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Principles for the Sustainable Design of Hospital Buildings

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ABSTRACT

Technological progress has had negative effects as well as positive effects if it affects the life industry and the entire ecosystem significantly through the great consumption of natural resources, and here the construction sector in general and the health sector, in particular, have a role in this. From the perspective of keeping pace with technological development, responding to environmental changes, and paying attention to hospital environments (especially since the emergence of modern epidemics), and because the construction sector is the largest consumer of energy in the world, which made international organizations move towards creating a sustainable environment in the construction of hospital buildings by reducing energy consumption. This research focused on studying the components and principles of sustainable design for hospital buildings and the environmental, economic, health, and social benefits of sustainable development in the healthcare industry. In addition to the research objective, which is to build a model as a guide to guide health care officials interested in applying sustainable design principles in hospital design, to achieve an ideal sustainable hospital environment. To achieve this goal, a comprehensive theoretical framework was built by adopting a descriptive and analytical approach and extracting the most important vocabulary and effective indicators for sustainable design in hospitals.

1. INTRODUCTION

Hospital buildings are of particular importance in any society, as how this type of building was designed, built, and operated has a profound impact on human health and the environment. Increasing interest in this sector, which is concerned with the health aspect, and building it sustainably, to be compatible with human health and the surrounding natural environmental systems [1].

Increasing global environmental problems such as climate change and the energy crisis, along with a lack of material resources, will lead to stricter environmental guidelines, regulatory measures, and an increase in prices. The repercussions of environmental problems have adverse health effects, but it is still difficult to determine the extent of it. Hospitals will face both aspects [2], and the World Health Organization has called on hospitals to play an active role in combating climate change. By applying sustainability criteria for the comprehensive design and development of hospital buildings and achieving general objectives related to preserving resources, increasing the effectiveness of health services, and minimizing and reducing negative impacts resulting from hospitals (waste, for example) or affecting these buildings (noise, for example). And taking into account reducing the movement of people and supplies to and from the hospital, paying attention to the social and economic integration of the hospital within the urban fabric, and achieving health needs without negatively compromising the nature of the site.

Studying hospital sustainability goes beyond just protecting the environment. The main characteristic of this field is the recognition of three interrelated dimensions: environmental, economic, and social. The planet faces many associated problems including poverty, ill health, overpopulation, resource depletion, food and water scarcity, political instability, and destruction of the life support systems on which we all depend [3]. We cannot solve one problem in isolation. Because they are all related to each other As it is known that the concept of sustainable development, in which all dimensions are balanced: environmental, economic, and social, in addition to the fourth dimension of health [4]. This is confirmed by the 2030 Agenda for Sustainable Development adopted by the United Nations Summit on Sustainable Development in September 2015 Agenda 2030, which sets out the so-called 17 Sustainable Development Goals (SDGs) and 169 goals. It develops a global action plan to support people, the planet, prosperity, peace, and partnership, which aims to make international efforts for sustainable development, by balancing three dimensions of sustainable development: economic growth, social inclusion, and environmental protection. Moreover, sustainable development requires that we balance our needs with the ability of future generations to meet their own needs [5].

In general, sustainable design is one of the most important areas of sustainable development that must been considered. Sustainable design is an integrated concept that has philosophical dimensions rather than just the exterior of a building or a particular model [6]. Sustainably designed buildings reduce their impact on the environment through energy and resource efficiency and the reduction of greenhouse gases. It is necessary to understand the principles governing sustainable design. The research aims to achieve the

most important indicators and effective vocabulary for sustainable design in hospitals to guide health care officials interested in applying the principles of sustainable design in hospital design. To achieve an optimal and sustainable hospital environment that promotes health and well-being reduces operating costs and saves energy.

2. METHODOLOGY

The research will adopt an analytical descriptive methodology to study the components and principles of sustainable design for hospital buildings and the environmental, economic, health, and social benefits of sustainable development in the healthcare industry. The research aims to build a model as a guideline for health care officials interested in applying the principles of sustainable design in hospital design, to reach an ideal and sustainable hospital environment, and the research goal will be achieved by extracting the most important vocabulary and effective indicators of sustainable design in hospitals through the following steps:

1. Reviewing the literature that deals with the importance of sustainable design and sustainable design principles in general.
2. Reviewing the literature that deals with sustainability in hospitals and its applications.
3. Extract the most important vocabulary and effective indicators of sustainable design in hospitals.
4. The practical study represented a review of the distinguished international hospitals in their design for the principles of sustainability. The study cases were subjected to systematic comparative analysis to show the most important vocabulary and effective indicators of sustainable design.

3. LITERATURE REVIEW

The main objective of the previous literature review is to study the components and principles of sustainable design for hospital buildings and the environmental, economic, health, and social benefits of sustainable development in the healthcare industry. And to extract the most important vocabulary and effective indicators of sustainable design in hospitals to guide healthcare administrators interested in applying the principles of sustainable design in hospital design. Achieving an optimal and sustainable hospital environment that promotes health and well-being reduces operating costs and saves energy.

