

A Proposed Methodology for Integrated Architectural Design of Smart Hospitals

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Abstract

INTRODUCTION: Urgent need has recently emerged to transform hospitals from buildings that not only achieve functional requirements, but also comply with modern technologies. This is so that they are able to self-adapt to external conditions and change their behavior according to users. This is compatible with emerging trends to convert cities and buildings in developing countries to smart.

OBJECTIVES: To develop a comprehensive methodology for proper dealing with smart materials & systems when constructing and finishing hospitals, leading to defining principles of an integrated architectural design for smart hospitals.

METHODS: The descriptive analytical approach included theoretical background on concept of smart hospitals, types of smart materials & systems and their role in hospital design.

RESULTS: An integrated methodology for proper architectural dealing with hospitals to allow them to be smart, which the study recommends to follow and complement between smart materials and systems.

CONCLUSION: The research conceived a proposed methodology for the architectural design of smart hospitals and identified mechanisms for utilizing smart materials and systems in developing hospital designs

Keywords: Smart hospitals, Smart materials & systems.

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1. Introduction

Smart hospitals are essential components of smart cities which have received great attention in most countries of the world. The interest in establishing smart hospitals is due to the intense varying requirements of patients, workers, and visitors. This requires achieving response and self-interaction with the internal environment, in addition to achieving adaptation and compatibility with external conditions, without direct intervention^[1].

Moreover, it is an essential step for automating the health care field in light of the intensity of the various internal systems^[2], which provides practical solutions for medical management and treatment by relying on information technology and building network infrastructure, such as mobile or remote health care and others^[3].

Also, this provides sustainable self-management of resources such as energy and water^[4], ^[5], reducing pollution by emissions and waste^[6]. Thus, the hospital environmental performance is improved, and the operating environment is

upgraded. This is carried in a manner that achieves safety, security, and user-comfort, as well as being in accordance with modern designs of hospital buildings, which focuses on transferring them from being only functional buildings to buildings that are designed, executed and equipped in a way that depends on artificial intelligence.

This is as a part of computer sciences that are interested in producing smart technologies which give characteristics to buildings similar to these of human intelligence^[7].

This approach is compatible with rapid technological advances and modern technologies which support interactive and integrated building construction and finishing materials (concrete, glass, etc.) in addition to supporting various systems (air conditioning, ventilation, safety and security systems, etc.).

The concept of architectural design of smart hospitals and their importance will be defined below in addition to identification of smart technologies associated with their design which leads to setting up a methodology to allow for relying on these technologies in designing smart hospitals.

2. The concept of smart hospitals, importance and advantages

The term "smart buildings" has appeared in the early eighties of the twentieth century to achieve integration between the environment, technology, and provide comfort in controlling electronic devices in buildings. Initially, focus is given to the technological side and support of communication between building systems (air conditioning, ventilation, safety, security, etc.) to achieve the building user's requirements and increase productivity, Smart buildings can be defined as buildings that are equipped in a technical manner that allows effective management of resources at the lowest cost^[8]. This is to be able to interact with the internal environment and adapt to the external environment^[9].

Hence, **Smart hospitals can be defined as:** hospitals that are able to continuously adapt and improve the internal environment to achieve the needs of its users by responding to external changes such as climate and security protection, and the interior changes in functional and surveying requirements in the building^[10].

This is done at specified times, according to information collected from the internal and external environment^[11] by means of inputs such as detectors^[12].

They are buildings that change constantly as a result of the continuous interaction between their components (location, operations, users, administration), and the relationships between them^[13].

This is done by using materials, systems and sensors that rely on self-interacting techniques with the environment to give the hospital additional features that are compatible with technological advances and medical requirements^[14].

Also, they are buildings capable of creating a good climate that helps to raise the efficiency of its users and effectively manage to reduce the cost of operation over its life span.

This is carried out by integrating environmental systems (energy, lighting, sound, temperature, communications, information network, etc.) to achieve rapid communication with the outside world by computer, optical fiber and satellite^[15].

The systems should be controlled and adapted by comprehensive integration and coordination without direct interference from the user^[16], with the exploitation of technological systems and building control systems to achieve the highest functional and technological performance for it^[17], so that the effective technology and architectural strategies related to global networks are formed to create comprehensive development and integration with users^[18], also to complete integration between jobs and technological systems, face current or future requirements and needs, and inspire sustainable life for future cities^[17].

Smart hospitals are concerned with providing an effective environment that helps users to achieve goals related to cost and environmental comfort, "safety and security", suitability flexibility^[19],^[20], sustainable energy and water, reduce emissions and waste pollution^[13], focuses on identifying the characteristics and capabilities of building an architectural hospital to achieve dynamic response to environmental factors and managing reactions in a manner that depends on anticipating environmental changes, and the use of renewable energy sources. The hospital-intelligence can be apparent in

its internal functions, the services that it provides, the management systems, or all three aspects integrated^[17]. It is also shows the correlation between its aims and modern design of hospitals, according to the following:

3. Characteristics and types of smart materials and systems, and their role in hospitals

Managing smart hospitals depends on the use of smart materials that are used in the construction and finishing of the building^[21], and smart systems through which the building is managed, according to the following.

3.1. Smart materials in hospital buildings

Smart materials are capable of providing a unique beneficial response when specific changes occurs in the surrounding environment^[22].

