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FULL LENGTH ARTICLE

Sustainable Practices in the Design, Modeling, and Evaluation of Medical Centers: A Case Study of Basilia City

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ABSTRACT

This study concludes that integrating sustainable practices into the design and modeling of medical centers significantly contributes to enhancing resource efficiency and reducing the environmental impact of healthcare facilities. The sustainability of these facilities can be further improved using advanced technologies such as Building Information Modeling (BIM), which simultaneously enhances the well-being of patients and staff. The study also highlights the importance of adopting globally recognized sustainability assessment systems and adapting them to suit the local context to ensure effective sustainability in future medical centers.

Keywords: Sustainable Practices ▪ Sustainable Design ▪ Medical Centers ▪ Building Information Modeling (BIM) ▪ Sustainability Assessment Systems ▪ Sustainability in Healthcare

1. INTRODUCTION

Sustainability practices in the design of healthcare facilities, including hospitals and medical centers, are a key priority for improving the environmental and economic impact of these establishments [1]. The importance of sustainable design lies in enhancing the efficiency of natural resource use, reducing carbon emissions, and promoting a healthy and safe environment for both patients and staff. Therefore, sustainable building strategies are vital for improving the quality of healthcare and reducing the environmental footprint of healthcare facilities [2–4].

The problem of this research lies in the significant challenges faced by Basilia City in achieving its goal of becoming the first sustainable city in Syria [4–7]. Sustainable practices are not yet applied in a formal, clear, and effective manner in medical centers. In addition, Building Information Modeling (BIM) technologies have not been implemented in medical centers, hindering the improvement of efficiency and coordination. Furthermore, the city lacks clear criteria for evaluating these practices, making it difficult to measure the achievement of sustainability goals. From this, research questions arise, such as: What sustainable practices are being followed? What software can be used to model sustainable practices? What criteria are used to evaluate sustainable practices in medical centers?

The aim of the research is to identify the most important sustainable practices to be adopted in the design of medical centers and to model these practices within a BIM environment, highlighting the benefits and importance of using BIM in medical projects. It also aims to assess these practices to ensure their effectiveness and improve future performance.

This study will inspect previous studies and literature on sustainability practices in the design, modeling, and evaluation of medical centers. It will also review best practices in this field, focusing on how sustainable design can be modeled

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and its benefits in designing medical centers using Building Information Modeling (BIM). Additionally, this study will cover the most well-known sustainability assessment systems, and the most suitable system for application in the Syrian context will be selected, based on its appropriateness to local conditions and the needs of medical facilities.

2. LITERATURE REVIEW

Sustainable Practices: These are activities and techniques that promote sustainability by reducing environmental impact and improving economic and social efficiency [8]. These practices include the use of renewable resources, green building technologies, and energy efficiency, with the aim of meeting present needs without compromising the ability of future generations to meet their own needs [9].

Sustainable Design: It is a general term that describes environmentally conscious design techniques in the field of architecture [10]. Buildings are designed in a way that respects the environment, taking into account the reduction of energy consumption, material use, and resources in order to minimize the negative impacts of construction and consumption and achieve greater harmony with the natural environment [11].

Medical Centers: These are specialized facilities that provide basic and advanced healthcare services, including diagnosis, treatment, and disease prevention, with a focus on primary care and promoting public health [12].

Building Information Modeling (BIM): It is the process of representing the physical and functional characteristics of a facility through a comprehensive digital model created using computers [13]. This model becomes a unified and shared source of information throughout the facility's lifecycle. It is used as a central tool for decision-making related to design, construction, maintenance, and environmental performance evaluation, contributing to improved efficiency and reduced errors in engineering processes [14–16].

Sustainable Rating Systems: These are a set of standards and metrics used to assess the impact of buildings on the environment and society [17]. These systems aim to improve building performance by analyzing environmental, economic, and social aspects, contributing to the achievement of an effective and sustainable design. These systems rely on scientific methodologies to evaluate sustainability comprehensively, helping in making informed decisions regarding design and construction [18].

Sustainability in Healthcare: Refers to the application of principles and practices aimed at reducing the environmental impacts of healthcare activities and promoting long-term public health [19]. This concept focuses on improving resource efficiency, reducing waste and carbon emissions, while ensuring safe and healthy environments for both workers and patients [1].

