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Modular Pandemic Hospitals: A Challenge for Living

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ORIGINAL STUDY

Modular Pandemic Hospitals: A Challenge for Living

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Abstract

Over the last several months, the COVID-19 pandemic has globally affected millions of humans and has changed every aspect of our daily life. Hospitals play a major role to combat this pandemic disease; however, they are struggling as they are confronted with a sudden influx of patients and are jammed to capacity with a lack of available beds and treatment spaces. In managing this health crisis, a rapid resolution concerning our perception and future hospital designs needs to change to save as many lives as possible. According to a pilot study with experts in architecture, four problems during the design of pandemic hospitals namely, time, space, hygiene and patients' needs, and psychology are to be faced. Hence, the designers need to create a new vocabulary or typology for hospitals. A paradigmatic shift in the design concept of hospitals towards what is called emergency or temporary modular hospitals will be herein discussed as a new approach to deal with this pandemic. In conclusion, the paper aims to understand the effect of the COVID-19 pandemic on hospital design and to create a prospected framework for architects and urban designers to find architectural solutions for this crisis.

Keywords: Emergency hospitals, Mobile hospitals, Modular construction, Pandemic hospitals, Prefabricated construction

1. Introduction

Over the last few months, the current COVID-19 showed how our hospitals were unprepared for this crisis. Hospitals are reaching their capacities with bed shortages and facility saturation. Hospitals which ought to be a refuge for the sick turned out to be risky for both patients and staff.

Architectural innovations and consequently, constructional techniques have to be used in the ongoing fight against the corona virus. Quickly constructed medical spaces that can adapt to the needs of patients and infection control are brought to the forefront. There are many ways to solve these problems in existing hospitals by altering the function of some spaces as a response to the pandemic disease.

Modular systems provide more advantages than conventional systems. They provide speed in construction, quality, repeatable designs and less labor, which made them suitable for the current crisis and any future outbreaks. The modular construction method indeed differs from the conventional construction process. Modules are built and prefabricated off-site and then transferred and assembled into a structure at their final destination. Modular units can be assembled as a set of volumetric elements, including walls, ceilings, and floors on-site, or can be delivered fully completed for rapid construction. Furthermore, these modules can be replicated anywhere in order to increase the capacity of hospitals. The modules can be stacked several stories high, positioned side by side, or arranged end to end to create a multitude of configurations and styles, Fig. 1.

This research paper will deal with a new architectural strategy for emergency or temporary hospitals that are both modular and mobile. In this new typology, we have to deal with the high degree of complexity associated with the design of hospitals. There are many functions within a hospital which are interdisciplinary but need to be taken into

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Fig. 1. Examples of Modular construction in hospitals. Ref.: https://www.archdaily.com/937840/alternative-healthcare-facilities-architects-mobilize-their-creativity-in-fight-against-covid-19.

account. Some of these functions include normal hospitals requirements, hygienic considerations, patients' psychological needs and space limitations. In order to reach good design framework for the design of pandemic hospitals, there must be collaboration between architects, construction engineers, doctors, and psychologists to share ideas.

The aim of this research paper is to highlight the emerging problems that arose at the interface of COVID-19 and their influence on hospital design. Our goal is to find architectural and constructional solutions to these problems as an attempt to stave the pandemic spread.

A framework will be proposed based on a questionnaire dealing with the most influential problems namely: time, space, hygiene and patients' needs, and psychology as the main problems facing pandemic hospital design.

In a new pandemic era, a radical change in the design of hospitals has to be achieved, and a shift toward modular mobile architecture is herein highlighted for the design of temporary pandemic hospitals.

2. Research methodology

The methodology applied Fig. 2, will begin with a pilot study to indicate the main problems facing pandemic hospital design. As a result of the pilot study, four main problems arose including the role of flexibility and adaptability in time, availability of space together with patient's needs, psychology, and hygiene.

A framework for pandemic design based on a questionnaire is put forward. The items being considered in the questionnaire have been critically assigned in accordance with a prediscussions and interviews with experts. Experts in medical, healthcare, hospitals' architectural design and construction have been consulted and their comments on the questionnaire have been taken into account in laying the questionnaire format and in the final proposals.

The research methodology is thus divided into two main stages as follows.