They are high-tech materials that have the ability to sense and respond to adaptation to environmental, internal and climatic changes^[22]. They are able to perceive and respond to many external stimuli in an organized manner^[23], stimuli that can be electrical, chemical or magnetic in nature^[12].

The difference between smart and traditional materials is seen in the composition and interaction with external influences and response to external stimulus in order to control temperature changes or solar radiation^[24]. Such materials form a part of the smart structural system and have the ability to sense its environment and calculate changes to the building^[25].

3.1.1. Smart material properties

Intelligent materials are characterized by the ability to return to their previous form, self-repair, strength, rigidity, ductility and high efficiency. In addition to the long life span, ease of manufacture, installation, aesthetics and environmental compatibility and the ability to respond quickly to hazards^[11].

3.1.2. Types of smart materials

According to the nature of intelligence, smart materials are divided into materials that change one of their properties (chemical, thermal, mechanical and magnetic) in response to a change in external conditions, and materials that transfer energy from one form to another directly, as in Figure 1. Table 1 illustrates types of smart building materials that correspond to the requirements of smart hospitals.

Figure 2 shows some of type of smart materials mentioned in the previous table. Also, Table 2 shows types of smart floors, walls and ceilings finishing materials compatible with the requirements of the smart hospital^[26],^[27], Figure 3 also shows types of walls and ceilings finishing materials mentioned in the previous table.

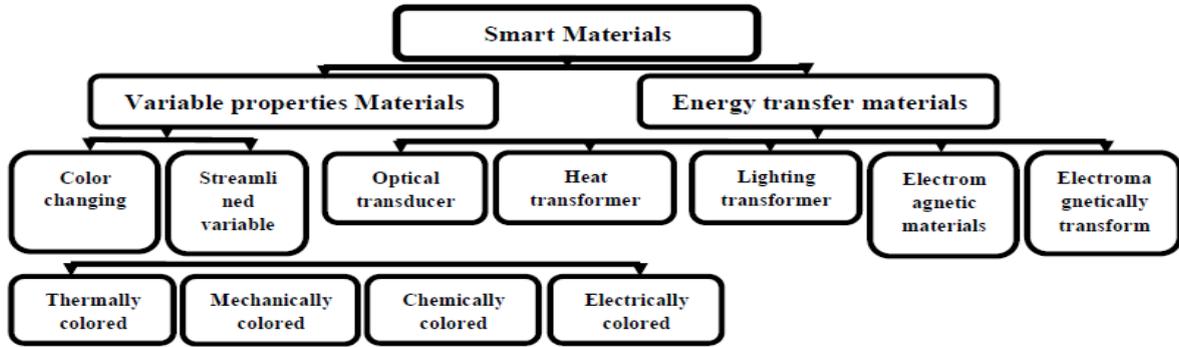


Figure 1. Types of smart materials [28]

Table 1. Types of smart building materials that correspond to the requirements of smart hospitals

Type	Material Name	Components	The use
Building Materials	Light-Transmitting Concrete	It is a mixture of concrete and fiber optics	It allows light to pass through it, and a view of the outside world
	Transparent Concrete	Concrete made from crushed glass and plastic materials that help to cohesion	Makes the building facade as a large glass window and withstands pressure
	Aerated Concrete	Aluminum powder is added to cement, lime and water to produce lightweight concrete	It is used for high-rise buildings and interior walls
	Pervious Concrete	Concrete with a porous structure that allows rain water to pass through to the ground, and is durable	It is used in sidewalks and floors
	Luminous Brick	It is made of transparent or colored polycarbonate panels and can withstand more than ordinary glass	It is used in high art buildings because it is glossy or matte
	Smart Brick	Stuffed bricks with sensors, processors, and wireless signal connections to warn of hidden pressures and damage in the aftermath of a disaster	It provides important and necessary information for firefighters and rescue workers and provides safety for them
	Smart Cement	Magnesium carbonate is put in place of calcium carbonate and absorbs carbon dioxide from the air	It is used to protect against pollution and Airborne infection transmission

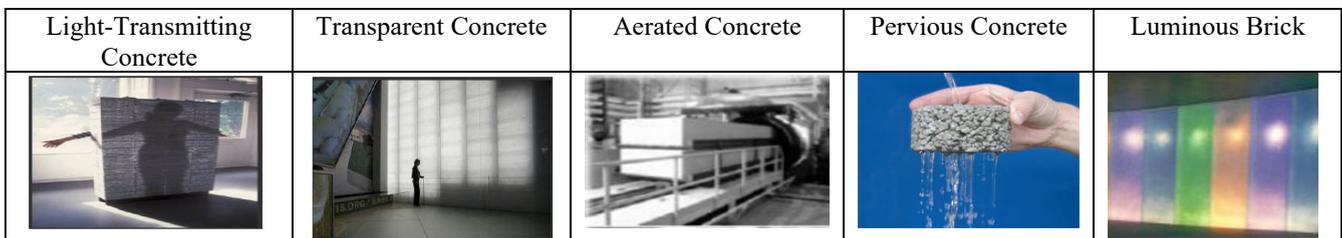


Figure 2. Types of smart materials

Table 2. Types of smart floors, walls and ceilings finishing materials compatible with the requirements of smart hospital [26] [29].