3. RESEARCH METHODOLOGY

3.1 Bibliometric Data Collection

In this research, a methodological strategy was adopted for collecting and analyzing scientific literature related to sustainability in the design of healthcare centers. Reliable sources such as Google Scholar, Sci-Hub, and Scopus were used to gather research, focusing on key topics such as Sustainable Practices in Healthcare Design and other relevant subjects. Additionally, bibliometric data analysis was applied to identify key research trends and the most influential academic resources [4, 20]. This approach aims to provide a comprehensive assessment of the available literature and identify research gaps to develop innovative and sustainable strategies in the design of medical centers [21, 22].

3.2 Inclusion and Exclusion Criteria and Working Mechanism

A total of 70 initial studies were collected from the Google Scholar database using bibliometric tools like Publish or Perish to facilitate the data-gathering process efficiently. After collecting the sources, a precise filtering mechanism was applied. Studies that lacked a full PDF file detailing the research were excluded, along with those that did not provide relevant or useful information regarding sustainability in healthcare center design. Paid studies were also excluded. As a result, only studies directly related to the topic, offering applicable insights for the development of this field, were considered, resulting in a final count of 28 studies. The aim was to answer the question: What sustainable practices can be followed in the design of medical centers?

3.3 Data Analysis

3.3.1 Bibliometric Analysis

Top Cited Articles. Table 1 lists the five articles with the highest citation counts in the collected literature.

Table 1. The most cited research in previous studies.

No.	Cites	Title
1	613	The sustainability of evidence-based interventions and practices in public health and health care
2	381	Sustainability of evidence-based healthcare: research agenda, methodological advances, and infrastructure support
3	359	Navigating the sustainability landscape: a systematic review of sustainability approaches in healthcare
4	235	The green print: advancement of environmental sustainability in healthcare
5	231	Fundamentals of integrated design for sustainable building

The most cited scientific articles serve as an indicator of the strength, impact, and quality of research in the field of sustainability in healthcare center design. In this context, five of the most prominent studies with the highest citation rates were identified from the Google Scholar database. As shown in the table, the article "The sustainability of evidence-based interventions and practices in public health and healthcare" had the highest number of citations, with 613 citations. In second place is "Sustainability of evidence-based healthcare: research agenda, methodological advances, and infrastructure support" with 381 citations, followed by "Navigating the sustainability landscape: a systematic review of sustainability

approaches in healthcare" with 359 citations. Next is "The green print: advancement of environmental sustainability in healthcare" with 235 citations, and in fifth place is "Fundamentals of integrated design for sustainable building" with 231 citations.

Most Productive Authors. The most productive authors identified in the bibliometric analysis are presented in Table 2.

Table 2. The most productive authors.

No.	Article Count	Authors
1	6	J. Faludi, S. Hoffenson, S. Y. Kwok, M. Saidani, S. I. Hallstedt
2	5	J. D. Sherman, C. Thiel, A. MacNeill, M. J. Eckelman
3	5	N. Campion, C. L. Thiel, N. C. Woods, L. Swanzy
4	5	B. Jönsson, G. Hampson, J. Michaels, A. Towse
5	5	J. Braithwaite, K. Ludlow, L. Testa, J. Herkes
6	5	E. Proctor, D. Luke, A. Calhoun, C. McMillen
7	5	S. Capolongo, M. Gola, M. Di Noia, M. Nickolova

Identifying the most productive authors in the field of sustainable practices for healthcare center design is a crucial step in evaluating the cognitive development in this area by highlighting the researchers who have published the largest number of studies. As shown in the table, the group of researchers J. Faludi, S. Hoffenson, S. Y. Kwok, M. Saidani, and S. I. Hallstedt have published six studies related to sustainability. Additionally, the following researchers have each published five studies: J. D. Sherman, C. Thiel, A. MacNeill, M. J. Eckelman, N. Campion, C. L. Thiel, N. C. Woods, L. Swanzy, B. Jönsson, G. Hampson, J. Michaels, A. Towse, J. Braithwaite, K. Ludlow, L. Testa, J. Herkes, E. Proctor, D. Luke, A. Calhoun, C. McMillen, S. Capolongo, M. Gola, M. Di Noia, and M. Nickolova.

Publishers of the Most Cited Research. Table 3 links the five most cited studies to their publishers.

Table 3. Publishers of the most cited research.

