the research problem, the definition of the knowledge gap, the design and development process, the demonstration of the proposed solution, the comprehensive evaluation, and finally, the communication and dissemination of the findings. This methodological model aligns closely with the primary objectives of this study, which center on the development of a novel framework (BLS-HCAF) targeting the issue of integrating Building Information Modeling (BIM) technology and Lean management practices in the planning and design phases of healthcare facilities.

By leveraging the iterative and developmental flexibility inherent in the Design Science Research (DSR) methodology, this research endeavors to make a valuable contribution to the field of sustainable hospital design by providing practical tools for engineers and designers to enhance the quality of healthcare and reduce environmental impact.

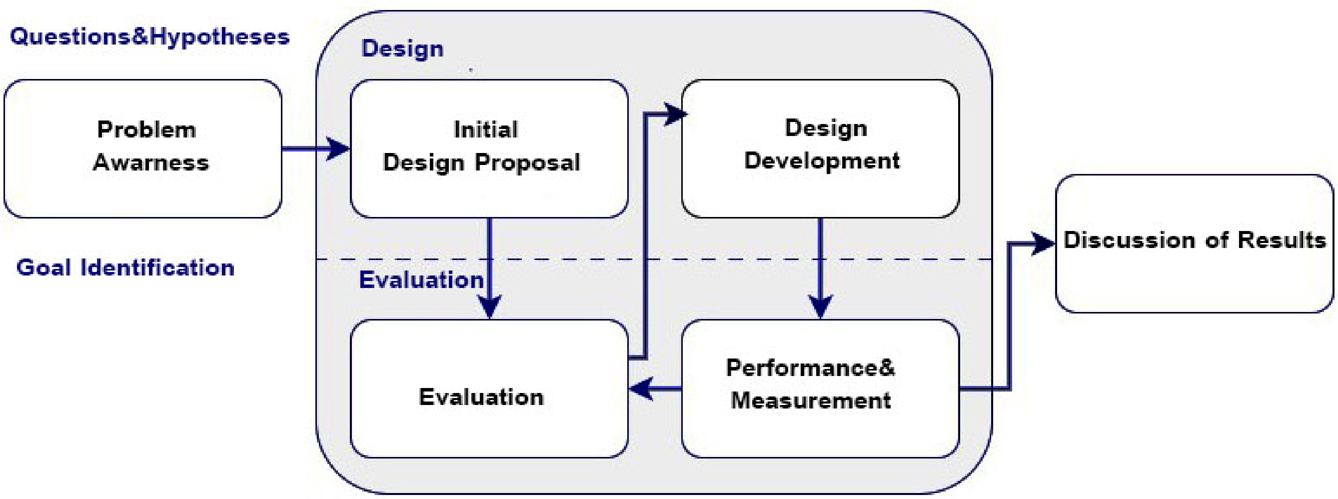

FIGURE 1 The Dsr Methodology Applied To Our Research
Source1: Authors, 2024

3. Literature Review

3.1 Sustainability in Hospitals

Healthcare facilities represent complex structures that integrate multiple functionalities, serving simultaneously as spaces for accommodation, treatment, and work. With the increasing reliance on advanced technology within the health sector, some perceive the achievement of sustainability in these buildings as challenging, if not contradictory to the demands of modern healthcare. Nevertheless, the concept of sustainability has become a global imperative, extending beyond the mere preservation of the environment and natural resources to encompass the enhancement of patients' quality of life and the promotion of their recuperative capacities. Research indicates that the patient's surrounding environment plays a crucial role in the recovery process, and that achieving sustainability in healthcare buildings directly contributes to patients' psychological well-being [[1]].

The building and construction sector in general, including hospitals, plays a vital role in addressing environmental challenges. As highlighted by the Governor's Green Government Council of Pennsylvania (2014), there is an urgent need to transform the construction sector into a "green" industry through waste reduction, maximization of resource efficiency, and the implementation of sustainable building solutions. Consequently, green hospitals are not merely buildings but rather an integral component of a comprehensive solution to confronting global environmental challenges [[2]].

3.2 Building Information Modeling(BIM)

Building Information Modeling (BIM) is considered a fundamental technology in the design and construction of contemporary hospitals [[3]], providing an accurate three-dimensional model of the project that facilitates collaboration and coordination among diverse stakeholders [[4]]. BIM can be utilized to realistically simulate hospital designs, enabling medical personnel and stakeholders to experience the space and offer valuable feedback prior to the commencement of construction activities [[5]].

The adoption of the Integrated Project Delivery (IPD) approach in healthcare projects, which fosters collaboration among all involved parties, amplifies the significance of BIM

1 Sara Bensalem, 'Sustainable Healthcare Archi-Techure Designing a Healing Environment', 2015.
2 GGGC, 2014. What is a Green Building? Governor's Green Government Council, Pennsylvania, U.S.
3 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>.
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>.

as a platform for effective communication and interaction [6]. Through BIM, architects, medical staff, and contractors can collaboratively develop a design that meets the needs of end-users and enhances the healthcare experience [7].

Furthermore, studies, such as the case study of the cancer center in Taiwan, have demonstrated that integrating BIM technology with virtual reality can enhance stakeholders' comprehension of the design and reduce the communication gap between them and the design teams. This approach provides an interactive environment that allows users to experience the space more realistically and provide more precise feedback [8].

Consequently, BIM stands as an essential tool for optimizing the design and construction of hospitals, offering detailed three-dimensional models and contributing to enhanced collaboration among the various teams working on the project [9]. However, the construction industry in general faces challenges in simulating projects prior to their execution due to their scale and complexity. To address this issue, a culture of "re-engineering" and the adoption of cutting-edge technologies such as BIM are necessary to improve production processes [10].