Type	Material Name	Components	The use
Floors finishing materials	Electric Energy Floors	It is equipped with a wireless transmitter to capture kinetic energy within people walk and convert it into electrical energy	Electric energy in lighting, etc., or stored excess energy in batteries for use at night
	Floors equipped with advanced protection system	They are tiles equipped with remote sensing devices as a protection system, so that people can be identified through the footprint.	Identify people, report to security systems, know people if they fall, and give an ultimatum
	Electrostatic Floors	Generates energy depending on pedestrians, and tiles are 50 cm x 50 cm, when people press them, they generate 0.1 watts	Clean energy that preserves the environment, reduces CO2, and saves energy consumption
	Phosphorous Ceramics	Made of glass with phosphorous pigments, organic and inorganic materials to be able to absorb sun energy, that used as visible energy at night	Heat resistance and chemicals materials, easy to clean and do not require special maintenance
	Narmada Slices	carbon strips surrounded by two polyethylene layers, and there are two copper strips on both sides of the strips that conduct electrical current, the	It generates thermal energy and is installed and. It is safe and isolated and has no risks from short circuit

Type	Material Name	Components	The use
		current passes from one copper strip to another through carbon to generate thermal energy	or water, transported easily from one place to another under carpet
Walls and ceilings finishing materials	Reflective Indoor Coatings	Reflects the lighting, which increases the feeling of lighting, and reduces energy consumption	Suitable for areas with limited sunlight with intensity and duration
	Dark Painting	Super black coating to dim the light 10:20 times	Resistant to unwanted reflection
	Shutoff valves	It contains water flow sensors in case of leakage	Prevent Infusion and its damage
	Optical fiber	Orientation devices to wave and light signals	For remote sensing application
	Chromogenic Glass	Its characteristics change according to the needs of the building	Give an aesthetic appearance and control of the light
	Self-cleaning Glass	that is chemically treated and coated with titanium oxide	Pollution resistance and infection control
	Coagulate Glass	It is placed between the two layers of the aerogel material, and responds to heat. It clots and changes to a semi-transparent mode	It changes according to requirements of space, and achieve thermal insulation and privacy
	Photochromic Materials	They are substances whose color characteristics change by exposure to light	Painting the elevation of building to interact with the sun and light
	Formable Aluminum Sheets	Flexible and moldable protects the building from ultraviolet radiation and is lightweight	Decorating the walls due to its softness, and ease formation
	Polystyrene Acoustic Panels	Made of cast polystyrene fibers and considered a sound absorbent material	It is used to control sound in interior spaces
	Hanging Granule Technology	Microscopic granules of a light-absorbing solid that between two glass plates coated with an electrically conductive material	Change of agglomeration of the granules changes the transparency of the glass, the entry outside light
	Status Variables (PCM)	Collect and store the thermal energy materials used to cool the vacuum in the summer or heating in the winter.	Its state changes when absorbing thermal energy or its release from a solid to a liquid state or vice versa
	Aluminum coated panels	They are aluminum panels with a rough surface, and these panels reduce energy consumption by 15%.	Used to store solar or wind energy and broadcast it in the building for heating and sound absorption
	Fluoropolymer panels	They are air-pressed transparent polymeric panels, one, two or three layers, which form the building sheath and are surrounded by a metal frame.	It provides heat insulation and UV protection and is self-cleaning and anti-combustion
	Microscope Slides	1 mm strips of acrylic and glass have small holes, when the sound waves are joined to it, the sound energy converts to thermal one, decrease the noise	It is used for acoustic insulation, and electrical energy for heating due to the heat produced
	Aerogel Glass	Porous, dry gel materials with little thermal conductivity. When exposed to heat, they quickly clot, the color of the glass changes to a semi state	Provides sound insulation and fire extinguishing ability, and reduces temperature.
	Photovoltaic Glazing	Transparent materials and when exposed to the sun, begins to disperse and reflection begins and turns to the visible spectrum at more rays.	To reduce solar heat gain, and thus reduce the cooling load, it generates little clean electricity
	Thermochromic Glass	Change optical and thermal properties according to the ambient temperature and solar radiation intensity.	Achieves shading, the glass remains transparent at lower temperatures and becomes opaque when raised
	Gasochromic glass	The idea of its work depends on pumping the hydrogen gas H ₂ or O ₂ oxygen into the cavity between the glass plates, absorbing the sun's heat	It absorbs the sun's heat, transports it to the internal space, and reduces the electrical consumption
	ElectroChromic Glass	Variable properties of substances, able to change their color independently responding to an external electrical catalyst	It controls the gain of sunlight, controls daylight, and reduces the need for artificial lighting
Liquid Crystal Technology	Two layers of glass with a liquid crystal when electricity is shed on it is arranged regularly, the glass becomes transparent passing light	Control the amount of light transmitted through liquid crystals between the two layers of glass	
Suspended Particle Glazing	It includes needle-shaped particles stuck in a liquid at random between two double glazing panels. When electricity passes, the particles are organized to pass light. When the particles stop moving, the glass dims and blocks the light.	It is used to protect against harmful UV rays when turned on or off and instantly controls the amount of Passer by light and heat	
Smart	Vital interfaces contain cells that resemble the lens	It controls solar energy entry,	