No.	Cites	Authors	Title	Publisher
1	613	R. C. Shelton, B. R. Cooper	The sustainability of evidence-based interventions and practices in public health and health care	Annual Reviews
2	381	E. Proctor, D. Luke, A. Calhoun, C. McMillen	Sustainability of evidence-based healthcare: research agenda, methodological advances, and infrastructure support	Springer
3	359	L. Lennox, L. Maher, J. Reed	Navigating the sustainability landscape: a systematic review of sustainability approaches in healthcare	Springer
4	235	J. D. Sherman, C. Thiel, A. MacNeill, M. J. Eckelman	The green print: advancement of environmental sustainability in healthcare	Elsevier
5	231	M. Keeler, P. Vaidya	Fundamentals of integrated design for sustainable building	Not specified

Identifying the publisher of the most cited research helps in evaluating the reliability and impact of sources in the field of research. Linking the five most cited studies to their respective publishers highlights the role of journals and academic institutions in promoting these scientific trends. From the table, we see that the publisher of the most cited paper, which has 613 citations, is Annual Reviews. The publisher of the second most cited paper, with 381 citations, is Springer. The publisher of the third most cited article, with 359 citations, is also Springer. The publisher of the fourth article, which has 235 citations, is Elsevier. As for the fifth article, which has 231 citations, the publisher is not specified.

Number of Articles Published Annually. This analysis helps identify time periods that saw increased interest in sustainable practices in medical centers and reflects the key research trends in this field. Figure 1 shows that five articles were published in 2015, four articles in 2016, two articles in 2017, two articles in 2018, one article in 2019, and nine articles in 2020, which was the year with the highest number of publications. Additionally, one article was published in 2021, three articles in 2022, and one article in 2024.

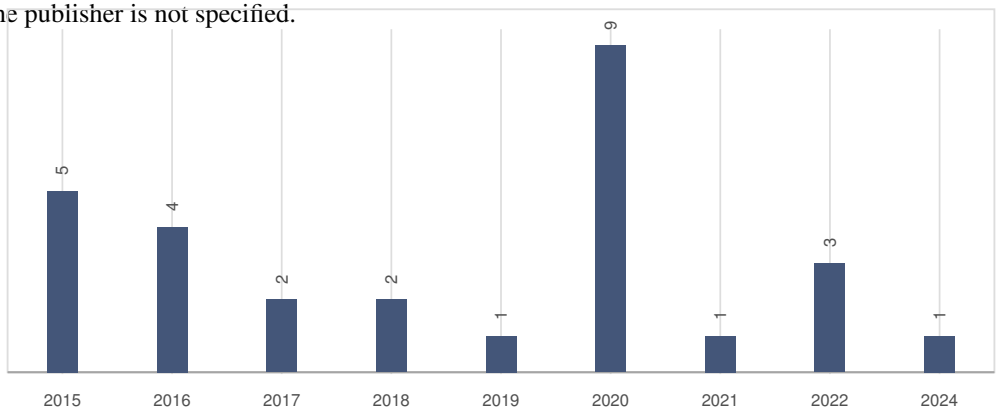


Figure 1. Articles count per year.

3.3.2 Content Analysis

Table 4 lists the practices mentioned in each study. The 28 studies are arranged from the highest to the lowest number of citations.

Table 4. Content analysis of practices within the research.

