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ARCHITECTURAL COMPARATIVE ANALYSES BETWEEN ROBOTIC SURGERY WARDS IN DIGITAL HOSPITALS AND TRADITIONAL SURGERY WARDS IN CONVENTIONAL HOSPITALS

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ABSTRACT

Recently, the integration between healthcare services and new technologies has been enhanced to be very necessary and effective inside digital Hospitals. Digital hospitals include a huge number of healthcare advanced technologies that have special digital and architectural requirement; these requirements cannot be provided in traditional hospitals. Many previous studies and guidelines addressed few numbers of digital hospital's rooms and their architectural requirements. Hence, in this study, healthcare advanced technologies has been determined for outlining the architectural consideration of digital hospital's rooms. Accordingly, Robotic Surgery Ward (RSW) has been compared with Traditional Surgery Ward (TSW) for: a) demonstrating the effect of an advanced technology (Robotic technology) on a digital hospital ward and b) helping designers to find out the main architectural and economic principles of designing RSWs besides TSWs. The main findings in this study are: a) outlining the main architectural characteristics of digital hospitals in general and digital hospital's rooms in specific, b) articulating the main architectural and economic aspects for RSW and robotic surgery rooms, which is different from TSW. As an application of the comparative analyses, possible design alternatives of RSW and TSW has been also proposed and compared.

Keyword: Digital Hospital design, Healthcare advanced technologies, Robotic Surgery Ward design, Architectural and economic considerations.

1. Introduction

The use of information and communication systems in healthcare services for the diagnosis, treatment, monitoring of diseases and the provision of health counseling is described as "e-Health"; a digital hospital is defined as a sub-component of e-Health [1]. Hence, the digital hospital is a hospital that improves healthcare quality and increases patient satisfaction by implementing Information Technology (IT) infrastructure; this will integrate all kinds of communication tools and medical equipment with each other, with other information systems, healthcare staff and patients. Digital hospital can expand the healthcare services by providing the digital connectivity and collaboration with healthcare

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staff in other remote hospitals or with patients inside their houses directly [2]. So, the outcomes of digital hospitals demonstrate that their efficiency increases by 35% because of the wide range of patients they serve [1]. Digital hospitals include a huge number of healthcare advanced technologies that have special digital and architectural requirement; these requirements cannot be provided in traditional hospitals. Due to the wide variety of healthcare advanced technologies , this paper aims at comparing the architectural and economic aspects of Robotic Surgery ward (RSW) and Traditional Surgery ward (TSW), this also includes the effect of healthcare advanced technologies on the design of digital hospital in general and their internal rooms in specific. Moreover, a set of possible design alternatives for both RSW and TSW have been outlined as a detailed application.

However, digital hospital can provide faster and safer service for patients, while reducing costs. Within previous studies, the various benefits for digital hospital have been addressed. For example, Reffat [2] concluded the main benefits of digital hospitals as: a) handling twice as many patients with a higher level of care without increasing hospital's staff or size, b) improving patient outcomes by reducing length of hospital stay and c) achieving efficiencies of diagnosis and treatment for patients within the shortest time. Also, Kilic [1] illustrated the digital hospital's benefits have been represented as: a) Closed Loop Drug Delivery system for the right medicine to the right patient, b) Real-time location services track medical assets, equipment, patients, and staff to improve patient care, c) digital integration, automation of medical information systems and e-Health Networks. Korea digital Hospital Export Agency [3] concluded other benefits for digital hospital as: a) health data that can be forwarded via sensors, cameras and early warning systems without requiring follow-up by humans and b) efficiencies of medical technologies as digitalized medical equipment, diagnosis and treatment, so, digital hospital is safer and healthier. Courbis [4] outlined that digital hospital stuff has less workload, documentation and administration effort, so the result is increasing staff satisfaction and economic efficient.

On the other hand, numerous studies focused on the challenges which face digital hospitals within their design and establishing process, or during operation and renewal stages. Courbis [4] concluded the challenges of digital hospital such as: the high cost of the digital medical equipment, IT infrastructure and the additional construction cost ranges from 5% to 10% for the building. Reffat [2] studied the rapid development of medical equipment considerations and its need for a flexible design of space for ease of use. As well as, Kilic [1] illustrated the difficulty of accreditation and assessment of the digital hospital to receive a "Digital hospital" certificate. Whereas, to be promoted as a digital hospital, a certificate by the accrediting agency Healthcare Information and Management Systems Society (HIMSS) must be assessed and awarded. HIMSS uses the universally accepted accreditation and standard model EMRAM (Electronic Medical Record Adoption Model) to assess the digital processes and determine the stages of applicant hospitals.

Healthcare Advanced Technologies have been determined in various studies, for example, Sprow [5] determined the common healthcare advanced technologies are: robotic surgery, telemedicine and Electronic Medical Record and others. Some studies have acknowledged the effect of the healthcare advanced technologies on some rooms in digital hospital. For example, Martin [6] illustrated that, telemedicine technology requires new room at quit location, without windows, light colors for wall print and Information and Communications Technologies supplies for telemedicine Carts. Also, Kenyon [7] found that Electronic Medical Record technology provides wide area of archive stores and administration can reach up to 1000 m^2 as at Henry Ford hospital in Michigan, USA[*].

[*] Henry Ford Hospital (HFH) is an 877-bed tertiary care hospital, education and research complex in USA. It was one of the first to begin using electronic patient records to ensure the highest quality and safest patient care, as well to convert to digital hospital [7].

Numerous studies focused on the influence of robotic surgery technology in the design of robotic surgery rooms. The main considerations of the digital robotic operating rooms (ORs) and relevant equipment have been concluded by Matthew et al. [8]. Also, Kpodonu [9, 10], Rostenberg et al. [11, 12] and Emergency Response Centre International Institute [13] studied the architectural considerations of cardiothoracic hybrid ORs, and Endovascular hybrid ORs. For Neurosurgery hybrid ORs, Gow et al. [14] determined its size, robots, imaging system and relevant equipment of, while Michael et al. [15] focused on both Neurosurgery hybrid ORs and Orthopedics hybrid OR architectural considerations. As well as, few international design guidelines also addressed more specific design considerations for digital hospital spaces such as Health Authority Abu Dhabi guidelines [16] and the Facility Guidelines Institute [17]. The detailed architectural comparison between RSW and TSW in design cases (the whole ward, room details, requirements, main zones in architectural plans and others) were not found in the literature.