Type	Material Name	Components	The use
	Mashrabiya	of the imaging camera, to automatically reduce and enlarge the holes according to the light intensity.	reduces air conditioners and allows light to enter without solar radiation
	Sun Break Technology	Fiberglass, aluminum or glass-reinforced sheets are strong and flexible, which are used with elevations to open or close automatically as needed to reduce heat and energy.	It is dynamics, changing its shape, composition and orientation to respond to environmental factors, and climate change
	Solar Cell Coverage Techniques	Solar capacitors are combined with the glass tiles and put them on the roofs over the solar cells to absorb and deliver energy while protecting them from external influence.	Solar energy absorption, storage and utilization in solar cells
	Cira Light SunTrackers Skylight	They are roofs that take advantage of daylight, using solar powered GPS. Mirrors cover the building's sunlight with a prismatic lens that distributes light regularly.	Clean lighting technology, sustainable solar-powered lighting solution to save energy

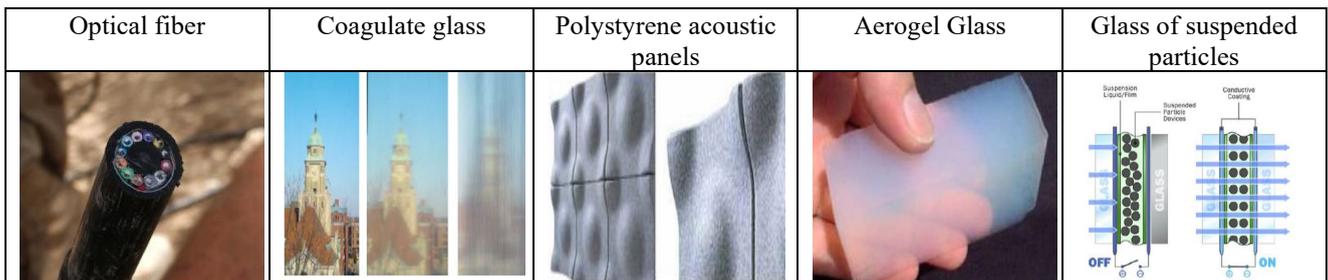


Figure 3. Types of walls and ceilings finishing materials

3.2. Intelligent systems in hospitals

Smart systems are defined as a set of inputs that are prepared in specific ways that achieve certain desired goals^[15]. They compose of a group of interconnected elements such as sensors, motors, controllers, and computers that are managed together to control the main functions of buildings and control subsystems such as heating, ventilation, cooling, etc^[30]. Specific software are that linked to hardware such as switches, communication media, and connectivity materials such as wires, equipment, and data entry means^[31].

This plays an important role in building economics and management^[10], as well as energy conservation through various effective programs, to obtain optimum performance and help with operation and maintenance.

3.2.1. Components of smart systems

It consists of three components: **Input Systems** for collecting information on factors associated with the building, using reception devices such as internal sensors distributed in the rooms according to the type of sensor and the shape of the space^[32], or external sensors that attach to the top of the rooms or on the exterior^[31].

Information processing is carried out to obtain information, data from input, analyze and process them to control other systems in an integrated manner^[33].

Then the **Outputs System** includes the output of the data processing, through which clear decisions are enforceable. The response to this is either internal, such as responding to wind loads, or external as changing the intensity of lighting, or opening or closing doors automatically^[33]. Its role in the

building can be determined in making it an architectural product capable of knowledge, decision-making and self-response^[1].

3.2.2. Characteristics of smart systems

Intelligent systems are characterized by their high efficiency when using high quality insulating and conductive materials, the possibility of simultaneously combining several activities and controlling several services such as lighting, air conditioning. In addition to the ability to receive several variables from different sources in a highly complex way, such as lighting several rooms with varying degrees of lighting intensity. Also this includes the ability to handle and manage peak periods by reducing loads, monitor and analyze internal and external environments and implement operational functions without human intervention.

This is to remotely control systems via the Internet^[34]. With the importance of the role of automation in developing architectural environments by relying on technical equipments and communication devices^[35], the effect of virtualization, communication technologies, the Internet, and virtual reality.

3.2.3. Types of smart systems

Smart systems include three types: control and access control systems, direct digital control systems, and communication systems, as shown in Table 3.

Table 3. Types of smart finishing compatible with the requirements of the smart hospital [26] [29].

The System	System Name	Nature	Use
Access control systems	Identification Systems	Invisible sensors are placed under tiles or in concrete, safe because the electricity that flows through them is very weak.	It gives an alert when there are people who are not authorized to enter the place, and ensure that the person has access
	CCTV & Video Surveillance	Live and direct surveillance devices in some places	Used at the entrances and corridors, monitored and recorded video and transferred by internet
	Thermal Imaging Camera	It detects and measures by temperature differences	Allows observation of what cannot be seen while ensuring quality and safety
	Image Recognition System	It depends on the quality of the photos and the lighting and background	It detects and encodes faces in videos and photos
Direct digital control systems	Smart Sensors	System for analyzing weather forecast, measuring potential environmental, fire alarm, and monitoring spaces	Used to monitor lighting, noise, humidity, temperature, and built-in control, proximity and touch sensors, for safety and fire control.
	Heating, Ventilation and Air Conditioning	A control system consisting of a set of rings grouped together	Maintaining the environmental conditions required for vacuum and monitoring them, and improving the quality of indoor air
	Energy Efficiency monitoring	It closes the systems at times of occupancy or with the schedule of works	Individual control in each room to conserve energy, monitoring energy consumption by user
	Lighting Control Systems	Management in line with the needs of each building, according to its type, area and percentage of occupancy	Monitor bills, measure the amount of electricity consumption, and provide information and data directly to the consumer
	Addressable Fire Alarm System	Each detector has a title and guides about the fire or smoke with a separate report	Instructs the fire zone to send signals if smoke reaches a certain level
	Smart Plumbing Systems	Automatic devices with faucets to collect the used water and reuse it for irrigation	It aims to conserve water through the use, detection of water leakage, and its location
	Vertical Communication	Associated with vertical communication between building elements	It contains an alarm system, surveillance cameras and communication equipment
Communication systems	Addressing Communications Devices	For converting traditional systems to addressing, with the possibility of linking them to traditional systems	It is used to facilitate maintenance, reduces communication costs, and gives high quality connections
	Network (LAN)	Wireless networks	Check high speed small buildings are used
	Network (WAN)	Wireless networks	Achieve high speed data over a wide areas