3.1 Sustainable building design

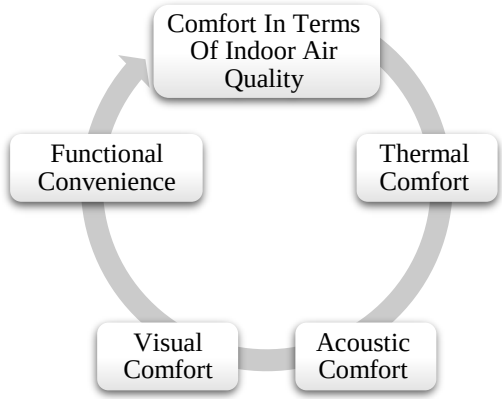
Sustainable design is one of the most important areas of sustainable development that must be taken into account. Sustainable design is an integrated concept with philosophical dimensions rather than just the exterior of a building or a specific model. Sustainable design is in keeping with the surroundings while introducing sustainable concepts, durability, longevity, and appropriate building materials with a sense of place [6]. A sustainable building was described as a healthy building because it not only meets the physiological requirements of humans but is also directly related to the psychological factor in evaluating the success of the building by the principles of sustainability. The ecological considerations of the surrounding environment are also not isolated from the individual building, which requires formulation that suits the requirements of sustainability [7]. There are five main aspects to providing human comfort and achieving well-being within buildings, and they represent basic principles of a sustainable building, as shown in Figure 1. These aspects are created through which design patterns address using scientifically studied methods to produce a localized climate inside the building that matches the scale of human comfort. Any building in which these five elements are achieved is considered environmentally sustainable [7].

Paola Sassi, in her book: Strategies for sustainable architecture indicated that there are two goals for sustainable architectural design as follows [8]:

First: sustainable buildings must be metaphorical (stepping gently on the ground) by minimizing the environmental impacts associated with their construction, their life in use and their end-of-life. Sustainable buildings should have small environmental impacts.

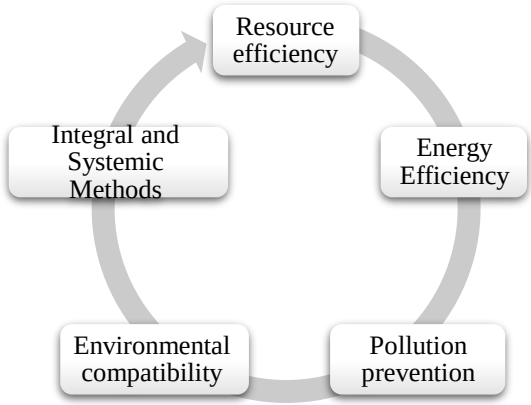
Second: Buildings must make a positive and appropriate contribution to the social environment in which they live, by satisfying the practical needs of people while enhancing their surroundings and their psychological and physical well-being.

The Organization for Economic Co-operation and Development (OECD) project set five goals for sustainable buildings [9], as shown in Figure 2.



Source: [7]

Figure 1. Basic principles of sustainable building



Source: [9]

Figure 2. Sustainable building goals

Based on the above, sustainable building can be defined as holistic thinking related to the construction and management of the built environment, taking a life-cycle perspective. To

mean not only new environmentally oriented building designs but operation and maintenance, environmentally friendly, and not only sustainably producing building materials and components but responsive use requirements derived from the overall environmental requirements derived from the overall environmental requirements.

3.2 Principles of sustainable design

Sustainable design is the harmonious integration of architecture, landscape, and interior design together with components of electrical, mechanical, and structural engineering.

Jong-Jin Kim, proposed a framework for sustainable architectural design, in which he presented three principles of sustainable architectural design as follows [10]:

- **The economy of resources** (by reducing the natural resources that are introduced into the building, reusing, and recycling).
- **Life Cycle Design** (provides a methodology for analyzing the building process and its impact on the environment).
- **Humane Design** (focuses on the interactions between humans and the natural world).

The framework here aims to help designers looking for sustainable design find "a solution rather than giving them a set of solutions." These principles provide a broad awareness of the environmental impact, local and global, as shown in Table 1.

Sustainably designed buildings reduce their impact on the environment through energy and resource efficiency. It is essential to understand the principles governing sustainable design before analyzing their relevance and recognition in different parts of the world [9]. The design of the sustainable building is based on three dimensions: 1) environmental, 2) social, and 3) economic. The environmental dimension can be achieved by reducing the use of non-renewable resources, reducing the use of toxic materials, using recycled materials, and reducing energy. The economic dimension can be achieved by analyzing the cost of the project life cycle. The social dimension can be achieved by optimizing the user aspects of the building.

Table 1. Conceptual framework for sustainable design

Principles of sustainable design		
Humane Design	**Life Cycle Design**	**The economy of resources**
strategies		
Preserve natural conditions	Pre-construction phase	energy conservation
Urban design site planning	construction phase	water conservation
Designed for human comfort	Post-construction phase	material preservation

Source: [10]

4. THE CONCEPT AND DEVELOPMENT OF HOSPITALS

Hospital buildings are the most complex types of buildings, including complex applications in the areas of climate control, air conditioning and energy needs. These buildings are characterized by the need for a strict climate and indoor air quality, in addition to high functional complexity [11]. Each hospital consists of a wide range of services and functional units, including diagnostic, treatment functions (such as clinical laboratories, imaging, emergency rooms, and surgery), and hospitality functions (such as food service and housekeeping, basic inpatient care or bed-related functions). This diversity is reflected in the breadth and specificity of the regulations, laws, and oversight that govern the construction and operation of hospitals. Ideally, the basic form of a hospital depends on its functions [12], and each of the hospital's extensive and ever-evolving functions requires including it mechanical, electrical and highly complex communication systems, specialized knowledge and experience.