Accordingly, this paper addressed the general design principles of digital hospital and their rooms in section 2. In section 3, the paper presented comparative analyses between RSW and TSW, either on the scope of wards or rooms. In section 4, proposed possible design alternatives of RSWs and TSWs have been presented as an application.

2. The main design principles of the digital hospital and the influence of healthcare advance technology

In a digital hospital, various healthcare advanced technologies provide a fully integrated set of applications and medical services. Thus, IT infrastructure technologies and devices should be considered from the beginning of the architectural design process of a Digital hospital. So, the four main design principles for digital hospital essentially depended on IT infrastructure are as follows [4, 5]:

a) Hospital space rationalization by using IT infrastructure technologies to separate between patient and administration area using the "paperless system"; it leads to the disappearance of all storage or archiving areas.
b) Establishment of the IT infrastructure and medical information system such as Picture Archive and Communication System and Electronic Medical Record.
c) Automating the infrastructure of Support-Services such as automation of the pharmacy unit.
d) A smart building that improve energy consumption

Also, the integration of the healthcare advanced technologies inside the digital hospital gave it special architectural characteristics; the most common architectural characteristics and considerations of digital hospital based on the literature are as follows [1, 2, 3, 4, 5, 7, 18, 19]:

a) In the scope of the whole digital hospital and their departments:

- Most common model types for digital hospital are Nucleus model and separated blocks model, which are linking by IT network.
- New departments in digital hospital have been added such as: Robotic surgery ward, Pathology lab, Angiography and Cardiac Catheterization lab, Nuclear

medicine, Satellite pharmacy, Picture archiving and communication system unit, IT center, Robotic surgery simulation center.

- Modular units for flexibility have been used to cater for digital hospital changes inside wards.
- Multi solutions for Digital hospital wards have been improved as result of digital communication.
- The department's area has been increased according to biotechnology and robotics requirements.

b) In the scope of some rooms of digital hospital:

- Expansion area has been added to rooms with digital equipment..
- Digital equipment's area ratio has been increased from 4% to 54% and non-digital equipment's area ratio has been reduced from 96% to 46% in last century.
- Medical IT infrastructure should be included, such as Electronic Medical Record, Picture Archive and Communication System, Physiological monitoring systems, Closed-loop medication management, ICT control access, Interactive digital way finding signage, Integrated nurse call, Real-Time Location System, Telemedicine service, Tele surgery service and Tele intensive care service.
- New digital spaces have been added, such as robotic surgery rooms, patient smart room, digitally integrated operating room, Automatic pharmacy, Digital Cath Lab, Smart exam room and Check-in kiosk.
- Medical equipment should been included, such as Digital imaging equipment, laboratory automation, sterile processing equipment and Radio therapy digital equipment.

Therefore, it is necessary to study the common of healthcare advanced technologies, either are digital techniques or digital medical equipment to extract the new rooms at digital hospital or current ones incorporate digital techniques within them. Hence, some rooms at digital hospital with the determining of room type, rooms' equipment, architectural considerations and the spatial relations have been illustrated in Table 1. In addition to that, the main architectural considerations of rooms and area requirement can be determined from the international guidelines of healthcare building as Health Authority Abu Dhabi guidelines [16] and the Facility Guidelines Institute [17]. However, robotic surgery ward has been selected as one of the best wards that demonstrate integrating healthcare advanced technologies, so the design of RSWs and its difference with TSWs will be addressed below.

Table 1: The main Architectural Considerations for a set of rooms in digital Hospitals. Summary of Kilic [1]; Courbis [4]; Sprow [5]; Weremeychik [19]; Kenyon [7]; Reffat [2]; Martin [6]; Rostenberg et al. [11,12]; Kpodonu [9,10]; Emergency Response Centre International Institute [13]; Clausdorff et al. [20]; Facility Guidelines Institute [17]; Health Authority Abu Dhabi guidelines[16]; Ahmed et al. [21]; Harsoor et al. [22]; Siddharth et al. [23]; Mille [24].