4. Modern design requirements related to smart hospital thought

The link between smart hospital and modern hospital design shows the importance of achieving interactive functionality, technology, user desires, environmental needs, and security and safety.

4.1.1. Requirements for functional interactivity

Recently, hospital design requirements are concerned with achieving: (a) Flexibility and self-response to changing in functional requirements leading to an improvements in the internal environment of occupants, (b) Functional expansion to accommodate future growth, (c) Interactive management of operational cost control aspects, (d) Adaptation to changes in uses, to achieve certain economic and technical aspects^[36], (e) The possibility of adding security and fire protection systems according to the requirements^[37], (f) Moving towards the digital space, enhancing medical services, using a model that provides business requirements, information technology, and improving work flow, (g) Integration of systems and technology to serve users,

interact with functions and capabilities of remote communication, periodic maintenance works, facilitate work movement, and internal communication^[17], (h) Development based on information technology, (EMR), and using of information regarding medical treatment and operation, as shown Figure4.

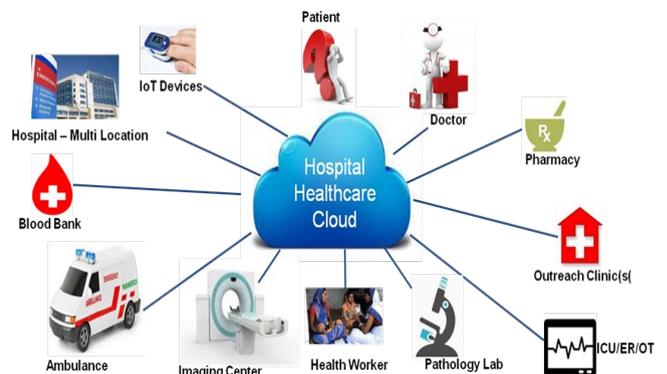


Figure 4. Identification of Smart Assets in Hospitals [40].

4.1.2. Technological considerations

Hospital designs are concerned with the requirements of: (a) Enhancing the participation of patients and companions in the medical process, by simplifying communication between them and service providers, (b) Improving work flow using the internet and mobile technology, (c) Reducing patient frequency rates on the hospital and waiting for them and sending notifications of service delivery times, (d) Ease of access and finding the way to and within the building to meet the needs of users^[17], (e) Relying on "Smart Planet", using sensors and transmitting information using the Internet of Things and artificial intelligence^[23], (f) Providing electronic health records for patients^[2], (g) Avoiding paperwork to counter the abundant information that is newly produced by medicine^[38], (h) Automated operations dependent on information and communications^[17], (i) Use of radio-frequency identification (RFID) systems and the participation of doctors and nurses in parallel^[39], (j) Monitoring building elements and providing a comfortable environment for occupants, using data transmission infrastructure networks, (k) Integration of technological systems for elevators, air-conditioning, lighting, fire and security, and communication systems (telephone, fax and internet)^[12]. (l) Using Internet and satellite communication for internal communication, automation, and building management^[17], such as Trinitas Regional Medical Center, New Jersey.

4.1.3. Achieving environmental considerations

The hospital is dealing with requirements: (a) Compatibility with the environment and sustainability by exploiting renewable energy sources and controlling light, heat, and ventilation^[41], (b) Reducing the use of traditional energy resources, and their cost^[42], (c) Reducing environmental pollution by reducing noise, gas emissions, and providing indoor air quality^[43], (d) Achieving quality for internal environments including: **Physiological Comfort** (programming the temperature, humidity and type of required ventilation according to users), **Thermal Comfort** (providing comfortable thermal conditions with thermal balance between the body and the environment), **Visual Comfort** (changing the level of lighting automatically according to the function and without stress), **Audio Comfort** (outer envelope acoustic treatment and insulation of internal spaces), **Saving Time and Effort** (supporting communications and technologies, monitoring, safe and safety systems, and communication with equipment) such as the University of Missouri Health Care, Columbia, **Long-term Cost Savings** (construction, maintenance, operation, automatic control of lighting, and ventilation of unoccupied spaces)^[44], (e) Providing environmentally friendly materials and systems that achieve social, and technical goals^[3], (f) Reducing risk, use less paper, recycle and generate less waste^[45]. (g) Improving environmental performance by improving site capabilities and preserving water and materials^[17].