2.1. First stage

The process will begin with an overview of the major issues surrounding the importance of the design's flexibility and adaptability in time, availability of space, as well as the patient's demands, psychology and hygiene. These points have been thoroughly examined in this document.

Through the outputs of the first stage, the paper will answer the research question: "How to achieve an optimum comfortable pandemic hospital design for a modular unit?".

2.2. Second stage

A framework for pandemic design based on a questionnaire will be introduced. The items considered in the questionnaire have been critically assigned.

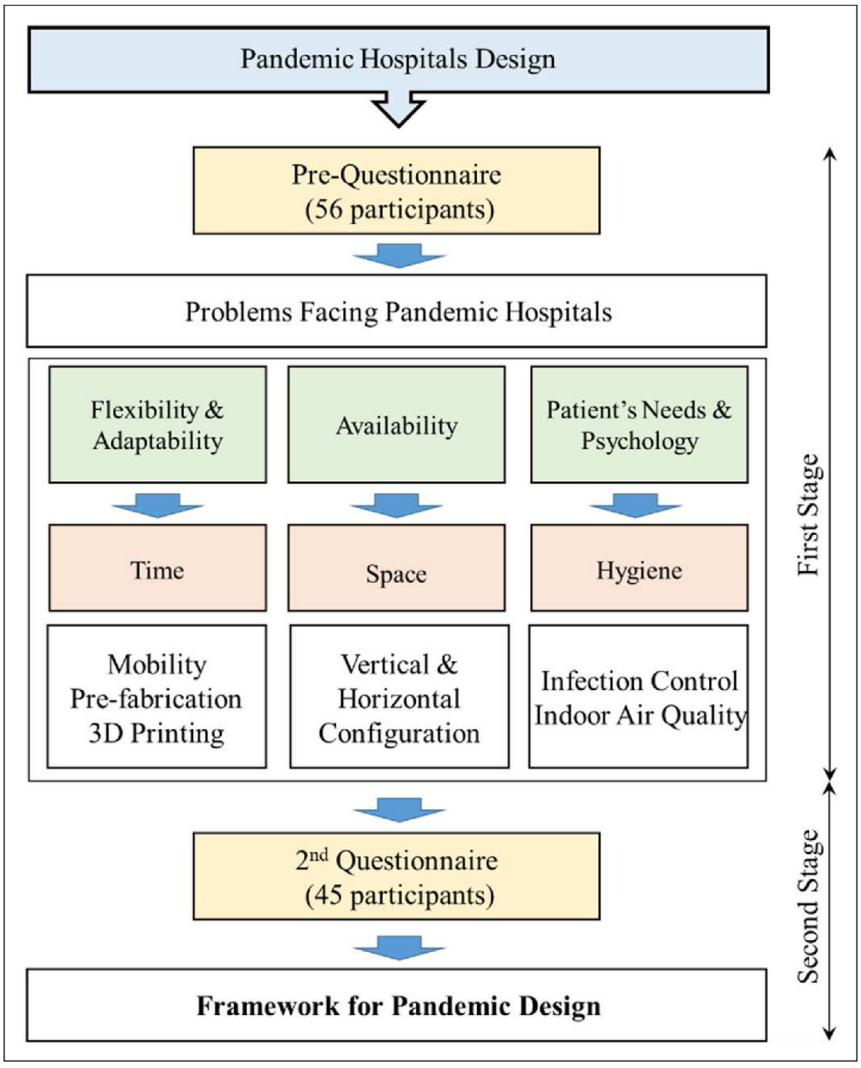


Fig. 2. Formation of the research methodology.

The paper will gain access to a form of a new conceptual design of pandemic hospital modular units through the outputs of the second stage.

3. Identification of the main problems facing pandemic hospital's design

To identify the main problems facing pandemic hospital design, a pilot study was conducted and documented. The pilot study is a preliminary study (pre-questionnaire) established to rank the different problems facing the design of pandemic hospitals to each other according to their importance before the analytical part of the research begins. Based on the review of literature on emerging problems facing hospital design in the pandemic time, the pre-questionnaire was conducted to identify the main problems facing pandemic hospital design.