The role of the hospital evolves as medicine advances scientifically and organizationally, from being a treatment center to being a health center. The new reality is that the hospital organization has a unique responsibility to meet the challenges of sustainability to the extent that the hospital is responsible for the health of the community. Hospitals must come up with a new definition of community health, a definition that goes beyond traditional measures to benefit the community. The hospital is the only institution that has the mission, intellectual resources, and access to centers of influence, attentional capacity, and leadership potential to help guide the community toward sustainability. This is the full meaning of hospital sustainability and the basis of a new social compact [13].

The principles of hospital design and planning have rapidly developed and passed through several stages during the past few decades, and they are as follows [14]:

First: "Functions Follow Design", where the services had to be adapted to the available structures. For example, the establishment of hospital facilities in any existing building such as an old barracks or a prison [14].

Second: "Design Follows Functions", the different occupational groups determine their requirements in terms of floor space, planning, and design of new facilities according to the needs of hospital jobs and staff. Fixed assets, such as operating rooms, imaging equipment, and laboratories, have been arranged to maximize capacity utilization. Patients have to adapt to job requirements.

Recently: The concept of "Design Follows First Patients, Then Functions" was adopted. The focus is now on integrating the needs of patients, hospital functions, and staff into the hospital design.

4.1 The concept of sustainability for hospitals

4.1.1 Why are hospitals important to sustainable development?

Gro Harlem Brundtland, Director-General of the World Health Organization in 2002, stated that sustainable development and health are interconnected; healthy living is the result of sustainable development, as well as a powerful and inestimable means to achieve this. We need to view health as a precious asset and a means to motivate Economic growth and poverty reduction [15], Health has been presented as inextricably linked to sustainable development in all politically important documents since the sustainability debate first began. Sustainable development in the hospital environment is one area in which services are improved in relation to the status of at least one of the dimensions without negatively affecting the others. In the ideal situation, solutions that optimize all dimensions are sought. By making the problem output to different settings or stakeholders more

visible, this approach allows for the mitigation of unintended side effects [16].

4.1.2 Sustainable hospitals

Sustainable design is seen as “best practice” because it reduces the life cycle and maintenance costs of a building, and reduces the negative impact of building on the natural environment, when sustainable solutions are not implemented in healthcare spaces, it will produce health problems related to unsustainable building practice. Problems include carbon emissions that can lead to cancer or other illnesses, sick building syndrome, respiratory illness, anxiety, mood swings, depression, and allergies. In addition, it creates a bit of irony because the only place people go to heal is where it slowly kills them through emissions and toxic substances [17].

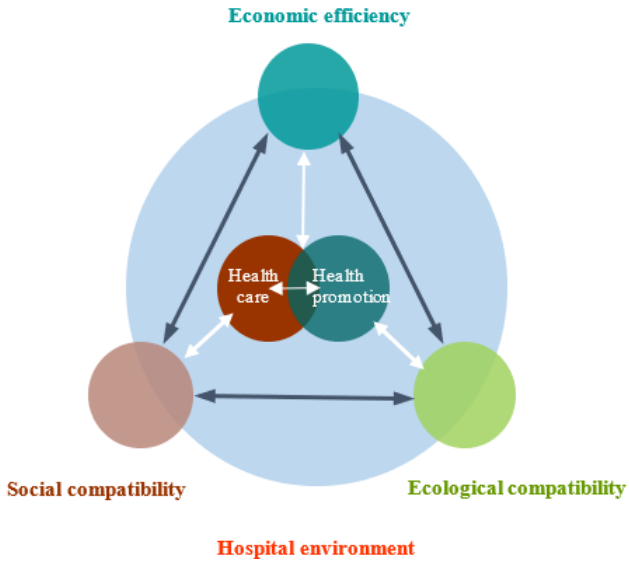
Unsustainable and inefficient hospitals are buildings with unsafe disposal of waste and untreated sewage, reliance on processed foods, and a fleet of fuel-intensive vehicles, making the environment sick. Today's healthcare organizations are finding new ways to incorporate sustainable design strategies into new construction to accelerate recovery, not only for patients but also for the planet.

The first challenge involves finding ways to identify appropriate strategies and measure their effectiveness more than just optimizing any one component, Sustainable design and construction represent the integration of materials and methods that together create the physical appearance of a building. The entire life cycle of building materials and products, as well as the building as a whole, must therefore be evaluated concerning its physical, ecological, and human contexts at the local, regional and global levels, for environmental and health considerations [18]. Since the World Summit on Sustainable Development in Johannesburg in 2002 identified health as one of five big priorities for the future [19], Healthcare has measurable goals and objectives that support sustainability and the ability of the healthcare system to thrive in its social, economic and environmental environment [20].

Hospital-wide sustainable development is an improvement activity in which the achievement of its core business, along with standards of medical quality and health promotion, is investigated concerning economic, social, and environmental sustainability [16]. In other words, we interpret considerablet sustainability in hospitals as an extension of quality standards to include social, environmental, and economic aspects. Thus, this approach applies to the concepts of quality and strategies used by modern hospital institutions. The Sustainability Triangle places health care and health promotion (as essential services) at the center of the system and provides additional quality criteria (sustainability criteria) for decision-making regarding essential services as illustrated in Figure 3. Therefore, the application of the "Sustainability Triangle for Hospitals" provides many benefits at the same time, which are as follows [21].

