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Green Hospital Frameworks and Their Impact on Healthcare Quality: A Review

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Abstract
Healthcare facilities constitute significant contributors to environmental degradation through substantial energy consumption, waste generation, and resource utilization. Green hospital frameworks address these challenges by promoting sustainable methodologies encompassing efficient waste management, energy conservation, water efficiency, and environmentally responsible infrastructure development. This review examines the influence of green hospital frameworks upon healthcare quality, with particular attention to patient safety, operational efficiency, and staff welfare.A narrative review methodology was employed, encompassing analysis of peer-reviewed publications, policy documents, and relevant literature concerning sustainability initiatives within hospital environments. The findings indicate that the adoption of green hospital practices yields measurable improvements in indoor air quality, reduces exposure to hazardous substances, and cultivates therapeutic environments conducive to patient recovery and staff health. Enhanced resource efficiency and reduced operational expenditures facilitate improved financial allocation toward direct healthcare services. Furthermore, superior working conditions contribute to increased staff satisfaction and productivity, thereby augmenting the overall quality of healthcare delivery. Nevertheless, several impediments to implementation persist, including considerable initial capital requirements, limited awareness among stakeholders, and insufficient governmental support. Successful adoption necessitates institutional commitment, comprehensive personnel training, and strategic long-term planning. The sustained integration of sustainability principles within healthcare systems will require strengthened regulatory frameworks and enhanced organizational preparedness.In conclusion, green hospital frameworks serve a critical function in advancing environmental sustainability while concurrently elevating healthcare standards. Their effective implementation depends upon coordinated efforts across institutional, educational, and policy domains.

Keywords: *Environmental sustainability, Green hospitals, Healthcare quality, Patient safety, Resource efficiency.*

1. Introduction
The healthcare industry links human health with environmental sustainability. Hospitals are among the buildings that have the biggest environmental effects. They use 2.5 times more energy per square meter than other commercial buildings and produce a lot of waste every day [1]. As per World Health Organization, health sector is responsible for 4-5% of greenhouse gas emission, hospital being one of the largest contributors [1]. The healthcare sector aims to heal but unknowingly harms the environment [2].If available resources are used efficiently by incorporating sustainable eco-friendly practices, Green Hospital projects will reduce the impact and improve healthcare services. [3] Research shows that features of green hospitals such as transportation, sustainable materials, waste management, indoor environmental quality, energy efficiency, and water efficiency can directly affect healthcare quality [4]. Healthcare outcomes are directly influenced by environment in healthcare facilities such as natural

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light, ventilation, views of nature, and comfortable temperatures infection rates, patient satisfaction, staff performance, and patient recovery [5, 6]. There is a significant opportunity at the intersection of quality improvement and sustainability.The aim of this narrative review is to summarize the body of research on green hospital frameworks and investigate how they relate to outcomes related to healthcare quality. This review aims to educate healthcare administrators, legislators, and practitioners about the possible advantages and difficulties of sustainable healthcare facility design and operations by identifying important domains of green hospital implementation and their related implications.

2. Conceptual Frameworks for Green Hospitals

2.1.Defining Green Hospitals

Green hospitals are healthcare facilities that are designed, built, and run with the aim of reducing environmental impacts and providing the best environment for patient care [7]. The idea of a green hospital is not just about energy conservation; it is a wide-ranging approach that considers the whole process of healthcare provision and delivery. Some of the characteristics of a green hospital include reduced energy and water consumption, reduced waste production, the use of sustainable building materials, enhanced indoor environmental quality, and the provision of sustainable transportation systems [8].

A lot of parallel developments can be used to trace the growth of green hospital concepts. The connection between patient outcomes and physical settings was highlighted by the evidence-based design movement in hospital architecture [9]. Concurrently, frameworks for measuring and identifying sustainable building practices were established by the green building movement, which is exemplified by certification programs like LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) [10]. Healthcare-specific sustainability standards that cover both environmental performance and clinical requirements have been created as a result of the junction of both movements [11]

2.2.Green Building Certification Systems

Several certification schemes have been specifically designed for use in healthcare facilities. LEED for Healthcare, designed by the U.S. Green Building Council, has been designed to meet the specific needs of healthcare facilities, including their 24/7 operations. Infection control and ventilation requirements are also included in this scheme. So far, around 4,000 projects have been certified in the world, amounting to over 86 million square meters of healthcare space, as of 2024 [12].Another scheme, BREEAM Healthcare, has been designed in the UK and focuses not only on environmental performance but also on health and well-being. Criteria have been included in this scheme to focus on patient experience, staff health, and clinical functionality. Other schemes include Green Star Healthcare in Australia, CASBEE Hospital in Japan, and several national schemes that have been designed to suit local needs and environments.These schemes generally include criteria in several categories, including energy efficiency, water use, materials, indoor environmental quality, site sustainability, and innovation. Adaptations have also been made to include specific needs in healthcare facilities, including infection control, emergency preparedness, and equipment needs, which are specific to this type of facility and distinguish them from other buildings