Ward	Room	Equipment			Room Type		Architectural considerations					Spatial relationship				Room Existance			
		Traditional	Digital new	General	Attached to existing room	new room /zone	Area average(m²)	Minimum Dimension (m)	Windows	Finishing material	Activity (W- wet D- dry)	Adjustment	Connected with	In floor with	Faraway	Mandatory	Has a priority	Recommended	Optional
Outpatient clinic	Hybrid exam room	Patient bed, doctor office	ICT devices - monitor - camera	IT integration - ICT devices	√ exam room	No	12	-	Yes	Generic	Dry	outpatient clinic						√	
	Telemedicine room	Patient chair, Doctor office	Telemedicine Carts, ICT devices - monitor - small digital medical equipment camera	IT integration, Diagnosis such as ECG, X-ray and microscope with the camera	No	√	16	1	No	Light wall paint - the flashlight	Dry		IT center	outpatient clinic	waiting area	√			
Administration	EMR scanning room	Offices	Computers - scanners	IT integration	No	√	10:20	-	Yes	Generic	Dry		registration desk	IT center	wet zone	√			
Inpatient	Smart patient room	Flexible bed	Bedside monitor ... - smart surveillance - IT integration	IT integration	√ inpatient room	√	6:18/bed	2.25	Yes	Generic	Dry		IT center	ICU	imaging		√		
Robotic surgery	Digital robotic surgery OR	Carbon Fiber Table, Parking supply carts, Support for lighting booms, Laminar airflow, Audio Video Integration, ICT devices, Camera, Monitors	*Da vinci xi, *Senhance, *[illegible] robotic	IT integration, Ceiling mounted equipment, screens and cameras, Carbon table, Parking supply carts, Automated drainage system for medicines and sterile instruments, Digital HVAC control sys, Power LED lighting controls	No	√	50:55	7.1	No	Lead Lined wall, Epoxy flooring, lead glass door and windows	Dry	control room		ICU		√			
	Cardiothoracic hybrid OR		Ceiling C-arm, Floor C-arm, Artis zee		No	√	54:161	8.1	No		Dry	control room		ICU		√			
	Neurosurgery hybrid OR		CT, MRI, PET, [illegible] discovery, Infinix 4D CT		No	√	72:190	8.5	No		Dry	control room, power supply	imaging	ICU		√			
	Orthopedics hybrid OR		Artis zeego, [illegible] discovery ICR, [illegible] robotic		No	√	30:90	8.9	No		Dry			ICU			√		
	Control room	-	ICT devices - monitors	ICT devices	No	√	12:18	2.25	No		Dry	robotic OR	IT center	ICU		√			
	Intraoperative MRI / CT	-	CT, MRI	-	No	√	40:160	8	No	Lead Lined wall	Dry	hybrid OR - power supply	control room		recovery			√	
	Technical power supply room	-	power supply	-	No	√	15		No	Generic	Dry	robotic OR			recovery	√			
	Telesurgery / CAVE room	-	Tele manipulator - ICT devices - computers	IT integration	No	√	20:30	1.6	Yes	Generic	Dry	control room	IT center		robotic OR		√		
	Recovery room	Patient bed	PACU	-	√ Recovery	No	10/bed	2.7	No	Generic	Dry	robotic OR			gas supply	√			
	Perfusion room	-	Perfusion equipment	-	No	√	20	-	No	Generic	Dry	hybrid OR	control room				√		
	Robot store	-	Digital robot	-	No	√	20	-	No	Generic	Dry	robotic OR	control room					√	
Imagining and Radiology	Digital imaging system room	Control office	Multifunction - xray	IT integration	No	√	40 + 12 control room	-	No	Lead Lined wall and floor	Dry			robotic surgery	inpatient	√			
	Digital Cath Lab	Control office	Digital subtraction angiography	IT integration	√ angiography room	NO	42 + 10 control room	-	No	Lead Lined wall and floor	Dry	robotic surgery			inpatient	√			
	Radiotherapy bunker room	Control office	Open MRI Upright	IT integration	No	√	30 + 12 control room	-	No	Lead Lined wall and floor	Dry	robotic surgery			inpatient		√		
Emergency	Flexible generic rooms	Bed, Medical equipment	Mobility and alternatives to be managed	IT integration, ICT devices	No	√	12:15	1	Yes	Generic	Dry & Wet	imaging	surgery		outpatient clinic				√

JES, Assiut University, Faculty of Engineering, Vol. 48, No. 2, March 2020, pp. 248–264

Table 1. Cont.

Ward	Room	Equipment			Room Type		Architectural considerations					Spatial relationship				Room Existance			
		Traditional	Digital / new	General	Attached to existing room	new room /zone	Area average (m^2)	Minimum Dimension (m)	Windows	Finishing material	Activaty (W= wet D=dry)	Adjustment	Connected with	In floor with	Far away	Mandatory	Has a priority	Recommended	Optional
Intensive care unit ICU	Intensive care unit bed	Flexible bed	Headwall life support system Mounted equipment	IT integration ICT devices	√ ICU	No	12:18	3	No	Antibacterial material	Dry	robotic surgery	TeleICU center		outpatient clinics	√			
	Tele ICU observation center and unit	Offices	ICT devices Camera RTLS	IT integration ICT devices cameras	No	√	100:120	-	Yes	Generic	Dry	ICU	IT center				√		
Medical Education and Research	Centralized Simulation center	Classroom equipments	Robotic surgery and imagining ICT control devices	IT integration ICT devices Surgery robots Classroom equipment	No	√	1100 for 4 simulation	-	-	Generic - Lead Lined wall	Dry	research and education hall	robotic surgery ward	digital robots store	patient zones	√			
	Simulated robotic operating room	Carbon surgery bed	Robotic surgery and imagining Monitors -Camera		No	√	50 : 80 / simulated	7:08	No	Lead Lined wall	Dry	control room classroom			break room	√			
	Central control room	Offices	ICT devices		No	√	30:50	4	NO	Glass wall	Dry	simulated OR			break room	√			
	Classroom to consultation	Student desks	Audio and visual device connected to OR		No	√	60 / simulated	7	Yes	Glass wall to OR	Dry	simulated OR	break room			√			
	Debrief room	Office	ICT devices - computers		No	√	20	3	Yes	Generic	Dry		control room				√		
	Stuff break room	offices	-		No	√	25 / room		Yes	Generic	Dry	classroom	research hall		simulated room			√	
Support Servic	Digital robots stores	-	New robots	IT integration - ICT devices supplies robot	No	√	15: 40/ robot		No	Generic	Dry	IT center			wet zones	√			
IT center	IT servers center	Offices	Computers ICT devices -serves	IT integration with all hospital sys	No	√	300	-	No	Generic	Dry	robots store	TeleICU - Telesurgery		kitchen and wet zones	√			
	ICT control room	-	Facility HVAC control		No	√	60	-	No	Generic	Dry	IT center					√		
Digital Technical for IT infrastructure	Digital Technical don't need to room	-	Digital consoles	IT integration	√ Clinics - ICU	No	-	-	-	-	-	outpatient clinics	IT center	imagining		√			
		-	Center for connected medicine	IT integration	√ waiting area	No	-	-	-	-	-	outpatient clinics	IT center	imagining & medical laboratory					√
		-	Check in kiosk	Integration with patients database	√ lobby of elevator & stair	No	2 / 1 kiosk	-	-	-	-	stuff workstations			administration		√		
		-	PACS	IT integration LED screens	√ robotic OR	No	-	-	-	-	-	surgery room	control room			√			
		-	RFID	IT integration - ICT devices connected with surgery robots and imagining	√ OR -emergency	No	-	-	-	-	-	OR - ED	IT center						
		-	RTLS	IT integration ICT devices	√ ICU	No	-	-	-	-	-	ICU	IT center					√	
		-	Robot doctor	IT integration	√ hospital wards	No	store=6	-	-	-	-	Interdepartmental mobility						√	
		-	Wayfinding Electronic kiosks	IT integratio Touch screen monitor	√ entrance	No	2	-	-	-	-	entrance					√		
		-	Remote medicien	IT integration - ICT devices	√ pharmacy	No	-	-	-	-	-		inpatient ward	support service				√	
		-	Supplies robot	IT integration	√ sterilization core	No	park = 2	-	-	-	-	supplied services	central sterilization					√	
		-	Computer assisted scheduling	Integration with patients database - LED screens in nurse station	√ nurse station	No	2	-	-	-	-		stuff workstation						√