1. The ability to create interest and understanding between the actors on the issue of sustainable development (global).
2. Health benefits (through patient care and health promotion) and linked to savings in the use of material resources (material and energy) and financial benefits, and thus to an increase in quality of life.
3. Environmental considerations in key decision-making (decisions regarding patient care and health promotion) in hospitals, such as decisions about conditions of service.

The social dimension of sustainable development in hospital buildings is the importance of patient well-being, which is more important in the spatial and volumetric organization of the interior and exterior spaces [22]. Environmental sustainability can be incorporated into health facilities by incorporating green building principles into design and construction. Green building design increases natural light and ventilation, preserves open spaces, includes features such as a rainwater reclamation system, and promotes a healthy indoor environment [2].



Source: [16]

Figure 3. The sustainability triangle for hospitals

Following the hospital's business strategic plan and achieving the hospital's balanced performance energy, the concept of sustainability is essential in the development of the hospital, which consists of aspects of human resources, financial management, and the physical environment. The concept of sustainability in the hospital: the implementation of the cultural environmental concept, the appearance of modern and local identity, the concept of green gate access for the elderly and people with disabilities, the concept of low maintenance, the reduction of energy resources, and the use of alternative energy. in addition, the reduction of negative environmental impact, the integrated design process, the concept of a parking area Environmentally friendly cars, anticipation efforts for the heat island effect, and the application of pedestrian facilities in cities to reduce carbon dioxide (CO_2) [23].

We conclude that hospital buildings must become sustainable, healthy, and technologically aware, meet the needs of their occupants, and must be flexible and adaptable to deal with change. This leads to the realization of a building that has the best blend of environmental, social, and economic values.

4.1.3 Sustainability in health care and the health system

Whereas the Sustainable Development Unit (SDU), established in 2008 by NHS England Public, Health England, defines sustainable healthcare as “the provision of high-quality healthcare and the improvement of public health without depleting natural resources or causing serious environmental damage”. Sustainable healthcare consists of healthcare products, services, and processes with superior environmental performance – without compromising the quality of care itself

[24]. The Forum for the Future and the NHS Sustainable Development Unit explored ways to move toward more sustainable health care in their document: Fit for the Future - Low Carbon Health Care Scenarios for 2030 [25]. Key recommendations in this document include the following steps:

1. Support for patient empowerment and appropriate participatory self-care.
2. Increase the use of information technology.
3. Find the sweet spot for low carbon/high-quality life.
4. Promote health rather than cure disease.
5. Take a leading role in health care in the change.

The World Health Organization defines an environmentally sustainable health system as one that "improves, maintains or restores health, while minimizing negative impacts on the environment and taking advantage of opportunities to restore and improve it, to the benefit of the health and well-being of present and future generations" [26].

The health, system refers to all the components that contribute to supporting health and social care including the NHS, social services, and public health [27]. a sustainable health system is described by the Sustainable Development Unit (SDU) as "Works within the available environmental and social resources to protect and improve health now and for future generations" This means working to reduce carbon emissions, reduce waste and pollution, make optimum use of scarce resources, build resilience to climate change, and enhance community strengths and assets [28]. The health system also refers to all the components that contribute to supporting health and social care, including the NHS, social services, and public health [27]. A sustainable health system is described by the Sustainable Development Unit as, "working within the available environmental and social resources to protect and improve health now and for future generations" [28].

Since hospitals provide care to patients within the community, it can be described as an inherent relationship with social responsibility and sustainability dimensions related to people. Patient care has always been one of the core businesses of hospital buildings, which perfectly fits with the social dimensions of the definition of sustainability.

5. SUSTAINABILITY APPLICATIONS IN HOSPITAL BUILDINGS

Hospital buildings have now become buildings with complexities related to completely different areas from each other. There is what is healthy and psychological, there is what is technical and informational, and there is what is environmental, social, economic and cultural … etc.

What is more important than that is the necessity of providing buildings with an innovative, beautiful, comfortable, and sustainable architectural design that accommodates all these complexities through sustainable and smart architectural solutions. To design healthy and sustainable buildings, there is a need to adopt an integrated system that combines energy, environment, health, and welfare schemes [4].

5.1 Green hospitals

Green buildings are seen as an effective way to implement environmental, economic, and social sustainability in the construction industry. The concept of sustainability is essential in responding to green hospital issues that relate to several aspects, such as the use of natural resources, the development of alternative energy, the use of an energy-saving system, as well as efforts to reduce carbon dioxide (CO_2) emissions in both the planning, implementation, and rehabilitation process. [23]. The green hospital movement began a few years ago after the US Green Building Council (USGBC) released the Leadership in Energy and Environmental Design (LEED) standards for building construction. Despite the high initial construction costs, green hospitals have been shown to reduce energy costs in the end. The hospital's green design has also been linked to improving patient outcomes and employee retention. Newly constructed and renovated hospital buildings have been LEED certified [14].

5.1.1 Principles of sustainable design for green hospitals and their benefits

The design of green hospitals is based on many principles, as follows [29]:

- Lighting design for buildings: increase the use of natural light and reduce the use of artificial light. This can be achieved by using operable, transparent openings in greener yards, installing translucent skylights, or using low-power LED lighting. Daylighting has positive effects on patients' well-being and is a very good source of Vitamin D as well.
- Indoor Air Quality: Improve indoor air quality by using indoor plants that emit oxygen and reduce pollutants. As well as using a minimum amount of VOCs in construction.
- Pure and green interior building materials: The walls and surfaces of hospitals resist the growth of pathogenic bacteria, fungi, and viruses.
- Gardens and landscaping: It is one of the most aesthetic tools of the green hospital concept. Plants are considered to infuse positivity and reduce negativity.