3.3 The Design and Planning Process for Hospital Buildings

The lifecycle of a hospital building encompasses several stages, commencing with initial planning and extending to the final decommissioning of the facility [11]. The design phase

6 Roar Fosse, Glenn Ballard, and Martin Fischer, 'Virtual Design and Construction: Aligning BIM and Lean in Practice', *IGLC 2017 - Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, July, 2017, 499–506 <https://doi.org/10.24928/2017/0159>.

7 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>.

8 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>.

9 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

10 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

11 PMI. A Guide to the Project Management Body of Knowledge (PMBOK® Guide), 6th ed.; Project Management Institute, Ed.; Project Management Institute: Newtown Square, PA, USA, 2017; ISBN 9781628251845.

constitutes a cornerstone within this lifecycle, as critical decisions are made that significantly determine the building's long-term performance and efficiency. Notably, the costs associated with implementing modifications during the design phase are substantially lower compared to those incurred during the construction and operational stages [[12]].

Effective collaboration among diverse work teams in construction projects, such as architects and civil engineers, is paramount for achieving success. Weak interactions among team members can lead to rework and project delays, consequently increasing costs and negatively impacting design quality [[13]]. Therefore, the effective management of the design process is essential to ensure the attainment of project objectives. Design management encompasses the planning, organization, and supervision of all facets of the design process, from the initial definition of project requirements to the completion of final design documentation [[14]].

Recent years have witnessed a growing emphasis on the development of tools and systems for more efficient design management. These tools include information and communication technologies, such as Building Information Models (BIM), which enable the creation of detailed three-dimensional building models and facilitate collaboration among team members [[15]].

However, technology alone is insufficient to guarantee project success. Social factors, such as communication and cooperation among team members, play a crucial role in the success of the design process. Certain tools grounded in Lean principles have

12 PMI. A Guide to the Project Management Body of Knowledge (PMBOK® Guide), 6th ed.; Project Management Institute, Ed.; Project Management Institute: Newtown Square, PA, USA, 2017; ISBN 9781628251845.

13 Karim EL Mounla and others, 'Lean-BIM Approach for Improving the Performance of a Construction Project in the Design Phase', *Buildings* (MDPI, 2023) <https://doi.org/10.3390/buildings13030654>.

14 Svetlana S. Uvarova, Alexandr K. Orlov, and Vadim S. Kankhva, 'Ensuring Efficient Implementation of Lean Construction Projects Using Building Information Modeling', *Buildings*, 13.3 (2023) <https://doi.org/10.3390/buildings13030770>.

15 José Luis Salvatierra and others, 'Developing a Benchmarking System for Architecture Design Firms', *Engineering, Construction and Architectural Management*, 26.1 (2019), 139–52 <https://doi.org/10.1108/ECAM-05-2018-0211>.

demonstrated their effectiveness in fostering collaboration and building trust among team members, thereby contributing to improved project performance [16].

3.4 Lean Design

Evidence suggests the application of Lean Management principles and several of its associated tools within the design management process [17]. Furthermore, a case study demonstrated a transition from traditional planning to the utilization of the Last Planner System (LPS) in the design phase, resulting in enhanced stakeholder satisfaction [18]. Another study [19] corroborated that the implementation of the Last Planner System and collaborative planning fostered trust and commitment among team members, which are essential elements for effective team performance [20].

Integrated Project Delivery (IPD) has also emerged as a novel project delivery system, offering increased collaboration and improved performance through supply chain integration [21]. Lean Design integrates several fundamental elements within the design phase, such as active client engagement, value maximization, identification of all stakeholders' needs, concurrent design execution, and the deferral of decisions, with the overarching aim of minimizing rework [22].

Several Lean tools can be employed in Lean Design, including Target Value Design (TVD), Set-Based Design (SBD), Building Information Modeling (BIM), Choosing By

16 Rebecca Arkader, 'The Perspective of Suppliers on Lean Supply in a Developing Country Context', *Integrated Manufacturing Systems*, 12.2 (2001), 87–93 <https://doi.org/10.1108/09576060110384280>.
17 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
18 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.
19 Conference Paper and Vegard Knotten, 'Improving Design Management With Improving Design Management', July, 2016.
20 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>.
21 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>.
22 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>.

Advantages (CBA), and LPS [23]. Additionally, a matrix linking Lean Construction principles with BIM functionalities has been proposed, opening new avenues for research [24].

A study concluded that the application of Lean principles in the design of construction projects enhances efficiency and quality. However, the implementation of these practices varies significantly across projects, underscoring the need for tools to assess and improve their level of application.

3.5 The Significance of Integrating Building Information Modeling and Lean Methodologies in Healthcare Project Planning and Design

In light of escalating environmental challenges, the concepts of Lean construction and sustainability have become imperative across all sectors, including healthcare. Lean construction endeavors to achieve a balance between environmental, economic, and social needs by minimizing energy and water consumption, reducing waste, improving indoor air quality, and utilizing environmentally friendly building materials [25].

Building Information Modeling (BIM) plays a crucial role in realizing these objectives by enabling the creation of detailed three-dimensional project models and the integration of diverse engineering and operational data [26]. Leveraging these models, engineers and designers can evaluate building designs with greater accuracy and identify potential issues prior to the commencement of construction, thereby contributing to the reduction of costs, time, and effort [27]. Within the context of hospital design, BIM contributes to enhanced

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23 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.

24 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/>.