3.1. Participants

The sample was oriented to target population of 56 participants in each studying job titled "urban designers and architects." This sample consists of males and females. The sample was presented to 5 work experience groups, as shown in Table 1.

Participants were assigned to cover a wide range of work experience [Table 1]. shows the expert's participants' genders and their experience.

The sample fulfilled a number of criteria including: fitting in range of age groups with different working conditions and educational

Table 1. Experts' experience information.

Position title	Participants No. (%)
Gender	
Male	32 (56.14%)
Female	24 (43.85%)
Work experience	
0–5 years	10 (17.5%)
5–10 years	9 (15.8%)
10–15 years	5 (8.8%)
15–20 years	11 (19.3%)
More than 20 years	22 (36%)

backgrounds and understanding of the valuable physical and non-physical design qualities.

A linear scale is used to rank the problems facing the design of pandemic hospitals in response to each other according to their importance.

An online prequestionnaire was conducted for a 2-week period and the sample was oriented to target population of 56 participants. Reviewing the literature of facing problems in designing pandemic hospitals has been critically done by books, scientific journals, and research projects. The different problems that should be taken into consideration while designing hospitals in pandemic times are therefore formalized. They include technology, time, safety, hygiene, patient's needs and psychology, functionality, space, and cost.

3.2. The results

The participants run a prequestionnaire to rank the importance of each of the design parameters based on the participants' point of view using 8 points rating scale [from 1 "least priority" to 8 "highest priority"].

Fig. 3 demonstrates that time has been shown to have the highest priority followed by hygiene, then space and patient's needs and psychology has the least priority. These results have a very important line to identify which of the problems facing pandemic hospital design is more significant to be used in the paper.

The questionnaire emphasized that the pandemic modular hospital must take into consideration time, space, hygiene, and patients' psychological needs as major factors in design.

4. Emerging problems facing hospitals design in pandemic time

COVID-19 has posed huge challenges containing the spread of the disease, protecting health systems from collapse, and coping with economic shutdown (Merkur et al., 2020). It is creating unprecedented stresses on healthcare facilities and critical care systems. Hospitals play a crucial role within the health system in providing essential medical care to the community, particularly during a crisis. Hospitals struggled to adequately respond to an unprecedented and sudden demand for emergency care spaces and intensive care unit beds in a very short span of time (Capolongo et al., 2020).

Rather than just being a site where treatment takes place, healthcare facilities should also provide a therapeutic atmosphere in which the general

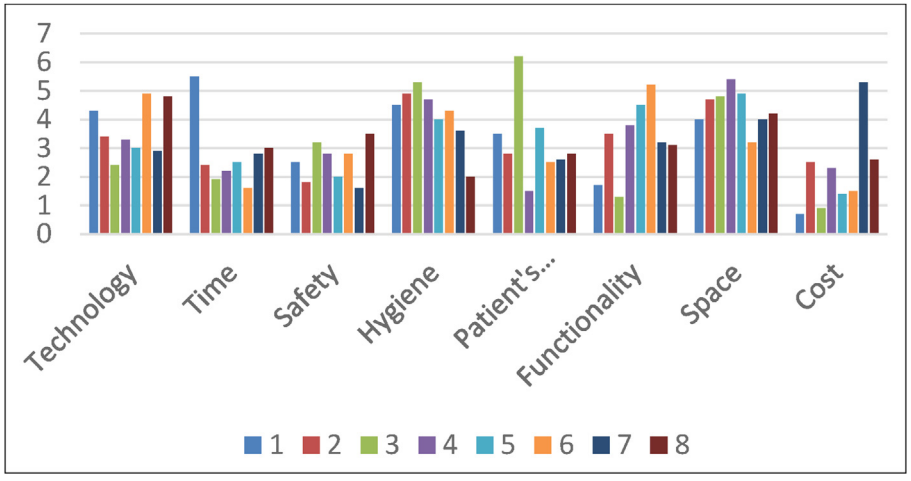


Fig. 3. The ranking of the main parameters facing the design of pandemic hospitals.

architecture of the building aids to the healing process and decreases the risk of healthcare-associated infections. As a result, the healthcare planning and design process must be sufficiently broad to encompass not only issues related to disease treatment, but also issues related to health promotion and disease prevention essentially, the creation of a safe, hygienic, flexible, and adaptable environment that meets the patient's psychological need.