While the Indian Green Building Council indicated a set of benefits for green hospitals, as follows [30]:

- Can reduce patient recovery time.
- Eliminates Sick Building Syndrome (SBS) for both patients and staff.
- Reduces stress levels of hospital staff, thereby improving the quality of care.
- Low consumption of energy and water.
- Green buildings can embody the concepts of the industrial environment that encourage us to emulate nature in using and reusing resources efficiently.

5.2 Intelligent hospital

The urgent need has recently emerged to transform hospitals from buildings that meet functional requirements to hospitals that are also compatible with modern technologies. The ability to self-adapt to external conditions and change behavior according to users. The interest in establishing intelligent hospitals is due to the diverse and intense requirements of patients, staff and, visitors, and this requires achieving response and self-interaction with the internal environment, in addition to achieving adaptation and compatibility with external conditions, without direct intervention [31].

The Pan American Health Organization defines a smart hospital as "a facility that is safe in the face of natural hazards, adapts to the phenomena of climate change, and contributes to

mitigating climate change. It is an accessible and fully functional health facility in the same infrastructure, during and immediately after the impact of natural hazard" [12].

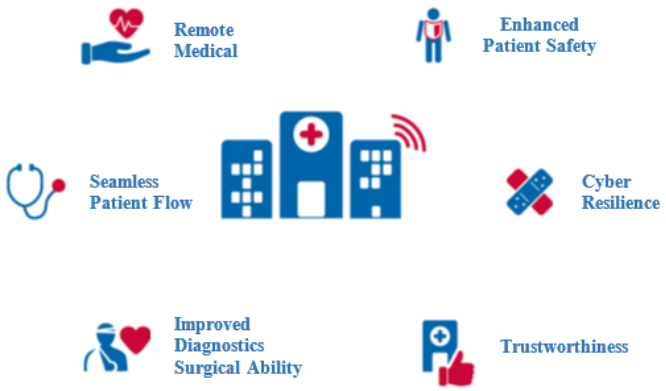
To achieve "Intelligent" hospitals, one has to make buildings and operations more resilient, to mitigate their impact on the environment and reduce pollution, there is a set of principles designed to achieve this, which also saves costs, reduces greenhouse gas emissions, achieves adaptation benefits, reduces risks and development [21].

5.2.1 Principles of sustainable design for intelligent hospital and their benefits

- The design of intelligent hospitals depends on many principles, represented by the following:
- Improve the structural integrity of healthcare facilities.
- Reduce energy and water use.
- Enhance energy security using low carbon and renewable sources.
- Improving air quality and reducing harmful emissions.
- Strengthen disease surveillance and control.
- Equip structures with efficient and environmentally friendly devices and fixtures.
- Other measures, such as the use of environmentally friendly flooring, paints, and furniture and furnishings, will contribute to increasing sustainability and reducing risks.

A group of studies revealed an interrelationship between five main structures considered essential for intelligent hospitals, which are as follows: Internet of Things (IoT), cyber-physical systems (CPS), Artificial Intelligence (AI), and management information systems (MIS) and technology service innovation, which are as follows [32].

The main objective and benefit of intelligent hospitals is to provide optimum patient care by making the most of advanced information and communication technology. The type and extent of ICT use greatly affects the hospital's goals, as well as the related challenges and opportunities, which are as follows [33], as shown in Figure 4.



Source: [33]

Figure 4. The goals of the intelligent hospital

5.3 Eco-friendly hospitals

An eco-friendly building or ecological building is a building that is eco-friendly and resource-efficient. This type of building is characterized by its efficiency in its use of local and renewable materials, in the energy needed to build it, and in the energy generated while it is in it [4]. Reducing energy use is one of the focus areas for eco-friendly designers, especially when considering ventilation and lighting. Maximizing the use of natural light during the day can reduce energy costs and improve the ambiance for building users. The importance of access to natural light and the impact this has on building users, including how behaviors can be significantly altered, have been identified. For example, the use of natural lighting improves sales volumes in retail outlets as opposed to artificial light [34].

The health sector can play a leading role in helping societies adapt to and mitigate the effects of climate change and the risks it poses to human health. In its 2009 report, the World Health Organization identified seven sustainable principles for an environmentally friendly hospital [35].

5.3.1 Principles of sustainable design for eco-friendly hospitals and their benefits

- Energy efficiency: Reduce hospital energy consumption and costs through efficiency and conservation measures.
- Green building design: Building hospitals that respond to local climatic conditions and are optimized to reduce energy and resource requirements.
- Alternative energy generation: The production and/or consumption of clean, renewable energy on-site to ensure reliable and flexible operation.
- Transportation: Using alternative fuels for hospital vehicle fleets, encouraging walking and cycling to the facility, promoting staff, patient, and community use of public transportation, and health care buildings on the site to reduce the need for staff and patient transportation.
- Food: Provide local food that is sustainably grown for staff and patients.
- Waste: reduce, reuse, and recycle, compost, use alternatives to incineration of waste.
- Water: Conserve water. Avoid bottled water when safe alternatives exist.