25 UNEP. (2019). Building a sustainable future: A global outlook on buildings and climate change. United Nations Environment Programme.

26 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>.

27 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.

design quality, increased energy efficiency, cost reduction, improved health and safety for patients and staff, and the facilitation of operational and maintenance processes [[28]].

The integrated BIM-Lean-Green System for Healthcare Construction and Facility design (BLS-HCAF) represents a novel approach seeking to reshape the building and construction industry. It primarily proposes enhancements in design processes through the adoption of new tools and methodologies capable of fostering flow and value, and promoting transparency, communication, and coordination among stakeholders, alongside an environmental commitment from the design team. The aim is to prevent costly and detrimental defects in subsequent phases such as construction, operation, and maintenance.

Studies indicate a strong synergy between Lean methodologies and Building Information Modeling (BIM) in optimizing the design and execution of healthcare projects. By integrating these approaches, significant improvements in process efficiency, cost reduction, and enhanced sustainability can be achieved. However, a research gap persists in exploring how to maximize these benefits in the early stages of design.

The researcher posits that the adoption of an integrated approach encompassing BIM, Lean, and Sustainable practices (BLS-HCAF) can provide an effective framework for achieving these objectives. By leveraging BIM tools and data analytics, the design team can optimize decision-making, minimize waste, and foster enhanced collaboration among diverse stakeholders. Furthermore, Lean methodologies can contribute to streamlining processes, improving workflow, and reinforcing adherence to environmental goals.

The integrated BIM-Lean-Green System for Healthcare Construction and Facility design (BLS-HCAF) represents an innovative approach to re-engineer the building and construction industry, proposing substantial enhancements in design processes. This is achieved through the application of novel tools and methodologies capable of promoting workflow optimization, realizing added value, and increasing the level of transparency, alongside improving communication and effective coordination among stakeholders, and fostering the design team's environmental commitment. The overarching aim of this approach is to prevent costly and detrimental defects that may manifest in subsequent phases, such as construction, operation, and maintenance. Studies underscore a strong

[28] 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>.

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synergy between the application of Lean methodologies and the utilization of Building Information Modeling (BIM) in optimizing the design and execution of healthcare projects. Through the effective integration of these approaches, tangible improvements in process efficiency, overall cost reduction, and enhanced sustainability can be realized. However, a notable gap persists in research exploring how to maximize these potential benefits, particularly in the early stages of the design process. In this context, the researcher suggests that the adoption of an integrated approach combining BIM, Lean, and Sustainable practices (BLS-HCAF) would provide an effective framework for achieving these ambitious goals. Through the optimal utilization of BIM tools and detailed data analysis, the design team becomes capable of enhancing the quality of decision-making, reducing resource waste, and fostering effective collaboration among various stakeholders. Moreover, Lean methodologies contribute to simplifying complex processes, improving workflow, and reinforcing commitment to specific environmental objectives.

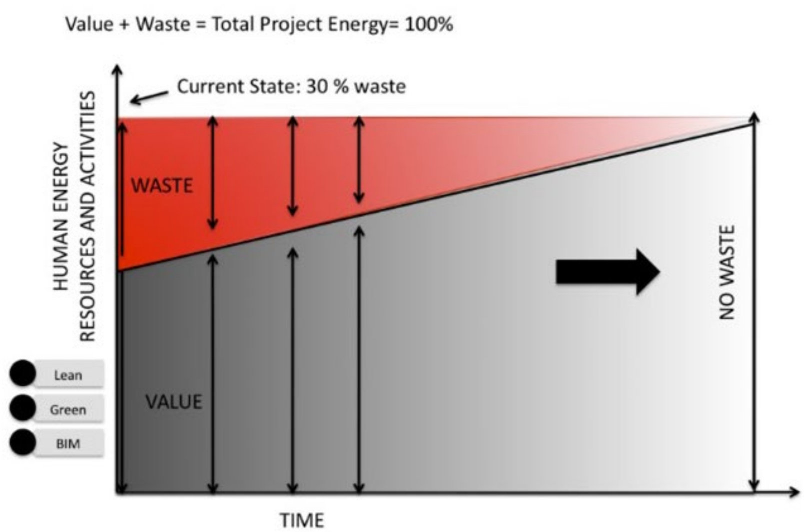

FIGURE 2 Project Energy Without Synergistic Integration

The adoption of this integrated approach in the early stages of design holds the potential to yield long-term positive outcomes, such as improved healthcare quality, reduced operational costs, and enhanced environmental sustainability. However, its successful

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implementation necessitates a shared understanding and a clear framework to enable design teams to fully leverage these technologies and methodologies [29].