No.	Cites	Title	Sustainable Practices
1	613	The sustainability of evidence-based interventions and practices in public health and health care	Improving resource management; collaboration between sectors (healthcare, engineering, and environmental) to ensure sustainable design [23].
2	381	Sustainability of evidence-based healthcare: research agenda, methodological advances, and infrastructure support	Resource management that reduces waste. This research focuses on the theoretical study of developing sustainable methodologies in healthcare centers and providing a strong sustainable research infrastructure [24].
3	359	Navigating the sustainability landscape: a systematic review of sustainability approaches in healthcare	Correct sustainable design; waste management; use of renewable energy; water management; improving indoor air quality; and reducing carbon emissions [25].
4	235	The green print: advancement of environmental sustainability in healthcare	Improving energy efficiency; reducing waste; promoting the use of renewable materials; innovation in design and implementing correct sustainable design; enhancing environmental performance through setting standards; and increasing awareness and education [26].
5	231	Fundamentals of integrated design for sustainable building	Integrated design that improves efficiency and reduces resource consumption; energy management; and life-cycle analysis (environmental and economic impact assessment of the building through its stages to reduce environmental harm and increase efficiency) [27].
6	216	The sustainability of healthcare innovations: a concept analysis	The research discusses the importance of sustaining sustainability even after implementation through institutional support, sustainable financing, continuous evaluation, and integration into the healthcare system.
7	183	Sustainable healthcare and environmental life-cycle impacts of disposable supplies: a focus on disposable custom packs	Sustainable design that reduces resources and design for end-of-life (i.e., recycling materials to reduce waste) [28].
8	130	Advanced therapy medicinal products and health technology assessment principles and practices for value-based and sustainable healthcare	The use of advanced medical products from a sustainability perspective and integrating environmental criteria into technology assessment decisions to reduce environmental impact [29].
9	121	A framework for measuring sustainability in healthcare systems	Improving energy efficiency and reducing emissions; reducing medical waste; using eco-friendly materials; and resource management (such as water and raw materials) while emphasizing the importance of integrating sustainability into decision-making [30].
10	106	Beyond the ostensible: an exploration of barriers to lean implementation and sustainability in healthcare	Applying Lean methods to reduce waste and improve overall performance and using techniques to analyze sources of resource waste [31].
11	95	Healthcare sustainability and the role of intellectual capital: evidence from an Italian regional health service	Good design expressed through the use of intellectual capital; technology supporting sustainability; knowledge management; and process improvement to enhance sustainable practices within the medical center [32].
12	83	Emergence of sustainability-based approaches in healthcare: expanding research and practice	Medical waste management; reducing resource consumption; environmental training for staff to learn eco-friendly practices in their daily work; and continuous performance evaluation [33].
13	83	Built to last? The sustainability of healthcare system improvements, programmes and interventions: a systematic integrative review	This research emphasizes the importance of continued funding, as well as the need to integrate programs into the healthcare system within the institutional framework to ensure the smooth continuation of operations after the initial funding ends [34].
14	81	Sustainable by design: a systematic review of factors for health promotion program sustainability	Adapting to the local context by designing solutions that align with challenges and needs, securing funding, involving the local community, and ensuring continuous evaluation, performance monitoring, and result assessment [35].
15	78	Social sustainability in healthcare facilities: a rating tool for analysing and improving social aspects in environments of care	Sustainable designs that are appropriate for the environment and community by focusing on the human aspect [36].
16	70	A research roadmap for sustainable design methods and tools	Developing sustainable design tools and establishing standards for sustainability assessment to reduce carbon emissions and resource usage, which helps improve sustainable design [37].
17	54	Leveraging design thinking to build sustainable mobile health systems	Sustainable design; flexible, adaptable design; and using technology to enhance the effectiveness of healthcare systems [38].
18	45	The future of sustainable healthcare: Extending product lifecycles	Using sustainable materials to reduce environmental impact; recycling strategy; improving operational efficiency by reducing waste and increasing productivity; and waste management [39].
19	23	A standard design process for sustainable design	Initial planning and setting clear sustainability goals from the start; studying local environmental conditions through site analysis; selecting sustainable materials; designing energy systems; and water management [40].
20	22	Sustainable design basics	Life-cycle-based design that includes consideration of environmental impact; use of renewable materials; improving energy efficiency; designing healthy environments for patients; and reducing waste [41].
21	19	Design for Health: Sustainable Approaches to Therapeutic Architecture	Integrating green spaces with design; natural lighting; natural ventilation; using environmentally friendly building materials; utilizing smart building technologies that reduce energy consumption and increase building efficiency; and design that considers patient well-being and psychology [42].
22	16	From evidence to design solution—on how to handle evidence in the design process of sustainable, accessible and health-promoting landscapes	Well-researched design based on studies; integrating green spaces into the design; and using sustainable materials [43].
23	14	Back and forth on sustainable development: A focus on healthcare organisations	Sustainable design that improves resource efficiency and reduces environmental impact; water resource management; renewable energy; waste recycling; flexible and multi-use design; and use of environmentally friendly materials [44].
24	9	Enhancing healing environment and sustainable finishing materials in healthcare buildings	Using environmentally friendly and recyclable finishing materials; using low-emission building materials; utilizing renewable energy sources; sustainable design that prioritizes patient health; improving indoor air quality; waste management; and water usage management [45].
25	9	Transitioning to sustainable healthcare: decarbonizing healthcare clinics, a literature review	Improving energy efficiency; utilizing renewable energy; waste management; surrounding green spaces to enhance design quality and air quality; and awareness and education on using sustainable practices within the center [46].
26	3	Sustainable Healthcare Architecture	Designing natural spaces; using sustainable materials; water management; and providing a healthy indoor environment [47].
27	2	Sustainable Building Certification in Healthcare and Patient Satisfaction	Sustainable design that includes healthy environments; improving indoor air quality; using sustainable building materials; adopting design standards to enhance performance; and achieving energy efficiency [48].
28	0	Unlocking the potentials of sustainable building designs and practices: A systematic review	Energy-efficient design; use of sustainable materials; water management systems; use of modern technologies; and flexible design [49].