5.4 Virtual hospital

A virtual Hospital is a means to provide remote hospital-wide care and monitoring for patients with infectious (eg, COVID-19) and non-communicable (eg, diabetes) diseases using telehealth-based communications, Internet of Things devices IoT, and artificial intelligence AI for disease patterns and identification [36]. Another view of the concept is a freestanding centralized facility staffed by healthcare professionals. Perhaps the most famous example of this is the Mercy Virtual Care Center, which opened in 2015 and is considered the world's first virtual hospital described as "the world's first dedicated telehealth facility" providing the four-story, 125,000-square-foot building. It is located in Chesterfield, Missouri, and is the center of Mercy's Virtual Care Program [37]. Accommodates 330 workers but no patients, medical teams in the care center treat patients located remotely in Mercy hospitals, doctors' offices, and even in their homes, as shown in Figure 5.

Source: [37]

Figure 5. Mercy center for virtual care

The basic sustainable principle of virtual hospitals is

efficiency. Rather than wasting valuable resources, for example, patients can stay home and reach a doctor at the same time. It also provides the

Virtual hospitals save costs and remove geographic barriers, in addition to the services they provide, and thus achieve the economic dimension of sustainability.

Through what has been presented, previous literature will be relied on to identify the most important vocabulary and effective indicators for sustainable design in hospitals and achieve guidelines to reach a guideline for health care officials interested in applying the principles of sustainable construction in hospital design, as shown in Table 2.

Table 2. Guidelines for indicators of sustainable design for hospital buildings

Sustainability Dimensions	Categories	Indications
Environmental Sustainability	Site	Sustainable Site Planning
		Gardens and landscapes
		Create suitable parking lots and bike paths
		Natural ventilation in public places
	The shape and orientation of the building	The form of the building to take advantage of the natural elements of the site (daylight, path of the sun, wind)
		Building location for linking to other buildings on the site
		Planning spaces within the building to respond (direct sunlight, external pollution sources)
		Integrating green elements into the design concept (green roofs, green walls)
	Indoor environment quality	Reducing pollutants, such as SO2, NOx, PM, CO.
		Use of indoor plants, indoor skylights
		Minimum VOC
		Use of anti-bacterial and anti-bacterial finish materials
	Energy	Use of low-carbon and renewable sources
		Use natural lighting during the day
		Monitoring the energy used for each demand by intelligent systems
		Monitoring the energy used in the user's area by intelligent systems
	Waste	Reducing the use of raw materials
		Reducing hazardous waste
		Reducing construction waste
		Using alternatives to burning waste
		Waste Recycling
	Materials	Use of sustainable materials
		Use of recycled materials
		Use of local materials
	Water	Water saving systems in the building
		Collect rainwater and/or gray water and reuse it for irrigation and reduce drinking water consumption
		Water saving systems in the building
	Pollution	Reducing CO_2 Emissions
		Reduce emissions of dangerous pollutants
Social Sustainability	Health and well-being of occupants and patients	Efficiency of natural ventilation in interior spaces
		Reducing the toxicity of finish materials using sustainable materials
		Thermal comfort
		Visual Comfort
		Acoustic Comfort
		Indoor environmental quality
		Design Quality
		Flexibility and adaptability and expansion of spaces
		Spatial and volumetric organization of indoor and outdoor spaces
		Equipment and Furniture
		Evidence-based design that integrates architecture, landscape and health planning
	Accessibility	Easy access to public transportation
		Easy access to amenities
		Space distribution
		Encouraging walking and cycling
	Awareness & education for sustainability	Educating the building occupants about the concepts of sustainability
	Innovation	Innovation in the design of the project
Economic Sustainability	Life cycle costs	The initial cost
		Operation and maintenance costs
		Increase the life of the building
	Get the energy	Generating clean and renewable energy
	Financial savings	Reducing and treating pollutants of all kinds
		Application of automation to the building management system
	Reduce transportation cost	Sustainable transport measures (the route of effective presence near public transportation infrastructure) in hospitals, use of alternative fuels, electric vehicles, use of bicycles and walking), virtual clinics and telemedicine

6. CASE STUDIES

The practical study is a presentation of the distinguished modern international hospitals in their designs for the principles of sustainability, and by adopting the descriptive analytical approach, and subjecting the study cases represented by hospital buildings to a comparative systematic analysis. And access to the most important vocabulary and effective indicators for the sustainable design of the study cases, as shown in Table 3. To provide guidance to healthcare administrators interested in applying sustainable building principles in hospital design. To create better hospitals that enhance health and well-being, reduce operating costs and save energy. As shown in Table 4.

Case 1: National heart center, Singapore, 2014.

The National Heart Center in Singapore is setting the standard as an excellent facility that sets a global precedent for the sustainable development of heart-related healthcare through environmental, social, and economic design [38]. The 35,299-square-meter, 12-story hospital the building is a green mark with a unique design that puts people first. Recognizing that the medical world is advancing so rapidly, the design incorporates modular building methods to ensure the building structure remains flexible and adaptable both internally and externally, allowing for future growth and development [39].

Case 2: Lady Cilento Children's Hospital, Australia, 2014.

A teaching hospital specializing in pediatrics. The 95,000-m2 hospital is an important new urban addition to the Brisbane area [40]. The hospital's innovative and colorful design includes pioneering diagnostic and treatment facilities providing specialized pediatric health services. The design presents an opportunity to challenge the prevailing functional and clinician paradigms and to radically rethink the model of care, considering issues of social, economic, and environmental sustainability [41].