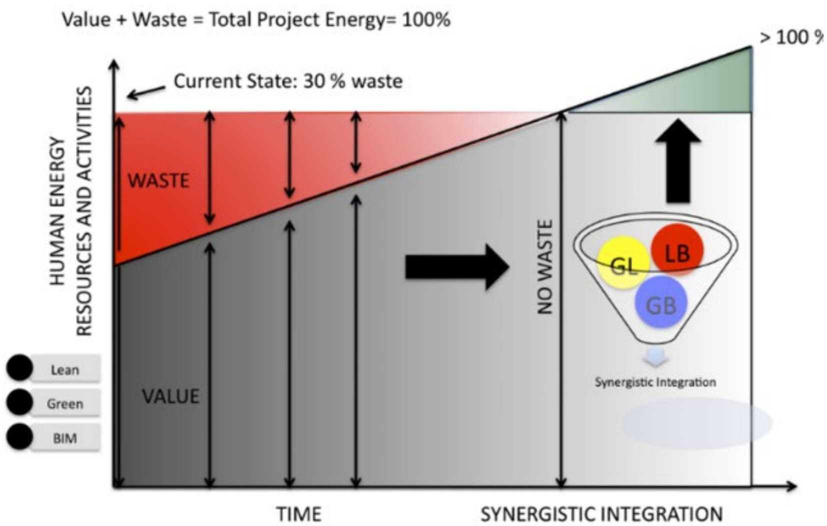

FIGURE 3 Project Energy Vs Gbl Synergistic Integration

As illustrated by (Figure 2) and (Figure 3), the construction industry grapples with significant levels of waste, with studies indicating that approximately 30% of resources are wasted during construction processes. Nevertheless, this waste can be substantially mitigated through the adoption of an integrated approach that combines Lean methodologies, Building Information Modeling, and Green practices (BLS-HCAF).
This integrated approach facilitates improved collaboration and coordination among diverse stakeholders, leading to waste reduction and accelerated project completion, as demonstrated in the comparison between Figure 2 and Figure 3 [30]. Furthermore, this approach enhances the effectiveness of both human and material resources, resulting in superior outcomes compared to the isolated application of each methodology. Consequently, the integration of BLS-HCAF provides a comprehensive framework for optimizing the performance of construction projects by emphasizing systems thinking and waste minimization.

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29 Enache-Pommer, E (2010) A synergistic approach to green building delivery, lean principles and building information modeling in the design of healthcare facilities, Unpublished PhD Thesis, , The Pennsylvania State University.
30 Ballard , G. , Liu , M. , Kim Y.W. , Jang , J.W. 2007. Roadmap for Lean implementation at the Project Level. Construction lndustry lnstitute, University of Texas, U.S.

4. Conceptual Framework

To establish the conceptual framework for this research, a comprehensive review of established scientific methodologies for framework development was undertaken. This review encompassed an array of techniques, including Morphology Analysis (MA), Cross-Impact Matrix (CM), Multi-Criteria Decision Analysis (MCDA) methods (such as the Analytical Hierarchy Process, ELECTRE, and Multi-Attribute Utility Theory), Design Structure Matrix (DSM), System Dynamics, and Quality Function Deployment (QFD). Each of these methods was subjected to rigorous scrutiny and analysis. The analytical process involved a critical assessment of each method's relevance to the specific research problem, alongside a detailed examination of its inherent advantages and limitations. Furthermore, a hypothetical application of each method was conducted to explore potential relationships between Sustainable Healthcare Standards, Lean Design Management practices, and BIM tools. The primary objective in selecting a suitable methodology was to align with the defined goals and requirements of the framework, which include the capacity to: (1) ascertain the relationship between two variables; (2) facilitate pairwise, in-depth, and root-level analysis; and (3) quantify the interconnection or relationship level. Following a meticulous evaluation of these diverse methodologies and a careful consideration of the aforementioned criteria, the researcher concluded that Quality Function Deployment (QFD) presents the most efficacious tool for the development of the conceptual framework. The subsequent section details how QFD effectively addresses the specified criteria.

4.1 Quality Function Deployment QFD

Quality Function Deployment (QFD) is a robust methodology employed to systematically link customer requirements to design specifications, thereby ensuring the production of products that meet customer expectations. This tool is predicated on the fundamental principle that customer satisfaction constitutes the ultimate objective of any productive process [31]. QFD is characterized by its capacity to translate qualitative customer needs

31 Akao, Y. (1990). Quality Function Deployment: Integrating Customer Requirements into Product Design. Productivity Press, Cambridge, MA.

into measurable quantitative specifications through the utilization of matrices, the most renowned of which is the "House of Quality" [32].

The Quality Function Deployment (QFD) method is a flexible tool applicable across diverse domains, including manufacturing, software development, and construction. Within the construction sector specifically, QFD has been successfully implemented to enhance project quality and address user requirements. This method has been utilized in the design of external wall panels [33], in the design of building interiors [34], and to mitigate design defects in buildings [35]. Furthermore, another study demonstrated that the application of QFD in construction projects contributes to the precise identification of user requirements and the establishment of strong relationships between users and contractors, ultimately leading to increased customer satisfaction [36].

In addition to these applications, QFD has been implemented in the design of sustainable buildings, where it has been employed to design green hospitals that meet user needs while considering environmental aspects [37]. A comparative study conducted between the QFD method and the intuitive design approach revealed that buildings designed using QFD exhibit approximately 10% lower energy consumption compared to those designed using traditional methods [38].

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32 David Arditi and Dong-Eun Lee, ‘Assessing the Corporate Service Quality Performance of Design-Build Contractors Using Quality Function Deployment’, *Construction Management and Economics*, 21.2 (2003), 175–85 <https://doi.org/10.1080/0144619032000079716>.

33 ROBERT L ARMACOST and others, ‘AN AHP FRAMEWORK FOR PRIORITIZING CUSTOMER REQUIREMENTS IN QFD: AN INDUSTRIALIZED HOUSING APPLICATION’, *IIE Transactions*, 26.4 (1994), 72–79 <https://doi.org/10.1080/07408179408966620>.

34 Serpell, A. L. F. R. E. D. O., & Wagner, R. O. D. O. L. F. O. (1997). Application of quality function deployment (QFD) to the determination of the design characteristics of building apartments. Lean construction, 355-363.

35 Luis Alarcon and Daniel Mardones, ‘Improving the Design-Construction Interface’, 1998.

36 Romeo John and others, ‘Awareness and Effectiveness of Quality Function Deployment (QFD) in Design and Build Projects in Nigeria’, *Journal of Facilities Management*, 12.1 (2014), 72–88 <https://doi.org/10.1108/JFM-07-2013-0039>.