2.3.Environmental Key Performance Indicators

The recent literature has emphasized the need to establish standardized measures to assess hospital environmental performance. A scoping review by D'Agostino et al. identified six domains of sustainability, namely, energy management, waste management, water consumption, greenhouse emissions, transportation and mobility, and site sustainability, with 18 environmental key performance indicators (EKPIs) proposed in these domains to measure and benchmark healthcare facilities' performance.Total energy intensity (kWh per square meter), the proportion of renewable energy, and energy savings attained through efficiency measures are examples of energy

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performance metrics. Recycling rates and waste production per bed are examples of waste management metrics. Usually, water use is expressed as volume per square meter or per bed. Carbon dioxide equivalents per bed are used to calculate greenhouse gas emissions [19]. Healthcare administrators can use these indicators to monitor environmental performance and find areas for improvement.

3. Key Environmental Domains in Green Hospitals

3.1.Energy Management

The largest impact and cost for most hospitals is their energy consumption. Hospitals are 24/7 operations, and this means they require a significant amount of energy to provide heating, ventilation, air-conditioning, lighting, and hot water, among other operations [20]. Green hospital strategies in energy management include improving building envelopes, high-efficiency heating, ventilation, and air-conditioning, LED lighting, renewable energy, and smart building management, among others [21].

Research has shown that there is a great potential for energy reduction in hospitals. A comparative study of three European hospitals that implemented integrated management systems found that there was a reduction of 20-28% in energy consumption per patient day due to sustainability strategies in hospitals [22]. Dell Children's Medical Center of Central Texas, which is recognized as the first LEED Platinum hospital in the world, reduced its energy consumption by 60% compared to conventional hospitals by employing integrated design strategies such as orientation optimization, high-performance envelopes, and renewable energy strategies, among others [23].

3.2.Waste Management

Hospitals also generate a considerable amount of waste, estimated to range between 2-4 kg per bed per day [24]. Waste types include general waste, recyclable waste, hazardous waste, pharmaceutical waste, and infectious waste, which require special treatment. In green hospital waste management, the waste hierarchy of reduction, reuse, recycling, and disposal is a major consideration [25].Since 20-30% of hospital waste is generated from the operating room, it is an area of great concern for waste reduction management in hospitals [26]. Various strategies for waste reduction in the operating room include recycling clean materials, reprocessing single-use medical devices, and optimizing surgical supply kits. To reduce 4,700 kg of waste and save around $116,000 in purchase and disposal costs, the University of Minnesota Medical Center changed their kit in the operating room to include fewer unnecessary throwaway goods [27].

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3.3.Water Management

The water consumption rate for hospitals is about 400 to 500 litres for each bed every day. This is really high compared to buildings. The reason is that hospitals have medical needs like sterilization and dialysis.The strategies for water management in a hospital are simple. We need to install water-saving fixtures and equipment for sterilization. We also need to have rainwater harvesting systems and grey water recycling systems for a hospital. This is how we can manage water in a hospital. [29]A study by the Institute for Healthcare Improvement showed that water savings of 15-40% can be achieved by the implementation of water-saving strategies without compromising infection control and patient safety [30]. The Khoo Teck Punt Hospital in Singapore saved a tremendous amount of water by the implementation of an integrated water management system that includes the collection of rainwater, condensate collection, and water-saving landscaping [31].

3.4.Indoor Environmental Quality

Indoor environmental quality refers to a combination of air quality, thermal comfort, lighting, and acoustic conditions. This aspect is very important in healthcare facilities since some patients may have

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weakened immune systems. Some healthcare workers may work long hours in challenging conditions. A green hospital promotes natural ventilation in appropriate clinical conditions, uses high-efficiency filtration, and provides optimal lighting conditions. A green hospital ventilation system aims to provide a balance between energy efficiency and infection control. A study has established that ventilation rates humidity control, and ventilation distribution can reduce healthcare infections. Natural ventilation in appropriate clinical conditions, combined with displacement ventilation and demand control ventilation, can reduce energy consumption. This can be achieved in non-clinical conditions. A combination of natural ventilation and ventilation systems can provide a healthy indoor environment. This can be achieved by ensuring a healthy indoor environment. A healthy indoor environment can be achieved by ensuring natural ventilation in appropriate clinical conditions. This can be achieved by ensuring a combination of natural ventilation and ventilation systems. A combination of natural ventilation and ventilation systems can provide a healthy indoor environment. This can be achieved by ensuring natural ventilation in appropriate clinical conditions