4.1.4. Achieving users' desires

Hospitals are concentrated on the requirements of: (a) responding by changing the behavior of materials according to the needs of occupants, in terms of adapting to external conditions, (b) Integrating electronic tools and means to provide comfortable environments and enhancing employee safety according to work changes^[1], (c) Managing resources automatically to increase the efficiency and

satisfaction of occupants, (d) Linking automated control systems with information systems, to address occupant requirements and make buildings responsive, (E) Modernizing the building's electronic systems and equipment without the need to replace existing electrical connections to address future requirements^[10], (f) Providing climate control, energy, air-conditioning and ventilation systems for the users comfort^[17], (g) Electronic control of communication networks and fire-fighting systems according to the user's desires^[46], (h) Application of technology in storing patient data, reducing traffic distances for workers to reduce stress, waiting, and stay times^[47], (i) Utilize mobile and Internet of Things technologies to provide effective communication between patients and caregivers such as the Ohio State Wexner Medical Center, Columbus .

4.1.5. Achieving

The hospital is currently concerned with requirements: (a) Electronic control of building systems in order to protect from fire, and mitigate dangers^[17], (b) Continuous monitoring of systems to achieve conditioning and dealing in emergency situations^[48], (c) Providing hospital automation systems and methods of control, monitoring of materials, and their internal installation^[10], (d) Electronic programming of hospital components and systems according to the expected possibilities which allows them to act and adapt accordingly, to overcome the negative effects of the environment^[49]. (e) Restoring building systems safely, quickly and easily, (f) Making quick decisions with regards to energy management, maintenance, communications, fire protection, safety, etc., and achieve integration between systems to achieve maximum safety for its users^[50], (g) The use of remote communication systems to control transmission of infection^[17].

5. A proposed methodology for the integrated architectural design of smart hospitals

The methodology is based on five main stages, as shown in the Figure 5.

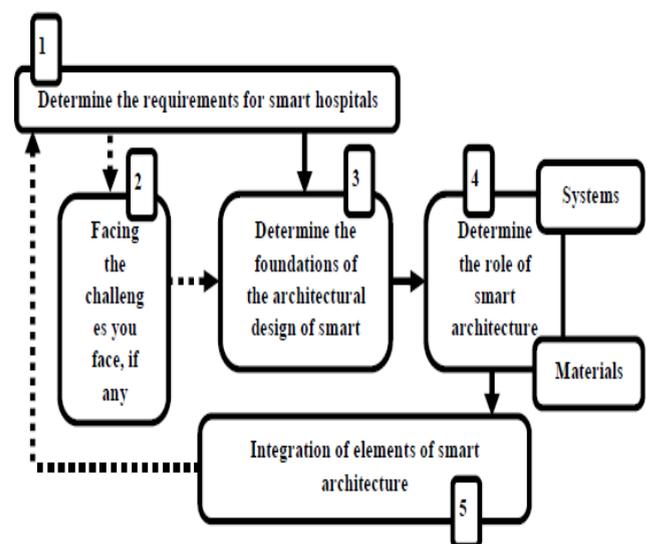


Figure 5. A proposed methodology for the integrated architectural design of smart hospital buildings

First stage: Defining modern design requirements related to smart architecture thought

In this stage, modern design requirements, previously identified in item 4 will be studied, and a reference to local conditions, operating policies, user requirements, and stability is required to utilize the premise of using smart materials and systems.

Second stage: facing the main challenges impeding hospitals to become smart

At this stage, challenges encountered by designers when dealing with the design of smart hospitals will be identified, including: (1) Conflict in priorities among requirements mentioned in the previous section (2) Weaknesses pertaining to dealing with smart hospitals such as the system failures, human errors, natural disasters, failure to link devices to systems, insufficient physical security of components, non-compliance with regulatory standards and user behavior. These challenges are addressed by referring to officials, operating policies and future plans of services, in order to address weaknesses, using smart materials and systems in addition to achieving integration among them.

Third Stage: Defining the proper basics of the architectural design of smart hospitals

This stage defines the principles of architectural design that meet the goals and requirements of smart hospitals and face the challenges associated with them, Figure6, including:

- A- Providing information in an adaptive manner that achieves interaction with the environment and changes functional requirements to suit user needs.
- B- Providing high flexibility, and achieving information security [28].
- C - Self-control and change of status of materials according to changes in the surrounding environment and users' desires.
- D - Coordination between hospital systems and devices in a way that allows for the integration and analysis of data [51].
- E- Providing information to patients under care during their stay.
- F- Smart rooms in hospitals allowing patient and relatives to see medical information.
- G- Using smart technology and mobility systems such as tablets and smart phones [3].
- H- Using smart technologies like WiFi, active RFID, sensors and integration platforms.
- I - Combining existing hospital technologies with new smart programs to reducing required time for providing services.
- J- Internet of Things (IoT) applications for detection and follow-up, using artificial intelligence.
- K- Overcoming the disadvantages of the traditional information systems, and building the basic network environment [52].
- L- The tele-care system, expanding hospital boundaries and reducing frequency of visits.
- M- Identification systems to track and document patients or employees and infection control.
- N- Availability of communication and integration of smart devices to provide the correct information in the right place and time.
- O- Using building management software to monitor its services, energy conservation, operation and maintenance.
- P - Patient monitoring and automatic data transfer, with

- automation of special units such as Intensive Care (ICU) [53].
- Q- Remote voice, video, storage, and forwarding technologies[53].
- R- Intelligent automatic operations and task automation to achieve safety for patients and convenience for doctors.
- S- Real-time location system (RTLS), hand-washing monitoring, nurse call system, communication control, employee messaging, call-bell and notification of medical staff assistants on mobile devices, emails [20].