√ Yes

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3. Architectural comparative analyses between robotic and traditional surgery

Through the robotic surgery, the surgeon uses one of two methods to control the robots, either via a direct tele-manipulator or through computer control. However, the comparative analyses outcomes between RSW and TSW are: a) demonstrating of the effect of an advanced technology (Robotic technology) on a digital hospital ward and b) helping designers to find out the main architectural and economic principles of designing RSWs besides TSWs. The impact of using robotics in surgery affects the design of both ORs and spaces where robotic devices are stored when not in use. The size of robots requires additional floor space be allocated to both the ward and OR, and their utility requirements introduce a set of cables and power supplies and information and communications technologies devices [11, 12]. To design the OR of robotic surgery, robots and imaging equipment location should be identified, then other equipment locations and requirements, e.g. ceiling lights, surgical and video integration surgery workflow can be determined. Robotic surgeries require specific types of ORs: a) digital integrated OR and b) Hybrid OR. A digital integrated OR is defined as an operating room that is equipped with the necessary equipment (booms, lights, routers, touch panels, device control, capture systems, etc.) to facilitate the flow of communication, data, video and the overall interaction of the healthcare providers with the patient (Akridge [25]). A Hybrid OR is a surgical OR that is equipped with advanced medical imaging equipment such as fixed C-Arms, Computed Tomography "CT" scanners or Magnetic Resonance Imaging "MRI" scanners beside robotic and navigation techniques (Ahmed et al. [21]). On the other hand, within the traditional surgery, neither surgical robots nor advanced medical imaging equipment are involved, but only the traditional surgical equipment is used. Based on the variety between robotic surgery rooms and traditional surgery rooms, there are some differences between the design of RSW and the design of TSW as detailed later. The details of the comparisons in the scope of the whole ward and internal operating rooms are detailed in the following two sections.

3.1. The scope of surgery ward: RSW vs. TSW

Comparative analyses between RSW and TSW have been concluded (as shown in Table 2); this comparative analyses have been conducted in terms of the main architectural characteristics as: a) location, b) the average area of the ward, c) internal zones, d) corridors’ type, e) ORs’ types, f) the average area of ORs, g) main surgical tools and h) features of the ward. These architectural characteristics can be classified to 2 categories as: a) characteristics mentioned in literature, which were clearly addressed in a relevant previous studies and b) characteristics extracted analytically, which refer to what have been analyzed and extracted by authors based on previous studies.

According to the previous analyses, it can be stated that:

- The relations between RSW and new medical wards (as angiography ward and simulation education center) refers to the need for wider area to include those huge ORs, therefore it needed expensive budget. However, TSW was adjacent to intensive care unit and connected with emergency ward.
- The components of RSW were various that TSW, where the zones of RSW consisted of the 4 main zones: Operating rooms zone, patient zone, stuff zone

and support service zone, in addition spaces attached to ORs zone. However, TSW consisted of the 4 main zones only.

- The establishment of RSW is required more addition area than TSW by percentage about 35%. For example, the small area for RSW was 900 m^2 instead of 600 m^2 for TSW
- The zone of spaces attached to ORs includes a set of rooms that are relevant to surgical robots' service as: a) Tele surgery room, b) technical power supply room, c) intraoperative Magnetic Resonance Imaging "MRI"/ Computed Tomography "CT" room d) pump room, e) robot store and f) radiology technicians' office.
- RSW can serve multiple disciplines in one place/ward, so it included on 5 types of ORs: a) digital robotic OR, b) Cardiothoracic hybrid OR, c) Neurosurgery hybrid OR, d) Endovascular hybrid OR and e) Orthopedics hybrid OR, against to 2 types in TSW that are small and large conventional OR.
- Various surgical robots and advanced imaging equipment were used inside the robotic surgery rooms, so, wide work area was required for them and accordingly increasing area of ORs to exceed 70 m^2. However, the area of traditional surgery rooms not exceeds 70 m^2.
- Digital robots inside ORs require IT infrastructure, so RSW cannot be established at traditional hospitals as a developmental stage.
- Robotic surgery technology helps surgeons to perform extremely complex surgeries, short hospitalization for patient, reduce hospital outgoing, in addition Effectiveness and efficiency in training, teaching and research.
- Spaces' area and cost can be saved in TSW, as well as the safety of intraoperative robot failure.

Table 2.

Architectural comparative analyses between Robotic Surgery Ward and Traditional Surgery Ward. Summary of Ahmed et al. [21]; Akridge [25]; Rostenberg et al. [11, 12]; Gillespie et al. [26]; Schwarz et al. [18]; Harsoor et al.[22]; Health Authority Abu Dhabi guidelines [16]; Beasley [27]; Kpodonu [9,10]; Clausdorff et al. [20]; Facility Guidelines Institute [17].