37 Lincoln C Wood and others, ‘Green Hospital Design: Integrating Quality Function Deployment and End-User Demands’, *Journal of Cleaner Production*, 112 (2016), 903–13 <https://doi.org/https://doi.org/10.1016/j.jclepro.2015.08.101>.

38 Vilūnė Lapinskienė and Violeta Motuzienė, ‘Integrated Building Design Technology Based on Quality Function Deployment and Axiomatic Design Methods: A Case Study’, *Sustainable Cities and Society*, 65 (2021), 102631 <https://doi.org/https://doi.org/10.1016/j.scs.2020.102631>.

To illustrate the practical application of QFD, the House of Quality (HoQ) matrix was utilized in the design of a children's nursery, where user requirements were linked to design specifications to ensure the fulfillment of children's needs [39]. These studies collectively indicate that the QFD method is a powerful and effective tool for enhancing project quality within the construction sector, as it aids in identifying user requirements, improving the decision-making process, reducing costs, and increasing customer satisfaction.

4.2 Foundational Principles and Application Procedures of Quality Function Deployment

The Quality Function Deployment (QFD) methodology, often visually represented as the "House of Quality" owing to its diagrammatic structure, provides a systematic approach to product and service development. (Figure 4) illustrates a standard House of Quality (HOQ), delineating its various constituent elements. The QFD analytical process is structured into eleven distinct steps, each of which will be elaborated upon in the subsequent sections.

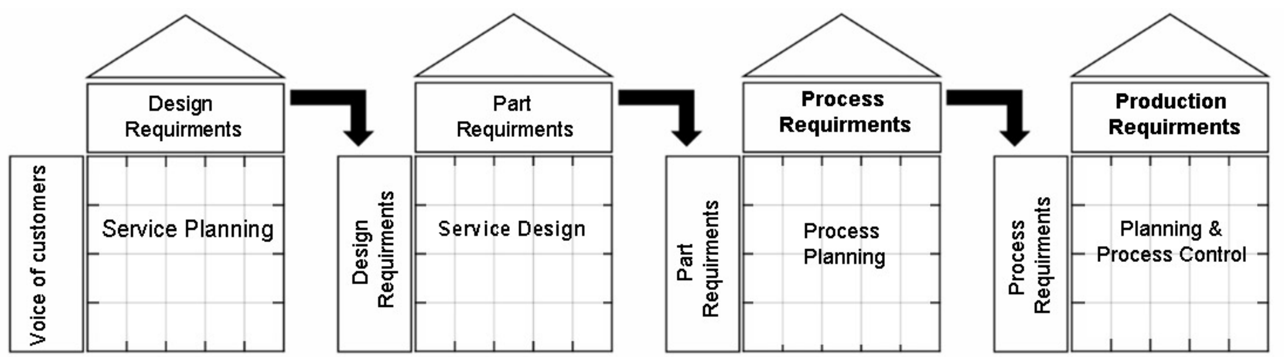

FIGURE 4 Stages of QFD

The implementation of QFD involves a series of matrices. In its complete application, four matrices are utilized. The initial matrix, due to the pictorial structure of the analysis process, is termed the House of Quality (HOQ). While the term "House of Quality" is often used synonymously with QFD, this primary matrix alone does not constitute the

39 David Joaquin Delgado-Hernandez, Katherine Elizabeth Bampton, and Elaine Aspinwall, 'Quality Function Deployment in Construction', *Construction Management and Economics*, 25.6 (2007), 597–609 <https://doi.org/10.1080/01446190601139917>.

entire implementation. The HOQ takes customer requirements and translates them into technical (design) requirements. Subsequently, the second matrix transforms these technical requirements into part characteristics, which are then expressed in terms of process requirements in the third matrix. Finally, quality control specifications are established in the concluding matrix.

The HOQ constitutes a critical element within the QFD process as it captures the voice of the customer and establishes a pathway to guide subsequent efforts [[40]]; it is the most frequently employed component of QFD. The steps involved in developing the HOQ are outlined in the subsequent text. (Figure 4) [41] illustrates the constituent elements of the House of Quality (HOQ). Each element is numbered according to the sequence of its completion during the HOQ construction. The analysis process within QFD is segmented

into 11 steps, which will be discussed in the following sections (Figure 5).

Voice of customers (1)

The initial step in the QFD process involves the identification of customer requirements, which delineate the priorities of customer demands or needs and are typically expressed in broad terms. These customer needs (requirements) are commonly gathered through surveys, interviews, focus groups, and other comparable methodologies [[42]].

Customer requirement weighting (2)

The subsequent step involves prioritizing the customer requirements (voice of the customer) by assigning a weight that reflects the significance of each requirement. Typically, the weight is expressed as a percentage and can be determined through surveys or online questionnaires. It is also crucial to gather the importance rating of each need during the identification of customer requirements. Customer needs can be defined at primary, secondary, and tertiary levels, with each level providing increasing detail about

[40] Herzwurum G. and Schockert S. (2006), "What are the best practices of QFD?", Proceedings of the 12th International Symposium on Quality Function Deployment. Tokyo.

[41] Ouda, H. (n.d.). . *A Futuristic Vision for Employing Quality Function Deployment (QFD) As an Ap* https://www.researchgate.net/publication/326985944

[42] Herzwurum G. and Schockert S. (2006), "What are the best practices of QFD?", Proceedings of the 12th International Symposium on Quality Function Deployment. Tokyo.

the expressed need. These customer needs, sometimes referred to as the "Whats," are transformed into technical requirements, known as the "Hows," in the subsequent step.