Figure 6. The Basics of architectural design of smart hospitals

Fourth Stage: Defining the role of smart materials and systems in the architectural design of smart hospitals

At this stage, defining the contribution of smart materials and systems to achieve the basics of the architectural design of smart hospitals mentioned in the previous stage is determined, as shown in the following Table4.

Fifth Stage: Achieving integration between smart materials and systems inside smart hospitals

In this stage, ways to integrate the elements of the smart building (materials and systems) are specified to achieve functional compatibility and integrated buildings management. In addition to locating equipment and linking systems, devices and programs in a common structure and enhancing sustainability in buildings. This is done by referring to the schedule of requirements and types of smart materials and systems in the previous stage of methodology. Then identifying alternatives for smart materials and systems necessary to achieve each of the architectural design standards.

Furthermore, determining the most appropriate systems according to operating policies and capabilities available in the hospital, then determining the mutual effect between smart systems and materials in the fourth stage in addition to stipulating its link with the functions of the different spaces in the hospital. Furthermore, to determine the relationship between smart materials and systems according to modern design requirements, mentioned in the first stage, and ensure the integration between smart materials and systems that directly and indirectly affect the architectural design, as shown in the last cell at Table4.

This stage ends with a reassessment and testing of the methodology by returning again to the first step and making sure that modern design requirements related to smart architectural ideas are met.

Table4. Role of Smart Materials and Systems in the Architectural Design of Smart Hospitals

Design requirements and achieve integration	Building Materials					Floors-finish materials					Walls and ceilings-finish materials					Smart Material, Systems					
	Light-Transmitting Concrete	Transparent Concrete	Aerated Concrete	Pervious Concrete	Luminous Brick	Smart Brick	Smart Cement	Electric Energy Floors	Floors equipped with advanced protection system	Electrostatic Floor	Phosphorous Ceramics	Narmada Slices	Reflective Indoor Coatings	Dark Painting	Shutoff valves		Optical Fiber	Chromogenic Glass	Self-cleaning glass	Coagulate glass	Photochromic Materials
Function- User desires	●	●	●		●	●							●	●	●	●	●	●	●	●	Responding to change in job and future growth
All																					Improving the efficiency of the indoor
Security and Safety																					Safety and control of fire systems
User desires - comfort and safety																					Digital space and electronic archive
Technology- User desires																					Remote connection and maintenance
Technology - User desires -																					Effective communication between patients and service providers
User desires																					Reducing frequency and waiting for service
Function																					Find the way and ease of access to the hospital
Technology																					Smart infrastructure
Environmental needs- User desires																					Integration between electronic systems for maximum safety
Environmental needs																					Control and adaptation in the external environment
Environmental needs, and security and																					Renewable energy use, energy efficiency
All																					reduce pollution
Environmental needs																					The patient's audiovisual comfort
Technology																					Water conservation and sustainability
Function- Technology, Environmental needs																					Save time, effort and reduce operating
Function- Technology, user desires, Environment																					Recycling - environmentally friendly
Technology																					Remote control, motion monitoring and self-control
Functionality, Environmental needs																					Behavior change according to the desires of the users
Technology																					Health and safety promotion and information control
Technology																					Control and connectivity to electronic
Technology																					Ventilation and climate control for user comfort
Technology, security, safety																					Updating electronic systems and environment
																					Monitoring, recovery of building systems

Semi Direct Effect

Direct Effect

Cont. Table4. Role of Smart Materials and Systems in the Architectural Design of Smart Hospitals

Design requirements and achieve integration	Walls and ceilings finishing materials													Smart Material, Systems					
	Formable Aluminum Sheets	Polystyrene Acoustic Panels	Hanging Granule Technology	Status Variables (PCM)	Aluminum coated panels	Fluoropolymer Panels	Microscope Slides	Aerogel Glass	Photovoltaic Glazing	Thermochromic Glass	Gasochromic Glass	ElectroChromic Glass	Liquid Crystal Technology		Suspended Particle Glazing	Smart Mashrabiya	Sun Breaks Technology	Solar Cell Coverage Techniques	Cira Light Sun Trackers Skylight
Function - User desires	●																		Responding to change in job and future growth
All	●																		Improving the efficiency of the indoor environment
Security and Safety								●											Safety and control of fire systems
User desires - security and safety																			Digital space and electronic systems
Technology-User desires																			Remote connection and communication
Technology - User desires																			Effective communication between patients and service providers
User desires																			Reducing frequency and waiting time for service
Function																			Find the way and ease of access to the hospital
Technology																			Smart infrastructure
Environmental needs- User desires																			Integration between electronic systems for maximum safety, control and adaptation in the external environment
Environmental needs, environmental needs, and security and						●													Renewable energy use, energy efficiency
All	●	●				●	●	●	●	●	●	●	●	●	●	●	●	●	The patient's audiovisual comfort
Environmental needs																			Water conservation and sustainability strategies
Technology			●																Save time, effort and reduce environmental costs
Environmental needs			●																Recycling - environmentally friendly materials
Function- Technology,																			Remote control, motion monitoring and self control
Technology, user desires, functionality, Environment																			Behavior change according to the desires of the user
Technology																			Health and safety promotion and infection control
Functionality, Environmental needs																			Control and connectivity to electronic systems
Technology																			Ventilation and climate control for new comfort
Technology, security, safety																			Updating electronic systems and equipment
																			Monitoring, recovery of buildings systems