In Table 4, the practices mentioned in each study are listed so that their frequencies can be counted in Table 5. The 28 studies are arranged from the highest to the lowest number of citations.

Table 5. Main and sub-sustainable practices with their frequency.

	Frequency	Sub-sustainable Practices	Brief Definition	Main Practice
33	17	Healthy design	A design process focuses on reducing environmental impacts, improving resource efficiency, and enhancing user well-being by integrating sustainability considerations throughout all stages of product and facility development.	Sustainable Design
	3	Flexible design		
	4	Life-cycle-based design and reducing environmental impact		
	4	Integrating green spaces into the design, both inside the building and in its surrounding area		
	1	Good lighting within the building		
	4	Good ventilation within the building		
13	7	Waste management and waste reduction	It is a set of processes and techniques concerned with the collection, transportation, processing, and disposal of waste in a manner that protects public health and the environment, with a focus on reducing environmental impact and promoting sustainability.	Waste Management
	3	Waste reduction		
	3	Recycling		
11	2	The use of renewable and recyclable materials	It is the selection and use of building materials with positive environmental characteristics to promote sustainability and reduce negative environmental impacts.	Sustainable Materials Use
	9	The use of environmentally friendly and sustainable materials		
24	7	Improving resource usage to reduce environmental waste	It is the process of organizing and directing the use of natural resources such as energy and water in an efficient and sustainable manner, aiming to improve consumption efficiency and reduce waste.	Resource Management
	4	Using renewable energy		
	5	Improving energy efficiency		
	1	Reducing carbon emissions		
	2	Energy management and systems		
	5	Water management		
5	3	The use of sustainability-supporting technology	It refers to advanced systems and technologies used to improve the environmental and economic performance of buildings. These technologies include building management systems, sensors for controlling energy, water, and more.	Smart Building Technologies
	2	The use of smart building technologies		
5	2	The development of sustainability methodologies and knowledge management to improve processes	It refers to enhancing knowledge and understanding of sustainability and its practices, enabling individuals and communities to make informed decisions that lead to improved environmental performance.	Awareness and Education
	3	Increasing awareness and training employees on sustainable practices they may need in their work		
6	2	Securing funding and ensuring its continuity	It involves providing the necessary financial resources to support sustainability projects, along with conducting periodic assessments of the effectiveness of these projects to ensure the achievement of sustainable goals.	Funding and Continuous Evaluation
	4	Establishing standards to evaluate sustainable performance and monitoring it		

The table displays the number of times each sustainable practice (frequency) has been applied for each specific sustainable practice. The numbers indicate the frequency of each sustainable practice, providing insights into how common and widely used each practice is in the field of sustainability. For example, sustainable design was mentioned 33 times along with its sub-practices, making it the most common practice. It should be noted that a study might mention more than one sub-practice, which is why the count reached 33, even though the total number of studies analyzed is 28.

4. CONCLUSION

This study highlights the pivotal importance of incorporating sustainable practices in the design and modeling of medical centers to optimize resource efficiency and reduce environmental impact. The adoption of advanced technologies, such as Building Information Modeling (BIM), emerges as a key enabler for improving operational performance while fostering the health and well-being of both patients and staff. Moreover, the research underscores the necessity of utilizing globally recognized sustainability assessment frameworks, adapted to local contexts, as a foundational strategy for developing future-ready medical facilities that seamlessly integrate environmental stewardship with functional and operational excellence.

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