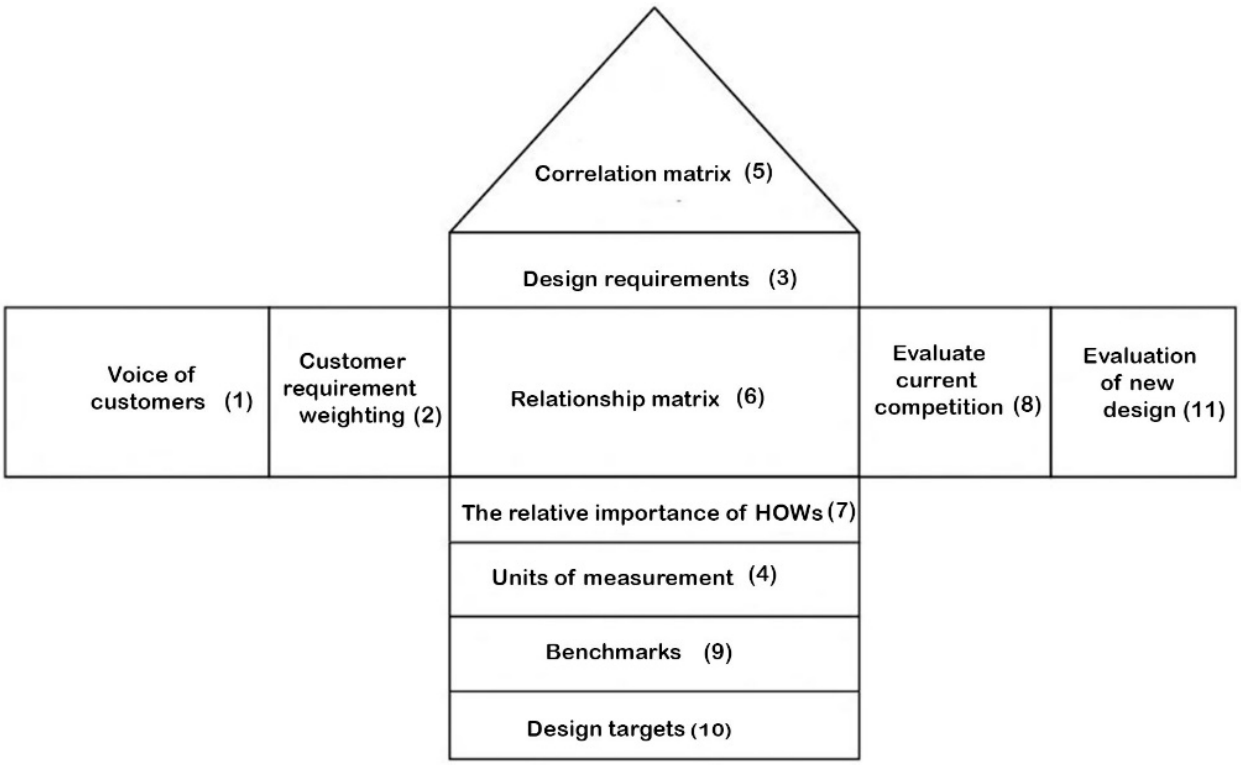

FIGURE 5 Formation (Steps) of House of Quality
Source: Authors, 2024

Design requirements (3)

In the third step, the design requirements must be translated into quantifiable technical measures, which represent the means of achieving the customer requirements. Design requirements are the technical requirements or design characteristics of the product or service that significantly influence the fulfillment of customer needs. These requirements represent the product's characteristics from a technical standpoint and are typically defined by the product development company. These characteristics are selected in a manner that best fulfills the customer requirements.

Units of measurement (4)

To ensure clarity in communication, the units of measurement (e.g., meters for length) must be established with utmost precision to prevent any potential misunderstandings.

Correlation matrix (5)

The correlation matrix represents the relationships between the design requirements, with the roof of the HOQ being used to illustrate this correlation. It aids in determining whether design requirements positively or negatively influence other design requirements. The product development team evaluates the relationship between the design requirements or characteristics. This helps the product development team understand how they impact each other's performance and how they collectively affect the fulfillment of customer requirements. To visually represent these correlations, the following symbols are used: (●) to denote a strong positive correlation, (○) to indicate a positive correlation, (❌) to represent a negative correlation, and finally, (❎) to signify a strong negative correlation.

Relationship matrix (6)

The relationship matrix elucidates the influence of design requirements on customer requirements. By assigning a weighted score (on a scale of 1 to 9, where 9 signifies a very strong influence and 1 a very weak influence) within the matrix, the strength of the correlation can be determined. This relationship matrix forms the core of QFD analysis. It establishes the significance of technical characteristics in satisfying customer requirements. Based on the impact of technical requirements or design attributes on the fulfillment of customer needs, the product development team assigns a rating to each customer requirement and design characteristic.

In QFD analysis, the linkage between customer needs (listed in the left-hand column) and technical requirements (listed at the top) is established through what is known as the "relationship matrix" (as depicted in Figure 5). To quantify the strength of these relationships, specific symbols and corresponding scores are employed. A solid circle (●) indicates a strong relationship and is assigned a score of 9 points. An open circle (○) denotes a medium relationship, receiving 3 points. Finally, a triangle (r) represents a weak relationship, valued at 1 point. It is imperative that each technical requirement exhibits at least one strong correlation with a customer requirement; otherwise, it may suggest an inadequate fulfillment of a customer need. Conversely, if a technical requirement lacks any strong correlation with any of the customer needs, it is advisable to exclude this technical requirement from the QFD analysis.