Semi Direct Effect



Direct Effect



Cont. Table4. Role of Smart Materials and Systems in the Architectural Design of Smart Hospitals

Design requirements and achieve integration	Access control systems				Direct digital control systems							Communication			Smart Material, Systems
	Identification Systems	CCTV & Video Surveillance	Thermal Imaging Camera	Image Recognition System	Smart Sensors	HVAC Systems	Energy Efficiency Monitoring Systems	Lighting Control Systems	Addressable Fire Alarm System	Smart plumbing Systems	Vertical Communication Systems	Addressing Communications Devices	Network (LAN)	Network (WAN)	
Function- User	●				●										Responding to change in job and future environment
All	●	●			●	●		●			●				Improving the efficiency of the indoor environment
Security and Safety					●				●				●		Safety and control of fire systems
User desires - security and safety					●										Digital space and electronic archive
Technology-															Remote connection and maintenance
Technology -User desires -															Effective communication between patients and service providers
Technology -User desires -				●											Reducing frequency and waiting for services
User desires	●												●		Find the way and ease of access to the hospital
Function									●						Smart infrastructure
Technology					●	●				●					Integration between electronic systems for maximum safety
Environmental needs. User desires					●								●		Control and adaptation in the external environment
Environmental needs						●									Renewable energy use, energy efficiency
environmental needs, and security	●														reduce pollution
All					●	●			●						The patient's audiovisual comfort
Environmental needs															Water conservation and sustainability
Technology					●	●		●							Save time, effort and reduce operating costs
Environmental needs					●				●						Recycling - environmentally friendly materials
Technology, Environmental Technology, user desires-	●	●	●		●	●				●					Remote control, motion monitoring and self-control
Functionality, Environment					●	●						●			Behavior change according to the desires of the users
Technology						●						●			Health and safety promotion and information control
Environmental needs															Control and connectivity to electronic devices
Technology															Ventilation and climate control for user comfort
technology, security, safety	●	●	●	●	●	●	●	●	●	●	●	●	●		Updating electronic systems and equipment
															Monitoring, recovery of building systems

Semi Direct Effect



Direct Effect



5. Conclusions & Recommendation

The following are the most important conclusions and recommendations of the research.

5.1. Conclusions

- (1) There is a close link between the premises and principles of smart architecture and fulfillment of design requirements of modern hospitals.
- (2) The use of smart materials and systems contributes to achieving functional interactivity, technological considerations, environmental considerations, user needs, and enhances security and safety.
- (3) The integrated architectural design of smart hospitals can be achieved by a proposed methodology consisting of 5 basic stages that start with defining design requirements and ending with ways of achieving integration between the elements of the, as shown in the Figure5.
- (4) The concept of using smart materials and systems meets various design requirements for smart hospitals, according to their nature and characteristics, directly or indirectly, as shown in Table3.
- (5) The use of smart building materials allows responding to changes in functionality, while smart floor finishing materials generate clean energy and control movement in special spaces.
- (6) The architectural designer must review operating policies and design requirements of the hospital for an appropriate selection of materials and smart systems used within it.
- (7) Various types of smart glass are considered to have an influential role regarding the use of renewable energy and reducing energy consumption, thus reduce operating costs.
- (8) Integration in the architectural design of hospitals is achieved by monitoring the operations of all the systems used and providing utilities to link them with smart materials and achieving an appropriate level of comfort, convenience, safety and efficiency for workers.
- (9) The use of transparent concrete, phosphorous ceramics, smart sensors and (WAN) network contributes to achieving design requirements of smart hospitals in a way that exceeds other approaches.
- (10) Integration between smart materials and systems is achieved by taking into account the characteristics of smart materials and systems, and determining their relationship with the design requirements of smart hospitals.
- (12) Most smart materials and systems are concerned with improving the internal environment, and achieving thermal, audio, and visual comfort, as they affect energy, time, effort savings, and reduce costs.
- (13) The role of smart systems is apparent in achieving effective communication between smart hospital users and in self-controlled, systems according to their requirements.

5.2. Recommendations

Through the study, analysis, and results of the research, the research recommends the following:

- (1) Follow the proposed methodology when designing smart hospitals to achieve integration between elements of smart architecture.
- (2) Promoting using smart materials and systems.

- (3) Giving attention to achieving modern design requirements in hospital buildings, using smart architecture elements, including smart materials and systems.
- (4) Encouraging studies and research that develop smart materials and invent new interactive materials to keep pace with technological development in hospital design.
- (5) When designing smart hospital buildings, focus is given to activating integration between smart materials and systems and taking attention to materials and systems that meet more than one design requirement without affecting on any other requirement.
- (6) Activating the role of smart systems and materials in obtaining smart hospitals with responsive and interactive properties.
- (7) Preparing methods for assessing smart buildings on an environmental basis, to know the extent of their impact accurately on the surrounding environment and its conservation.
- (8) Carrying out studies on smart systems to work together in an integrated way so that the building, is able to think and make decisions based on the variables surrounding it.
- (9) Preparing international and local codes for the architectural design principles of smart buildings, the most important of which are hospitals.

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