Case 3: Bendigo hospital, Australia, 2017.

The New Bendigo Hospital is Victoria's largest regional hospital. The project aims to provide world-class healthcare facilities and aims to provide a welcoming and positive environment that enhances well-being. It includes community facilities such as the Aboriginal Park and Child Care Center, with a total of 734 beds and 128 apartments. The hospital provides a calm and caring environment for staff, patients, and visitors by integrating architecture, landscape, health planning, and evidence-based design [42].

Case 4: Perth-childrens-hospital, Australia, 2018.

Built as part of the Queen Elizabeth II Medical Center and adjacent to the existing Sir Charles Gardner Hospital, Perth Children's Hospital combines innovation in medical technology with high-value aesthetic appeal and design features to aid in the recovery of patients. The hospital has a capacity of 298 beds and 12 operating theatres. The 120,000 square meter building consists of four interconnected blocks spanning up to ten floors and a spacious basement that covers the area of the hospital [43]. Digital engineering is instrumental in providing a structural solution that balances engineering requirements and potential future uses of a hospital, all in an economically sustainable way. A hospital that can serve future generations to receive the care they need and the training they need [44].

Table 3. The analysis of the case studies for the vocabulary and indicators of sustainable design

Project	Indicators for sustainable design of hospitals
 Source:[45] Case 1: National heart center, Singapore, 2014.	• A design philosophy based on the principle of putting patients, employees, and visitors first • The design concept was inspired by Medieval Courtyard Gardens and is based on the relationship between the healing properties of natural light and agriculture [38]. • The structure of the building is flexible and adaptable both internally and externally, allowing for effective and potential future growth. • Reducing walking distances and creating efficient circulation around the building [39]. • Great floating green gardens provide social connection and speed up the healing process by providing healthy doses of natural light, ventilation, and views for patients [45]. • The building achieves a 30% reduction in energy consumption due to the lack of direct west-facing facades, natural ventilation in the corridors, and use of renewable elevators.
  Source: [41] Case 2: Lady Cilento Children's Hospital, Australia, 2014.	• Evidence-Based Design Philosophy [40]. • Hospital design in response to the urban environment • feature facade a vibrant design inspired by the idea of a living tree with cladding inspired by plants [41]. • green and purple fin shading systems on the glazing block out Direct sunlight • Green roofs provide comfort and reduce the effects of the heat sink. • The colors used on the exterior and interior of the building are derived from the landscape colors. • Access to green spaces is a key element of design. • Rooftop gardens, green walls, enclosed courtyard gardens, and views of the surrounding gardens are part of the hospital treatment environment [41]. • Use of 2D and 3D art on a large scale throughout the building to enhance patient well-being and provide attractive distractions for young patients [40]. • Natural ventilation in the public places • Environmental and mechanical systems energy-saving • Collecting water for use in irrigation • Finishing materials comply with the safety Green Building Council's [41].

  Source: [42] Case 3: Bendigo hospital, Australia, 2017.	• Evidence - based design philosophy [42]. • The design is inspired by the size and proportion of Bendigo's heritage buildings, as well as the colors. • All interior corridors feature a floor-to-ceiling view of the landscape, while rooms have uninterrupted, expansive views and access to natural light. • Landscaped courtyards provide amenities for staff and patients, while secluded gardens provide a space for quiet reflection for cancer patients. The expansive green roof in the mental health area provides patients on the upper levels with a green appearance. • The use of wood and the quality of light provide a feeling of warmth and help to increase well-being. • Public spaces include large-scale works of art that provide vibrant energy and enhance the well-being of patients [42]. • The hospital's green roofs reduce glare and the heat island effect while improving thermal and acoustic performance. • The roof of the building contains a wide range of solar panels to generate clean energy and reduce greenhouse gases annually. • The hospital roof works to harvest and store rainwater. • Use recycled water systems as the primary source of water for landscape irrigation, toilet flushing systems, and heat rejection. • The cogeneration and Tripartite plant operates to allow simultaneous generation of electricity, heating, and cooling from fuel combustion or a solar heat collector [42].
  Source:[46] Case 4: Perth-childrens-hospital, Australia, 2018.	• Evidence - based design philosophy [43]. • Follow the flexible approach in design and the ability to change the interior spaces to suit different health career planning in the future (growth and renewal). • The design is characterized by creating a welcoming and family-friendly environment, enhancing human connection, and having links with nature [43]. • Design inspiration from adjacent Kings Park, including colors and views. • Simulation of nature. The building is in the form of a flower, with wings like petals. • Plenty of natural light, with large windows in each inpatient room [46]. • Access to 3,500 square meters of green space, including gardens and outdoor areas on the upper floors and rooftop gardens. • The double skin facade on the east and west facades (which houses most of the clinics, laboratories, and teaching spaces) with open views of Kings Park [46]. • The glass used in the facades is of the smart type, which controls glare and heat. • The facade changes throughout the day, as the motorized vents open and close within the path of tracking the sun [43]. • Emphasis on the green color, that is, like growth and renewal [47], • A special strong building structure that operates after a disaster • Widespread use of sculptures and drawings throughout the building to enhance patient well-being and provide distractions to decision points and destinations [47]. • Generation of energy from solar cells on the roof of the building [43].