The main architectural characteristics				Robotic Surgery Ward (RSW)	Traditional Surgery Ward (TSW)
	Location (Between others ward)	Adjacent to	Intensive Care unit	√	√
			Angiography	√	
			Intervention OR	√	√
		In the same floor with	Imaging	√	
			Pathology Lab	√	
			Obstetrics & Gynecology		√
		Connected with	Emergency	√	√
			Simulation education center	√	
			Sterilization center	√	√
			Inpatient	√	√
	Ward's average area	Small area range (4-6OR)		**900 m²**	**600 m²**
		Medium area range (6-10 OR)		**1400 m²**	**1000 m²**
		Large area range (10-15 OR)		**2000 m²**	**1500 m²**
	Internal zones	Operating rooms zone		√	√
		Spaces attached to ORs zone		√	
		Patient zone		√	√
		Stuff zone		√	√
		Support service zone		√	√
	Corridors' type	Type	One complex corridor (clean and dirty together)	√	√
			Two separated corridor (clean and dirty)	√	√
			Sterilization Core		√
		Width of ORs corridor (m)		3	2.2
	Operating rooms' type	Small conventional OR			√
		Large conventional OR			√
		Digital robotic OR		√	
		Cardiothoracic hybrid OR		√	
		Neurosurgery hybrid OR		√	
		Endovascular hybrid OR		√	
		Orthopedics hybrid OR		√	
	ORs' average area	30 : 50 m²			√
		50 : 70 m²		√	√
		70 : 90 m²		√	
		90 : 110 m²		√	
	Main surgical tools	Manual / Traditional surgical tools		√	√
		Surgical robots		√	
		Advanced imaging equipment		√	
	Features (advantages & disadvantages)	Shorter hospitalization for patient		√	
		Enable complex tasks		√	
		Minimize risk for communication-related errors clinical specialties.		√	
		Low purchase and maintenance cost of tools			√
		Reducing the hospital outgoings		√	√
		Saving space in operating rooms			√
		Effectiveness and efficiency in training, teaching and research.		√	
		Safety of intraoperative robot failure			√
		Not needed for radiation protection			√

No	Yes (√)	Characteristics mentioned in literature	No	Yes (√)	Characteristics extracted analytically

3.2. The scope of operating rooms: robotic surgery rooms vs. traditional surgery rooms

Regarding surgery rooms, Table 3 illustrates detailed comparative analyses between robotic surgery rooms and traditional surgery rooms. The comparative has been conducted based on a set of architectural aspects such as: a) main features of robotic surgery rooms and traditional surgery, b) their architectural considerations, c) main architectural details, d) main medical equipment, e) main electronic equipment and f) approximate economic cost. These architectural aspects have been concluded from previous studies as the most common aspects for ORs' design.

Table 3.

Architectural and economic comparative analyses between robotic surgery rooms and traditional surgery rooms. Summary of Rostenberg et al. [11,12]; Kpodonu [9,10]; Emergency Response Centre International Institute [13]; Clausdorff et al. [20]; Facility Guidelines Institute [17]; Health Authority Abu Dhabi guidelines [16]; Ahmed et al. [21]; Harsoor et al. [22]; Siddharth et al. [23]; Mille. [24]; Winkle et al. [28]; Rentz [29]; Dextrom [30]; Sharrock [31]; Richard [32]; Nunez [33]; Block [34]; Wasek [35]

			Robotic surgery rooms					Traditional surgery rooms	
			Digital robotic OR	**Cardiothoracic hybrid OR**	**Neurosurgery hybrid OR**	**Endovascular hybrid OR**	**Orthopedics hybrid OR**	**Small conventional OR**	**Large conventional OR**
Main feature		**Surgeries**	• Urologic. • Gynecological. • Gastrointestinal. • Colon and rectal. • Transplants. • General surgeries.	• Cardiothoracic. • Thoracic.	• Neurological. • Pediatric.	• Vascular.	• Orthopedic. • Spine. • Rheumatic.	• General surgeries. • Urologic. • Gynecological. • Colon and rectal.	• Cardiothoracic. • Neurological. • Orthopedic. • Vascular.
Main feature		**User**	• Interdisciplinary team of surgeons. • Anesthesiologists. • Perfusions. • Echo Tech engineering. • Nursing: Scrub -Cath lab - OR. • Interventional cardiologist. • Surgical imaging technicians. • Echo cardiographer. • Radiology Technicians. • Patient.					• Interdisciplinary team of surgeons. • Anesthesiologists. • Nursing • Patient	• Interdisciplinary team of surgeons. • Anesthesiologists. • Nursing • Interventional cardiologist. • Perfusions. • Patient
Architecture considerations		**Area range (m^2)**	50-70	54-68	55-90	54-90	72-108	30-36	50-60
Architecture considerations		**Minimum dimension (m)**	6-7	6.5	6.5-8	6.5-7.5	8-10	5	6
Architecture considerations		**Room height (m)**	3	3.6	3.6	3.6	3.6	3	3
Architecture considerations		**Shape**	Square	Rectangle	Rectangle	Rectangle	Square	Square	Rectangle
Architecture considerations		**The direction of the corridor with the shape long side**	Parallel	Parallel	Parallel	Parallel	Parallel	Parallel	Parallel
Architecture considerations		**Room Existence**	Mandatory	Mandatory	Mandatory	Has a priority	Has a priority	Mandatory	Has a priority
Main architectural details	**Doors**	**Width (m)**	1.4	1.4	1.8	1.4	1.8	1.2	1.2
Main architectural details	**Doors**	**Material**	Automatic sliding lead stainless glass		2 layers of operable sound mitigation door	Automatic slidinglead lined stainless glass	2 layers of operable sound mitigation door	stainless glass	stainless glass
Main architectural details	**Opening window**	**Width (m)**	1.5	2	2	2	2	No windows	
Main architectural details	**Opening window**	**Material**	Tempered glass window overlooking control room	Electric glass window overlooking control room	Lead Lined glass window overlooking control room	Electric glass window overlooking control room	Lead Lined glass window overlooking control room		
Main architectural details	**Furniture patient table**	**Type**	• Fully integrated table • Breakable tabletop	• Non-metallic carbon fiber tabletop • Fully fledged table	• Fully motorized movements of the table and tabletop • Non-metallic carbon fiber tabletop		• Floating Ctable • Non-metallic carbon fiber tabletop	• stainless patient table	
Main architectural details	**Furniture patient table**	**Position**	• Diagonal		• Parallel to long side • Diagonal (with artis Zeego)	• Parallel to long side	• Parallel to long side • Diagonal (with artis Zeego)	• Diagonal	
Main architectural details	**Main mounted furniture**	**Mounted**	• Surgical boom • Anesthesia boom • Anesthesia equi • Displays mounted • Media pendants	• Surgical boom • Anesthesia boom • Anesthesia equipment • Displays mounted • Media pendants • Imaging unit • X-ray shields				• Surgical boom • Anesthesia boom • Anesthesia equipment	
Main architectural details	**Room fabric finishes (Material)**	**Floor**	• Smooth, washable sup resistant terrazzo • linoleum floor		• Raised floor (12 cm) Terrazzo •Topped Aluminum supportable panel	• Smooth, washable sup resistant terrazzo • linoleum floor	• Raised floor (12 cm) Terrazzo •Topped Aluminum supportable panel	• Terrazzo	
Main architectural details	**Room fabric finishes (Material)**	**Wall**	• Laminated polyester and smooth light painted with steel corner	• Lead Lined wall 2:3 mm	• Vibration isolation pad, heavy lead lined wall	• Lead Lined wall 2:3 mm	• Vibration isolation pad, heavy lead lined wall	• Antibacterial ceramic	
Main architectural details	**Room fabric finishes (Material)**	**Ceiling**	• Support for boom mounted • Sufficient space for HAVC	• Support for boom mounted • Sufficient space for HAVC • Reinforcement for imaging mounted				• Support for boom mounted • Sufficient space for HAVC	
Main architectural details		**Lighting**	• UCV canopy lighting system • General ambient light • Focus and precise L high level room illumination • Green light 500:1200 Lux					• General ambient light • Focuse light above patient table	