The relative importance of HOWs (7)

Within the design characteristics of QFD, it is also essential to establish their priorities based on their significance. To achieve this, each of the design characteristics' weights (derived in Step 6) should be multiplied by the priority rating (determined in Step 2). Subsequently, based on the aggregate score, a priority is assigned to each design requirement. This prioritization process assists the product development team in allocating resources effectively to specific design characteristics.

Evaluate current competition (8)

In this section of QFD, the product under design is evaluated (using a rating scale) in comparison to other products from the customer's perspective. The objective of this assessment is to determine the relative positioning of the designed product against competitors in terms of fulfilling customer requirements. This section is located in the leftmost column of the matrix. A scale from 1 to 5 can be employed, where five represents the most favorable rating for each competing product.

Benchmarks (9)

Benchmarking constitutes a significant aspect of QFD. It facilitates the evaluation of the product against established standards and provides direction for the design process to achieve customer satisfaction.

Design targets (10)

Following the competitive analysis (in Step 8) and performance measurement, the subsequent step involves establishing new targets for product improvement. Utilizing the findings from the current competitive assessment and the importance ratings of customer needs, target values are selected for the technical requirements. These target values prioritize requirements where competitors perform well and those with higher importance ratings receive greater emphasis. Subsequently, technical difficulties are determined based on the level of challenge associated with achieving the defined target values for each technical requirement. The rating is typically conducted using a five-point scale, where 1 represents the least difficult and 5 the most difficult.

Evaluation of new design (11)

Following the establishment of new targets, the subsequent step involves re-evaluating the customer requirements against the proposed design. This section completes the basement of the house where the importance ratings are recorded. These importance ratings are calculated to determine which technical requirements will receive the most attention in the subsequent steps of the QFD process. The importance ratings represent the relative weights of each technical requirement based on the weight of each customer

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need and its relationship to the technical requirement. The weight of each technical requirement is calculated using the following expression:

$$W_j = \sum_{i=1}^{n} d_i \, r_{ij} \qquad (1)$$

where Wj represents the weight of the technical requirement j, Ii is the importance rating of the customer requirement i, and Rij is the correlation coefficient between the customer requirement i and the technical requirement j, which can be extracted from the "relationship matrix" in the HOQ diagram. The relative weights are then determined using the following equation:

$$Z_j = {W_j}\Big/{\sum_{k=1}^{m} W_k} \qquad (2)$$

where Zj represents the relative weight (importance rating) of the technical requirement j. technical requirements with higher importance ratings and weaker performance compared to competing products are carried over to the second phase, where another matrix is constructed to determine part characteristics using the same process outlined above. In this case, the technical requirements are entered in the left-hand column of the new matrix. This process continues until the final matrix in the QFD implementation is completed.

4.3 Establishing the Initial Framework

In this section, we will analyze the construction of a House of Quality model for each Lean Design Management practice associated with Quality Function Deployment, as illustrated in (Figure 6), by following these steps:

Phase 1 in Constructing the House of Quality: Identifying and Prioritizing the Governing Factors of Hospital Sustainability Criteria

The process of constructing the House of Quality (HOQ) commences with a meticulous evaluation of customer requirements, which, in the context of this study, are represented by hospital sustainability criteria. This initial phase aims to identify the core governing factors that contribute to the achievement and application of these criteria in the design and construction of sustainable hospitals. These governing factors are derived through diverse research methodologies encompassing focus groups, expert surveys, in-depth interviews, and a systematic review of pertinent literature. These governing factors represent the essential requirements for realizing the desired sustainability objectives. For instance, "the reduction of toxic chemical compounds" is a pivotal sustainability criterion and can be considered the "customer" within this framework, while the presence of an integrated and multidisciplinary design team represents the "requirement" that enables the incorporation of health and environmental sustainability considerations into the various design stages, thereby reducing the likelihood of using harmful chemical substances. In the subsequent step, these requirements or governing factors are prioritized based on their relative importance, where each customer procedure requirement is evaluated on a defined scale, and its final priority is ranked based on its cumulative value.