Table 4. Explain the analysis of the case studies and the statement of indicators and vocabulary of sustainability used in each case study

Categories	**Indicators for sustainable**	Case 1	Case 2	Case 3	Case 4
Site	Sustainable Site Planning	*	*	*	
	Gardens and landscapes	*	*	*	*
	Create suitable parking lots and bike paths	*	*	*	*
The shape and orientation of the building	The form of the building to take advantage of the natural elements of the site (daylight, path of the sun, wind)	*	*	*	*
	Building location for linking to other buildings on the site	*	*	*	*
	Planning spaces within the building to respond (direct sunlight, external pollution sources)	*	*	*	*
	Integrating green elements into the design concept (green roofs, green walls)	*	*	*	*
Indoor environment quality	Reducing pollutants, such as SO_2, NOx, PM, CO.	*	*	*	*
	Use of indoor plants, indoor skylights	*	*		*
	Minimum VOC				
	Use of anti-bacterial and anti-bacterial finish materials		*		
Energy	Use of low-carbon and renewable sources	*	*	*	*
	Use natural lighting during the day	*	*	*	*
	Monitoring the energy used for each demand by intelligent systems		*		*
	Monitoring the energy used in the user's area by intelligent systems		*		*
Materials	Use of sustainable materials	*	*	*	*
	Use of recycled materials	*	*	*	*
	Use of local materials	*	*	*	
Water	Water saving systems in the building		*	*	
	Collect rainwater and/or gray water and reuse it for irrigation and reduce drinking water consumption		*	*	
Pollution	Reducing CO_2 Emissions	*	*	*	*
	Reduce emissions of dangerous pollutants			*	

Health and well-being of occupants and patients	Efficiency of natural ventilation in interior spaces	*	*	*	*
	Reducing the toxicity of finish materials using sustainable materials		*	*	*
	Thermal comfort	*	*	*	*
	Visual Comfort	*	*	*	*
	Acoustic Comfort	*	*	*	*
	Indoor environmental quality	*	*	*	*
	Design Quality	*	*	*	*
	Flexibility and adaptability and expansion of spaces	*			*
	Spatial and volumetric organization of indoor and outdoor spaces	*	*	*	*
	Equipment and Furniture	*	*	*	*
Accessibility	Evidence-Based Design		*	*	*
	Easy access to public transportation		*	*	*
	Easy access to amenities	*	*	*	*
	Space distribution	*	*	*	*
	Encouraging walking and cycling	*		*	
Awareness & Education for Sustainability	Educating the building occupants about the concepts of sustainability		*		
Innovation	Innovation in the design of the project	*	*	*	*
Life cycle costs	The initial cost		*		
	Operation and maintenance costs				
	Increase the life of the building	*	*	*	*
Get the energy	Generating clean and renewable energy	*		*	*
Financial savings	Reducing and treating pollutants of all kinds			*	
	Application of automation to the building management system		*		*
Reduce transportation cost	Sustainable transport measures (the route of effective presence near public transportation infrastructure) in hospitals, use of alternative fuels, electric vehicles, use of bicycles and walking), virtual clinics and telemedicine	*	*	*	*

7. RESULTS AND DISCUSSION

After a careful presentation and analysis of case studies of sustainable global hospitals based on a descriptive analytical approach, in addition to referring to the previous literature, and subjecting the case studies to a systematic comparative analysis of the indicators and vocabulary that were obtained from the previous literature. It was concluded that the hospitals selected for the study, which were classified as sustainable, achieved high rates for using the principles of sustainability in their vocabulary and indicators. Thus, Table 2 can be proposed as a model guide to guide healthcare administrators interested in applying sustainable building principles in hospital design. To create optimal and sustainable hospitals that improve health and well-being, reduce operating costs, and save energy.

8. CONCLUSIONS

Through the previous presentation, it was founded that the concept of sustainability has a comprehensive meaning and is not limited to the narrow concept of reducing the consumption of natural resources necessary for life. Rather, it is an expression of achieving a suitable and healthy environment for humans that does not continue without the integration between ecosystems, the natural environment, and life-supporting systems, including in its humans, and several terms of sustainability have appeared, including green architecture, sustainable design, environmentally friendly design, and smart design. Its goal is to balance human needs, on the one hand, and the preservation of natural resources, and on the other hand, to reduce environmental pollution. Sustainable design is important in healthcare because hospitals have a significant impact on the economy. The quality of the built environment design is of vital importance in economic, environmental, and social terms. The three dimensions of sustainability (economic, environmental and social), affect the way people perceive and pursue sustainability in their environment. The success of designing sustainable hospitals in the world through increasing awareness, importance, and application depends largely on the dimensions of sustainability and the vocabulary and indicators of sustainable design. We conclude from this that hospital buildings must become sustainable, healthy, and technologically conscious, meet the needs of their occupants, and must be flexible and adaptable to deal with change. Thus, reaching a building that achieves the best combination of environmental, social, and economic values.

ABBREVIATIONS

SDGs: Sustainable Development Goals, OECD: Organization for Economic Co-operation and Development, CO_2: carbon dioxide, SDU: Sustainable Development Unit, NHS: National Health Service, USGBC: US Green Building Council, LEED: Leadership in Energy and Environmental Design, LED: Light-Emitting Diode, VOCs: Volatile.

Organic Compounds, SBS: Sick Building Syndrome, IoT: Internet of Things, CPS: cyber-physical systems, AI: Artificial Intelligence, MIS: management information systems, ICT: Information and Communications Technology.

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