4. Impact on Healthcare Quality Outcomes

4.1.Patient Outcomes

The association between patient outcomes and green hospital features has been well documented along various dimensions. One such study by Thiel et al. [36], which is a landmark study in the field, compared a newly constructed LEED-certified hospital with a traditional hospital in Pittsburgh, PA. The green hospital showed a 19% reduction in mortality rates, despite an 11% predicted increase due to the severity of the patient population. The bloodstream infection rates reduced by 70%, and the medication administration errors reduced by 49%.Length of stay is a critical factor that determines the efficiency of healthcare services and the rate of patient recovery from illness. The environmental factors have been linked to the length of stay in hospitals. A study that retrospectively reviewed patient records exceeding 85,000 found that the length of stay was significantly reduced for those patients whose beds were positioned near the window and had access to natural light exposure [37].Patients having access to views of nature have been known to benefit from the therapeutic effects of nature exposure. The seminal study by Ulrich on the effect of window views on the recovery of surgical patients found that the patient population that had access to views of nature had reduced pain medication and length of stay compared with the patient population that had access only to built environment views [38]. The study was replicated with different patient populations and clinical settings [39].

4.2.Staff Outcomes

Employees in healthcare facilities are an important asset whose performance directly affects the quality of patient care provided. Green hospitals with better indoor environments have been linked to better employee satisfaction, reduced turnover, and increased employee productivity [40]. A comparative study of LEED-certified and conventional hospitals in the same healthcare system found that the staff in a LEED-certified hospital had a lower turnover rate and higher employee engagement level.Indoor environmental quality parameters, such as natural light, thermal conditions, and sound quality, play an important role in improving employee performance in hospitals. Another study found that sound quality in hospitals, with reduced background noise and reverberation, could reduce communication errors and employee fatigue.The monetary benefits of employee retention in hospitals are considerable, with costs of hiring and training a replacement nurse estimated to be between $40,000 and $60,000 [44]. Green hospitals with better indoor environments could therefore benefit from reduced employee turnover in addition to other benefits.

4.3.Patient Satisfaction

Patient satisfaction has become a critical quality indicator, with reimbursement being tied to satisfaction scores in many health care systems. Green hospital features have been shown to impact patient satisfaction in several ways, including

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increased comfort, improved communication environments, and improved perceptions of care quality [45].The Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey measures several aspects of the physical environment, including cleanliness and quietness. Several studies have identified correlations between green building features and higher satisfaction scores in these areas. In a study of 3,275 U.S. hospitals, it was found that hospitals with higher environmental performance ratings also scored higher in terms of overall patient satisfaction [47].Specific green features that have been identified as impacting patient satisfaction include access to natural light, views of nature, comfortable temperatures, and quiet environments. In general, patients in green-certified hospitals report higher scores in terms of their perceptions of their environment than do patients in conventional hospitals, and this has been found to impact their overall satisfaction with care [48].

5. Implementation Challenges and Strategies

5.1.Financial Considerations

The adoption process is still significantly hampered by the belief that green hospitals are unaffordable. Life-cycle cost analysis frequently shows positive returns on investment through lower operating costs, even though some sustainable features may raise initial capital costs [49]. Payback periods for energy efficiency measures, in example, are usually between three and seven years, after which cost savings accumulate during the building's operating life [50].

To overcome upfront cost obstacles, a number of financing options have been developed. Hospitals can fund efficiency improvements through assured future savings through energy performance contracts [51]. Green bonds provide access to funding markets for sustainable infrastructure projects, often with attractive interest rates that reflect investor appetite for environmental efforts [52]. Government incentives including grants, tax credits, and refunds bolster the financial case for investments in green hospitals [53].

5.2.Regulatory and Standards Framework

The regulatory framework for green hospitals differs substantially in various countries. Some countries have implemented mandatory green building standards for public healthcare facilities, while others use voluntary certification schemes [54].The lack of standardized green building standards poses challenges for healthcare organizations that operate in multiple locations. These challenges may arise when trying to benchmark green hospitals [55].Infection control is a major challenge for green hospital design due to conflicting regulations for ventilation rates, air filtration rates, and pressure relationships that may conflict with energy efficiency requirements [56]. The success stories of green hospitals prove that these two requirements can be integrated during the design process [57].

5.3.Organizational Culture and Change Management

For a successful implementation of a GH, there is a need to go beyond facilities management and involve other aspects of the healthcare organization, such as clinical and administrative operations, in a commitment to a GH implementation strategy [58].

The implementation of an integrated management system, such as quality management (ISO 9001) and environmental management (ISO 14001), has been found to be effective in embedding sustainability into the culture of an organization [60]. This is because such management systems offer a framework for goal-setting, monitoring, and improvement, which is consistent with organizational objectives in general.

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