The following chart highlights the most important emerging problems facing hospitals' design in the pandemic time, Fig. 4.

4.1. Flexibility and adaptability in time

The sheer scale of the pandemic has brought profound change in hospital design towards the creation of deployable, portable, mobile, and temporary hospitals in a short time.

One of the good examples of pandemic hospitals is modular construction (Fig. 5). It is an approach that involves breaking down the structure of a building into scalable room-size volumetric units called modules. Hospitals are sectors that are suitable for modularization techniques as the layout of hospital rooms allows for the efficient use of modularization (Mangla et al., 2017).

Hospitals are systems with a high degree of complexity as they contain a multitude of functional connections. Through modular construction, modules for patient rooms, laboratories, intensive care units, radiographic units and other facilities can be obtained. These modules can be duplicated anywhere in order to increase the capacity of hospitals. The modules can be placed side-by-side, end-to-end, or stacked, allowing a wide variety of configurations in the building layout (Ganiron and Almarwae, 2014). Concerning the module connections; individual modules are tied together to form the overall building structure (Mangla et al., 2017). In constructing multi-module systems, supplementary modules to cover mechanical, electrical, electronics and communication, and technological systems can be attached to the system in specially designed modules to achieve an almost complete hospital (Indrawan et al., 2012).

The current COVID-19 pandemic also serves as a positive catalyst for establishing the long-term planning, investment and development of resilient and flexible hospital infrastructure with innovation in adaptable design and construction technologies (Kucan, 2020).

Modular construction systems can provide more flexibility of design, serving the potential for

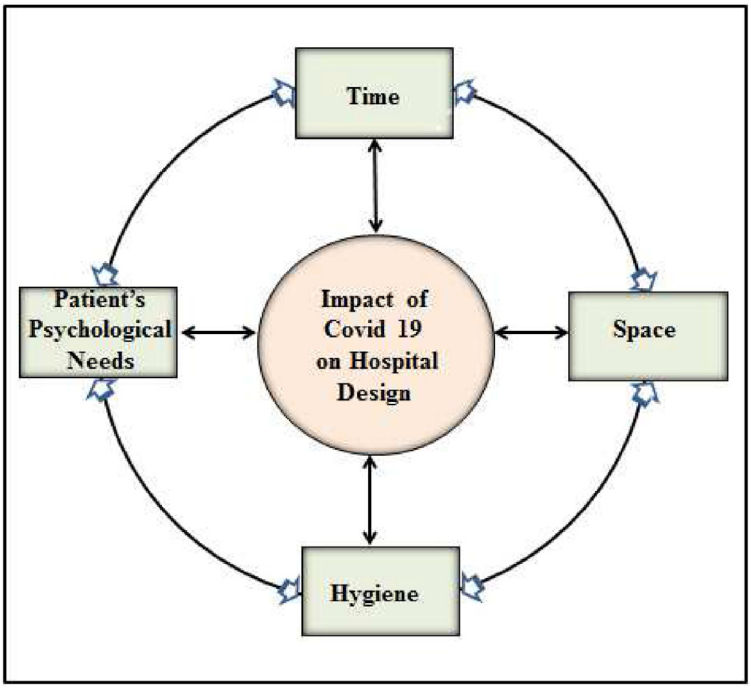


Fig. 4. Different emerging problems facing hospitals design in pandemic time in the design of temporary pandemic hospitals.

hospital expansion and rapid delivery of separate modular healthcare facilities (Smolova and Smolova, 2021).

From this point of view, the modular system can be achieved by the use of prefabricated structures, mobile systems, 3D printing, shipping containers and/or inflatable systems. The following are some basic constructional techniques and possible application in modular designs.

The concept of flexibility implies that the space is suited for accommodating any future changes in a timely and cost-effective manner, implying that it will last for longer (Elmokadem et al., 2017).

4.1.1. Prefabricated systems

Prefabricated (modular) construction is a process in which a building is constructed off-site. Buildings are produced in "modules" that when put together on site, reflect the identical design intent without compromise (Article2 Inflatable Emergency Hospitals tecnodimension, 2020).