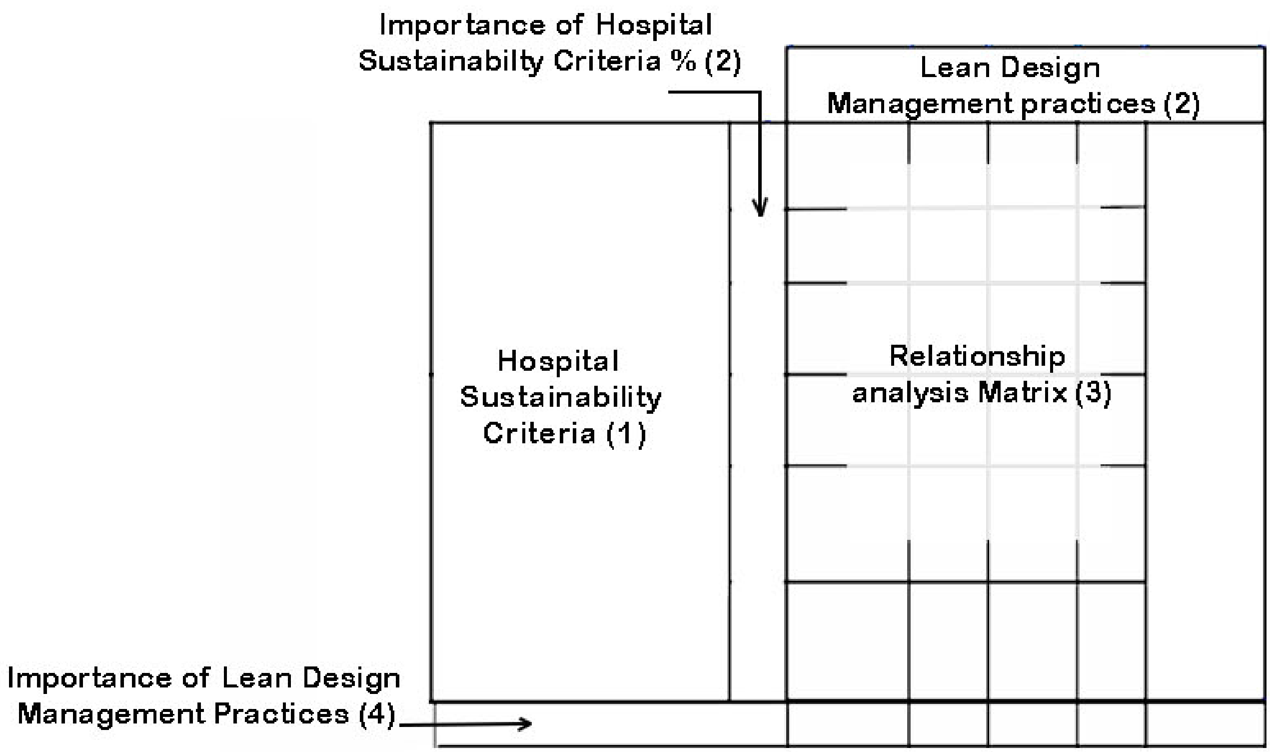

FIGURE 6 (BLS-HCAF) BIM Lean Sustainable Healthcare Assessment Framwork Structure
Source: Authors, 2024

.PHASE 2: IDENTIFICATION OF COMPREHENSIVE GOVERNING FACTORS FOR LEAN DESIGN MANAGEMENT PRACTICES

Within the framework of constructing the House of Quality (HOQ), Lean Design Management practices, augmented by Building Information Modeling, constitute the fundamental design requirements essential for supporting the realization of hospital sustainability criteria. This second phase aims at the systematic analysis and categorization of these practices into key influencing factors. To achieve this objective, the expertise of specialists can be leveraged through expert consultations in the domains of design, Building Information Modeling, and relevant project management, in addition to the findings of focus group studies and a comprehensive review of the scientific literature. These methodologies contribute to the identification of the governing factors that form the core of Lean Design Management practices.

Phase 3: Analysis of the Relationship Matrix between Customer Requirements and Design Requirements

The House of Quality (HOQ) serves as the central instrument for representing the analysis process of Lean Design Management practices, with its central section constituting the relationship matrix. This matrix systematically evaluates the level of correlation between customer requirements and their corresponding design requirements. The strength of these relationships is indicated by a specific score or points assigned to each pair of a customer requirement and its associated design requirement.

Within the context of this study, the relationship matrix aims to identify and quantify the degree of mutual influence between hospital sustainability criteria and Lean Design Management practices. Experts assess the extent to which each factor of a Lean Design Management practice supports the achievement of a specific factor of hospital building sustainability. Based on this evaluation, a weight will be assigned to each factor of the Lean Design Management practice, mirroring the methodology of QFD analysis, where this weight reflects the level of influence.

Phase 4: Determining the Absolute Weight and Prioritizing Factors of Lean Design Management Practices

The lower section of the House of Quality (HOQ) is dedicated to establishing the relative importance of the design requirements. To determine the prioritization ranking, the relationship value for each customer requirement is multiplied by its initial weight. The sum of these values is then calculated for each design requirement, yielding a column that illustrates the relative ranking or absolute importance of that design requirement. The relative percentage of these individual factors aids in identifying the most influential factor within a specific Lean Design Management practice. Similarly, all Lean Design Management practices are ranked to understand their relative impact on achieving hospital sustainability criteria.

By employing this framework, the evaluation of relationships between BIM-enabled Lean Design Management practices and hospital building sustainability criteria becomes feasible at a more granular level, as both sustainability criteria and Lean and BIM practices are decomposed into relevant factors. This contributes to an in-depth understanding of how a specific BIM-enabled Lean Management practice supports the achievement of hospital sustainability criteria. Furthermore, the weights derived from the relationship matrix and the resulting ranking can establish a clear understanding of the extent to which Lean Design Management practices and BIM influence hospital sustainability criteria.

5. Conclusion

This theoretical research underscores the critical importance of addressing sustainability challenges in hospital construction projects through a comprehensive and integrated approach. The conceptual framework presented herein, which synthesizes Quality Function Deployment (QFD) framework design, Lean Construction principles, and Building Information Modeling (BIM) technology, offers a novel pathway towards achieving enhanced sustainability outcomes in the design phase. The anticipated impact of this study lies in providing decision-makers and researchers with a robust methodological foundation for integrating sustainability considerations into the early stages of hospital development, ultimately leading to the advancement of more resource-efficient and environmentally conscious healthcare facilities. As this research represents an initial phase of an ongoing scholarly endeavor, the proposed framework will be subjected to empirical validation and iterative refinement in future studies to enhance its robustness and applicability across diverse contexts. To this end, surveys and questionnaires will be distributed to design professionals, construction managers, and hospital facility managers to assess their perceptions of the framework's feasibility, usability, and potential benefits. These surveys will gather data on the perceived ease of implementation, the clarity of the framework's guidelines, and the anticipated impact on project efficiency and sustainability goals.

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