		Robotic surgery rooms					Traditional surgery rooms	
		Digital robotic OR	**Cardiothoracic hybrid OR**	**Neurosurgery hybrid OR**	**Endovascular hybrid OR**	**Orthopedics hybrid OR**	**Small conventional OR**	**Large conventional OR**
Main medical Equipment	**Surgical robots = Work Area (m²)**	• Davinci = 20 • Zeus robot = 15 • Rosa robotic = 15 • Telelap ALF-X = 40 • TransEnterix = 40	• Davinci = 20	• Neuromate = 15 • Rosa roboto = 15	• PIC robot = 15 • Davinci = 20	• RIO robot = 15 • Davinci = 20	No surgical robots	
	Imagining equipment = Work Area (m²)	Not required	• Ceiling C-arm = 15 • Floor C-arm = 20 • Artis zee = 15	• Artis zee biplane = 20 • Infinx I biplane = 20 • Atris zeego = 30 • Ge-discovery 730 = 30 • MRI = 25	• Ceiling C-arm = 15 • Floor C-arm = 20 • Stereotaxis Robotic Navigation Technology = 35	• Atris zeego = 30 • Ge-discovery 730 = 30 • CT = 15	No imaging equipment	
	Medical equipment	• Anesthesia equipment • Laparoscopic towers hold insufflator • Medical piped gas	• Anesthesia equipment • Medical piped gas • Heart-lung by pass • Construct injector • Transthoracic & intravascular echo	• Anesthesia equipment • Medical piped gas • Heart-lung by pass • Construct injector • Brain navigation	• Anesthesia equipment • Medical piped gas • Heart-lung by pass • Construct injector • Transthoracic & intravascular echo • Mobile AS pirate	• Anesthesia equipment • Medical piped gas • Construct injector	• Anesthesia equipment • Medical piped gas • Construct injector	• Anesthesia equipment • Medical piped gas • Construct injector • Heart-lung by pass • Brain navigation
	Traditional equipment	• Built-in glass and stainless cabinets • Equipment carts • Ceiling mounted boom					• Built-in glass and stainless cabinets • Equipment carts • Ceiling mounted boom	
Main electronic Equipment	**ICT devices and system**	• Electronic touch panel • IT integrated equipment • Video camera holder • Monitors • Audio-video system • Media beam					No ICT devices	
	Media equipment	• Media beam (power -network - Video) • 4:6 touch screen monitors mounted and on wall					No media equipment	
	Picture Archiving and Communication System (PACS)	• Ultrasound (IVAS) on wall • OR integrated system • RLTS & RFID system • Data management					No PACS system	
	Electrical power	• 24 electric outlets at height 1.5m • Emergency generator with automatic 2 ways change over facility					• 12 electric outlets at height 1.5m • Emergency generator with automatic 2 ways change over facility	
	General Equipment	• Electrical installing and heating channels • Fire extinguishers • Medical gases piped • Air changer and optimal temperature					• Fire extinguishers • Medical gases piped • Electrical installing and heating channels • Air changer and optimal temperature	
Approximate economic cost (Million $)	**Surgical robots cost (M $)**	1.5 - 3	1.5 - 2.25	0.6 - 0.8	1.2 - 2.25	1.0 - 2.25	No surgical robots	
	Imaging equipment cost (M $)	Not required	0.3 - 1.2	1.2 - 2.3	1.5 - 2.85	1.5 - 2.25	No imaging equipment	
	Other equipment and furniture (M $)	1.0 - 1.6	1.0 - 1.3	1.0 - 1.3	1.0 - 1.3	1.0 - 1.6	0.35 - 0.5	0.5 - 0.8
	Cost of space ($ / m²)	500 $/m²	1000 $/m²	1000 $/m²	1000 $/m²	1000 $/m²	500 $/m²	500 $/m²
	Ceiling reinforcement (M $)	No needed for it because imaging mounted is not required	0.08	0.08	0.08	0.08	No needed for it because imaging mounted is not required	
	Lead lined shielding wall (M $)		0.1	0.1	0.1	0.1	No needed for it because imaging mounted is not required	
	Total approximate cost M $	**2.7 - 3.6 M$**	**3.1 - 3.9 M$**	**3.1 - 3.8 M$**	**3.0 - 4.9 M$**	**4.4 - 5.8 M$**	**0.5- 0.8 M$**	**0.7 - 1.0 M$**

Note:
• IT : Information Technology • ICT : Information and Communications Technology • PACS : Picture Archiving and Communication System • HVAC : Haeting, Ventilation and Air Conditioning
• MRI : Magnetic Resonance Imaging • CT : Computed Tomography • PET : Positron Emission Tomography
• Total cost of OR is included surgical robot cost + imaging equipment cost + other medical equipment cost + (cost of space x area of OR) + ceiling reinforcement cost + lead line shielding cost
• The economic cost was estimated based on international prices of robots, equipment and construction.