The prefabricated modular hospital is thought to be a suitable solution for emergency preparedness. It provides the most efficient solution for different spaces. This system gives an advantageous alternative to conventional structures that suit the pandemic crisis (Kuo, 2020; Gunawardena et al., 2014).

It is the fastest way to build buildings in a very short time with economic prices. The timing from concept to finished product is remarkable. It can produce a fully equipped hospital formed of modules that are designed and constructed internally according to the proposed activity that will occur inside them. There is a spectrum of solutions for modular structures and they can accommodate isolators and patient rooms. This system provides modules that can be transported from site to site.

Prefabricated modules also can withstand any type of climate and can employ solar energy to operate the necessary technical installation, Fig. 6.

4.1.2. Mobile systems

Mobile architecture is an architecture that represents physical movement and changes places within a time range (Jennifer and Mobile, 2002; Mokhtar and Shedid, 2019). A mobile hospital is formed of small modules with full equipment and can be moved and placed in site.

Deliverability of the units is either by ground or by helicopter if the situation calls for it. This provides a shorter response time for needed areas.

In mobile hospitals, two issues need to be considered: modularity and mobility. The construction module of mobile architecture approaches construction and size of a typical container (Bakoweski, 2016).

According to the versatile nature of modular hospitals, we can design the layout.

Mobile hospitals can be built at any time and in any place in a very short time. They are designed according to the same standards of permanent hospitals. They come with not only medical equipment, but also power, drainage, plumbing and isolation.

Fig. 5. Examples of modular design of mobile hospital. Ref.: https://www.futurarc.com/project/modular-design-of-mobile- hospitals-for-the-treatment-of-covid-19/.

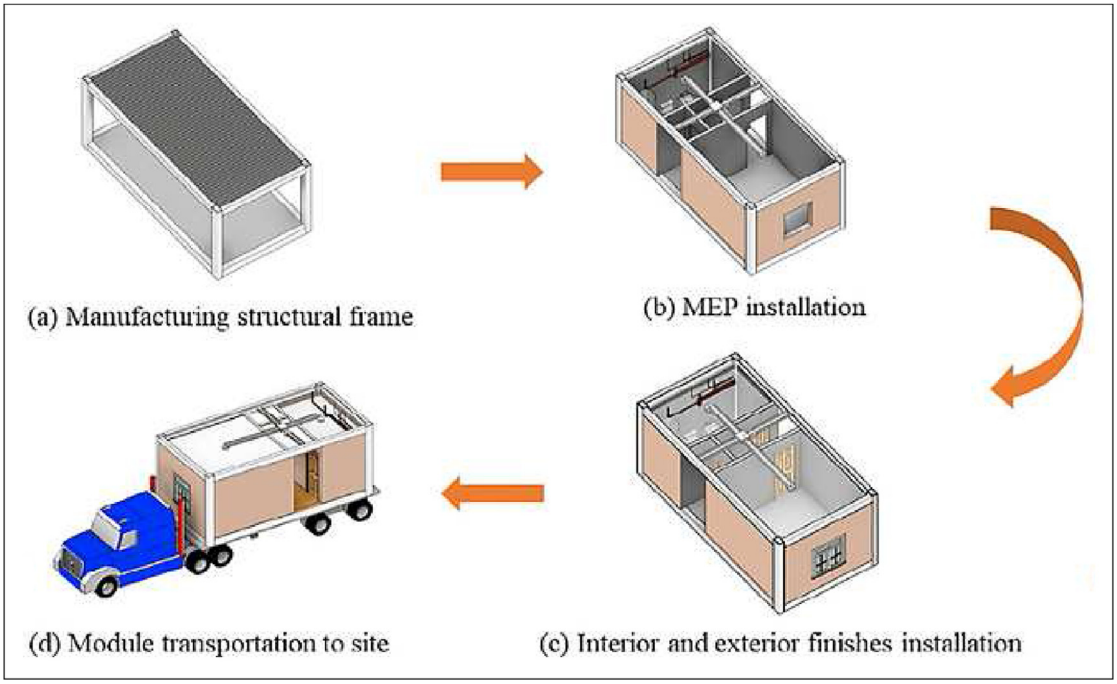


Fig. 6. Modular prefabrication construction-from manufacturing to site installation. Ref: https://www.researchgate.net/figure/Modular-construction-from-manufacturing-to-site-installation_Fig. 4_331306591.

4.1.3. 3D printing

Three-dimensional printing refers to an automated additive manufacturing process in which three-dimensional models using CAD are created by laying down successive layers of material. This is done using 3D printer in site (Kidwell, 2017).

3D printing can be used to produce full-scale small buildings. It has many advantages compared to traditional on-site construction. It saves time, labor, costs and saves material. Moreover, it gives architects the freedom to produce any forms. This makes 3D printing a suitable method in modular construction for pandemic hospitals.

4.1.4. Shipping containers

Shipping containers can quickly and effectively be transformed into full-service mobile hospitals and can be transported where needed (Bulmer, 2020). The units are stackable, self-contained, with maximum isolation and are re-useable in the future (Article 1 Shipping Container Hospitals, 2020). They may need modifications such as adding windows, doors, ventilation, heating, air conditioning, insulation, interior furnishings and equipment as appropriate, Fig. 7.

4.1.5. Inflatable structures

Inflatable fabric structures are designed to be the quickest response to catastrophes as a pandemic disease. They are modular and can be easily transported and erected with just a compressor. Despite being soft shapes, they comply with all building regulations. They are high-resistance fabrics which are recyclable and fire retardant (Article 2 Inflatable Emergency Hospitals, 2020). They can form the hospital itself or as interconnections between any modular system and they can promote hygienic conditions, Fig. 8.

4.2. Availability of space

The basic functional units of the hospital together with new typologies of spaces according to the nature of the pandemic disease can be offered by modular systems. These units can be classified and grouped in accordance with their specialization and corresponding function; namely: specialized services units, diagnostics services units, general and auxiliary units (IHFG Part B, 2019). Modular hospitals can be adapted in size and arranged vertically and/or horizontally to suit available space requirements.

4.3. Patient's needs and psychology

4.3.1. Patient's psychology

During all the different phases of the design process, attention must be focused to the physical,

Fig. 7. Example of container hospital. Ref: https://www.medicalbuyer.co.in/railtel-who-inaugurate-mobile-container-hospital-at-visakhapatnam/.

psychological and social needs of all users (Biomed, 2020). Recent designs take the patient's psychological needs into account by trying to establish aspects as sense of place, transparency, nature and artwork, noise, color and natural lighting for a better quality of life. Hence, the shape of the exterior of the building, the distribution and composition of patient rooms, the presence of views to outside, furnishings, materials, finishes, colors, light (both natural and artificial), art installations, etc. Have to be considered (Pellitteri and Belvedere, 2010; Mokhtar, 2021). Such aspects are shown in details in Fig. 9.

4.3.2. Hygiene

Three main points are to be crucially adopted designing for the distances between people, disinfection of high-touch surfaces, and the control of airborne infection by preventing contaminated air (Harrouk, 2020). Additionally, hospitals require an integration of buffer areas between the isolation wards and spaces for acute healthcare equipped with oxygen, negative pressure and suction systems. Pandemic hospitals also should be divided into clean, semi-contaminated and contaminated areas to exclude the spread of any contamination. The architecture of hospital modules can be designed to ensure the satisfaction of patients, clinical staff, and public hygiene safety.

5. Questionnaire

5.1. Participants

On the 1st of February an online questionnaire was oriented to a target population of 45 participants in