Based on the previous analyses, it can be stated that:

- The number of users inside robotic surgery rooms was twice in traditional surgery rooms, so wide work area was required.
- Robotic surgery rooms had wide area range between 50:110 m^2 because of the required work area of robots that varied between 15:40 m^2. However the area of traditional surgery rooms did not exceeded 60 m^2.
- The height of some robotic surgery rooms was higher than traditional surgery rooms due to the mounted of imaging equipment and other media mounted.

- The patient table inside robotic surgery rooms should be movable and suitable with robots and imaging equipment movement. But, stainless patient table was used inside traditional surgery rooms
- Because of the usage of surgical robots and imaging equipment inside ORs, radiation protection material must be used as: heavy lead lined wall and vibration isolation pad.
- Also, the ceiling should be reinforcement for imaging mounted and the floor should be raised floor with aluminum panels to allow the electronic and electrical supplies. However, terrazzo floor was used for traditional surgery rooms.
- Automatic sliding lead stainless doors were used inside robotic surgery rooms to protect users from the Radiation of imaging equipment.
- There was not any window in traditional surgery rooms, although lead lined glass window are been in robotic surgery ward and overlooking control room
- According to the medical equipment, the surgeons inside traditional surgery rooms use medical and traditional equipment manually. Conversely, surgeons inside robotic surgery rooms use tele-manipulator or robot control tool.
- The main electronic equipment inside traditional surgery rooms limited to electrical power supplies and general equipment as medical gases. But complex electronic equipment were required inside robotic surgery rooms as: Information and Communications Technologies devices and system, media equipment and Picture Archive and Communication System.
- Based on the economic comparative analyses, it is found that establishment of Orthopedics hybrid OR was the most expensive because of the wide required area and the high price of the used surgical robots and imaging equipment. The cost of digital robotic OR establishment was cheap in order to no use of imaging equipment.
- Small and large conventional ORs' cost was the cheapest due to no required for surgical robots or imaging equipment

4. Proposed possible designs for robotic surgery ward and traditional surgery ward: architectural applications

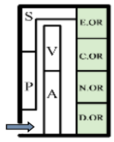
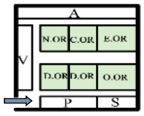
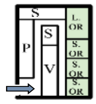
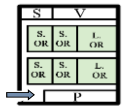
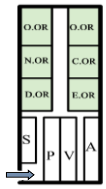
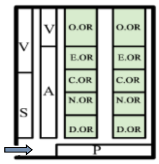
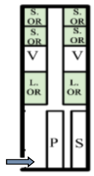
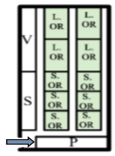
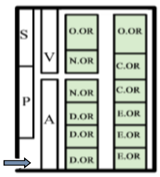
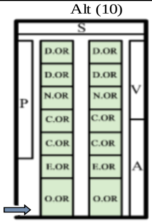
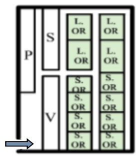
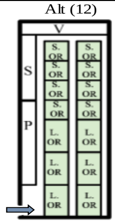
By following the previous main architectural aspects, many design alternatives of RSWs and TSWs could be proposed to help designers to work on their RSW and TSW designs. Accordingly, a set of 12 design alternatives of RSWs and TSWs have been presented as an application as shown in Table 4. All design alternatives have been proposed as rectangular shapes to simplify design process without any relations with other external wards. Also, previous architectural and economic considerations (came from the comparative analyses) have been used in the conducting the proposed designs. Then, the alternatives have been distributed among 3 groups are: a) the small area alternatives (4-6 ORs), b) the medium area alternatives (6-10 ORs) and c) the large area alternatives (10-15 ORs). Finally, the properties of design alternatives have been compared.

With analyzing and comparing the proposed alternatives of RSWs and TSWs, it obvious that RSWs had wide area that reached to 900 m^2 with just 4-6 ORS as obvious in alternatives (1) and (2), while TSWs are smaller and cheaper as in alternatives (3) and (4). In alternative (7), the support service zone was integrated with ORs to establish sterilization core, but it cannot be implemented in RSWs because there are control room for each OR. Alternative (10) included 14 wide ORs that required wide area of ward overall, hence waste area was created in other zones. Although alternative (12) contained the same ORs number, the

TSW's area was saved. As shown in Table 4, the comparative between the different alternatives can help designers to determine the appropriate required area for RSW or TSW based on ORs numbers. Also, the average total cost of ORs has been estimated as initial budget, whereas the cost of ORs can be considered the most important ratio of the whole budget of the surgery ward. Mostly, RSW designs were different than TSW in terms of required area, zones and cost. Hence, the design alternatives could be considered as initial designs that can help designers within the design process.

Table 4.

A set of 12 possible design alternatives of Robotic Surgery Ward and traditional Surgery Ward as applications

		Robotic Surgery Ward (RSW)		Traditional Surgery Ward (TSW)	
		Alt (1)	Alt (2)	Alt (3)	Alt (4)
The small area alternatives (4-6 ORs)					
Alternative properties	Ward area (m^2)	800	900	500	600
	Corridor type	One complex	Two separated	One complex	Two separated
	Number of OR	4	6	4	6
	Average total Cost ORs (Million $)	14	22	1.8	4.4
		Alt (5)	Alt (6)	Alt (7)	Alt (8)
The medium area alternatives (6-10 ORs)					
Alternative properties	Ward area (m^2)	1200	1400	800	1000
	Corridor type	One complex	Two separated	Sterilization Core	Two separated
	Number of OR	6	10	6	10
	Average total Cost ORs (Million $)	24	38	4.4	7.6
		Alt (9)	Alt (10)	Alt (11)	Alt (12)
The large area alternatives (6-10 ORs)					
Alternative properties	Ward area (m^2)	1500	200	500	600
	Corridor type	Two separated	Two separated	Two separated	Two separated
	Number of OR	12	14	12	14
	Average total Cost ORs (Million $)	45	51	8.8	10.8

P Patient zone; S Stuff zone; V Support service zone; A Spaces attached to ORs zone

D.OR Digital robotic OR; C.OR Cardiothoracic hybrid OR; N.OR Neurosurgery hybrid OR; E.OR Endovascular hybrid OR

O.OR Orthopedics hybrid OR; S.OR Small conventional OR; L.OR Large conventional OR; ➡ The proposed entrance of the ward

Note:
The dimensions of zones have been calculated from HAAD guidelines and based on the number of internal rooms as follows:

- Patient zone: width = 4m (Minimum dimension), Length= 20-40 m
- Stuff zone: width = 4m (Minimum dimension), Length= 14-34 m
- Support service zone: width = 4m (Minimum dimension), Length= 18-30 m
- Spaces attached to ORs zone: width = 4m (Minimum dimension), Length= 20-50 m
- ORs zone in RSW: width = 8-20m (Minimum dimension), Length= 36-60 m
- ORs zone in TSW: width = 6-14m (Minimum dimension), Length= 30-60 m

5. Conclusion

This paper presented comparative analyses between Robotic Surgery ward (RSW) and Traditional Surgery Ward (TSW). It started with focusing on the effect of healthcare advanced technologies on the design of digital hospital and illustrated the architectural considerations of digital hospital's rooms which have these healthcare advanced technologies. It was found that robotic surgery ward is one of the best demonstration of integrating healthcare advanced technologies. Subsequently, the comparative analyses between RSW and TSW has been concluded in terms of the main architectural characteristics as: a) location, b) the average area of the ward, c) internal zones, d) corridors' type, e) ORs' types, f) the average area of ORs, g) main surgical tools and h) features of the ward. These architectural characteristics can be classified to 2 categories as: a) characteristics mentioned in literature and b) characteristics extracted analytically. Finally, different design alternatives of RSWs and TSWs have been presented and compared as an application. Consequently, the appropriate required area and initial budget of RSW or TSW could be determined.

It can observe that the establishment of RSW needs wide area to include those huge ORs, accordingly it needs expensive budget. The components of RSW were various than TSW, where the zones of RSW consisted of the 4 main zones: Operating rooms zone, patient zone, stuff zone and support service zone, in addition spaces attached to ORs zone. Also, RSW can serve multiple disciplines in one place/ward, so it included 5 types of ORs against to 2 types in TSWs. A wide work area in RSWs was required because of the usage of surgical robots and imaging equipment. Mostly, Robotic surgery technology helps surgeons to perform extremely complex surgeries and reduce hospital outgoing, but spaces' area and cost can be saved in TSWs. As well, detailed comparative analyses between robotic surgery rooms and traditional surgery rooms has been conducted based on a set of main architectural aspects as (features of robotic surgery rooms and traditional surgery, their detailed architectural considerations, , medical and electronic equipment and approximate economic cost. As a result, robotic surgery rooms had wide area range between 50:110 m^2 because of the required work area of robots that varied between 15:40 m^2, as well as their specific height was around 3.6 m. Because of the usage of surgical robots and imaging equipment inside ORs, radiation protection material must be used. Also, complex electronic equipment were required inside robotic surgery rooms as: Information and Communications Technologies devices and system, media equipment and Picture Archive and Communication System. Based on the economic comparison, the establishment of Orthopedics hybrid OR was the most expensive OR because of the wide required area, while the digital robotic OR establishment was the cheapest, but the cost of traditional surgery rooms' establishment was 400$/$m^2$ in addition surgical equipment cost so the total cost did not exceed 1.0 million Dollar.

Hence, the proposed designed alternatives could be considered as initial designs that can help designers within the design process for their both RSW and TSW cases. The study can be extended to include the details of all RSW rooms and calculation of the total cost of the ward. Also, a design framework for RSW can be proposed to facility the design process and save designers' time and effort. In addition to a computational implementation can be developed based on the design framework to generate design alternatives of RSW computationally.

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تحليل معماري مقارن بين تصميم جناح الجراحات الروبوتية بالمستشفيات الرقمية وجناح الجراحات بالمستشفيات التقليدية

الملخص العربى:

بدأ مؤخراً تعزيز التكامل بين التقنيات الجديدة لخدمات الرعاية الصحية، وذلك لكونها ضرورية وفعالة للغاية داخل المستشفيات الرقمية. وتحوي المستشفيات الرقمية عددًا هائلاً من تقنيات الرعاية الصحية المتقدمة، وهذه التقنيات لها متطلبات رقمية ومعمارية لا يمكن توفيرها في المستشفيات التقليدية. وبناءً على ذلك، تناولت العديد من الدراسات السابقة وأكواد المعايير التصميمية عددًا قليلاً من تصميمات غرف المستشفيات الرقمية ومتطلباتها المعمارية. وتم حصر تقنيات الرعاية الصحية المتقدمة في هذه الدراسة لتحديد الاعتبارات المعمارية لغرف المستشفيات الرقمية. وفقًا لذلك، يقدم هذا البحث تحليل معماري مقارن بين تصميم جناح الجراحات الروبوتية وتصميم جناح الجراحات التقليدية، حيث يهدف هذا التحليل إلى إظهار تأثير التكنولوجيا المتقدمة (التقنية الروبوتية) على جناح الجراحات بالمستشفيات الرقمية، ويهدف أيضاً لمساعدة المصممين للحصول على الاعتبارات المعمارية الرئيسية والمبادئ الاقتصادية لجناح الجراحات الروبوتية والتقليدية. وتتمثل أهم المخرجات الرئيسية لهذه الدراسة في تحديد الخصائص المعمارية الرئيسية للمستشفيات الرقمية بشكل عام، وللغرف الداخلية لها على وجه التحديد، بالإضافة إلى توضيح الجوانب المعمارية والاقتصادية الرئيسية لأجنحة وغرف الجراحات الروبوتية واختلافها عن أجنحة وغرف الجراحات التقليدية. وكذلك تم اقتراح ومقارنة مجموعة من البدائل التصميمية لكل من جناح الجراحات الروبوتية وجناح الجراحات التقليدية كتطبيق للتحليلات المقارنة السابقة.

كلمات مفتاحية: تصميم المستشفى الرقمي، التقنيات الطبية المتقدمة، تصميم جناح الجراحات الروبوتية، الاعتبارات المعمارية والإقتصادية.