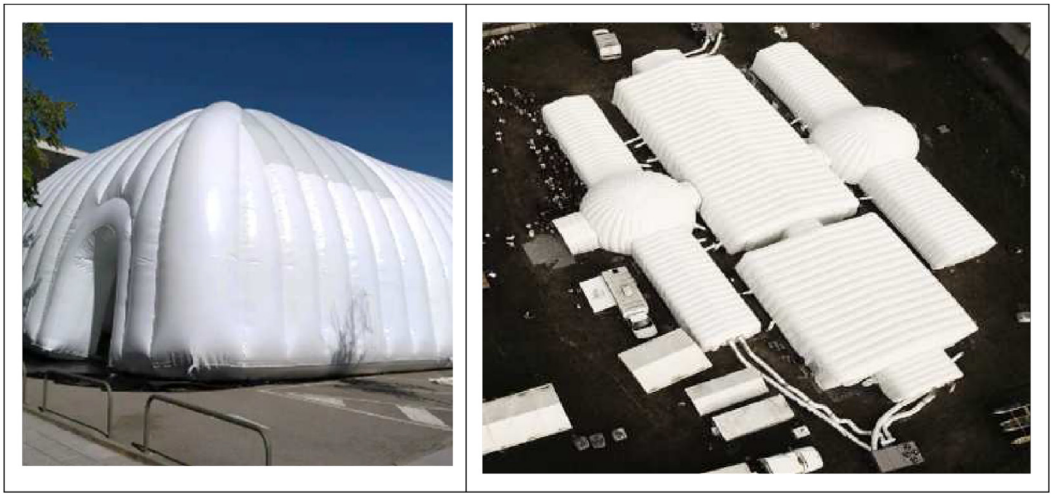


Fig. 8. Examples of inflatable hospital. Ref: https://archeyes.com/inflatable-emergency-hospitals-tecnodimension.

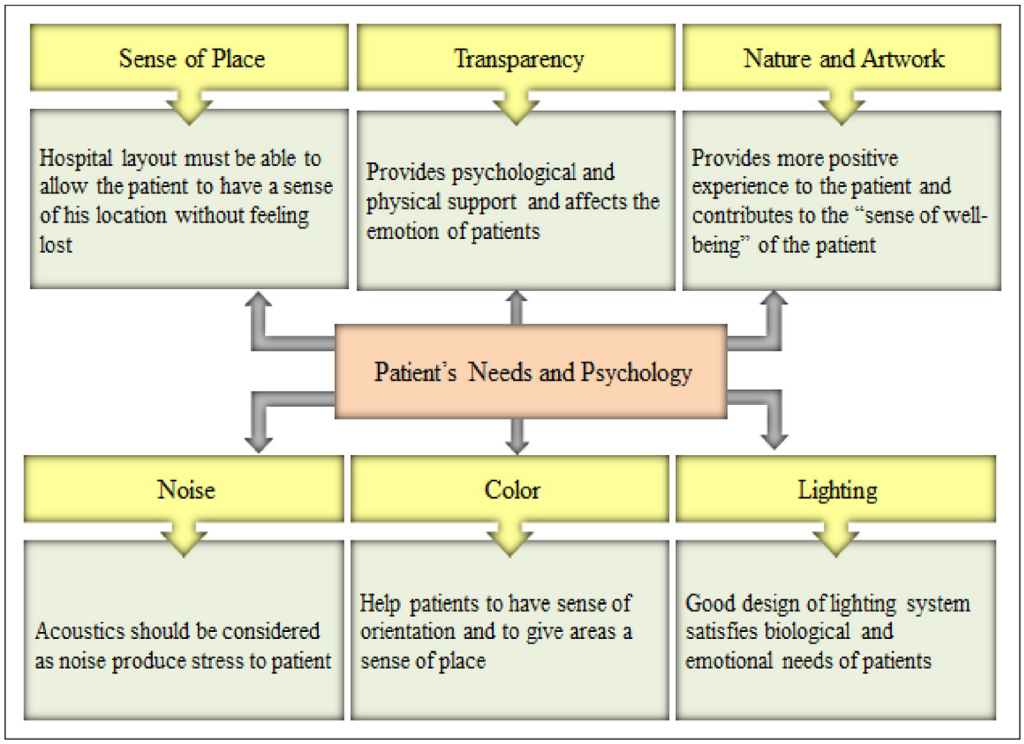


Fig. 9. Patients' needs and psychology. Ref: Authors.

each studying job titled 'urban designers and architects '. This sample consists of males and females. The sample presented work experience groups.

The sample fulfilled a number of criteria including fitting in range of age groups with different working conditions and educational backgrounds and understanding of the valuable physical and non-physical design qualities.

5.2. Stimuli

Based on the pre-questionnaire, an online questionnaire has been oriented to deal with four proposed aspects (namely time, space, hygiene, and psychology).

The questionnaire has two sections:

The first section is a matrix table used to:

(1) Determine which of the previous four proposed aspects can achieve the concept of future emergency hospitals, as shown in Fig. 10.
(2) Arrange the patient's psychological need's aspects (namely: the sense of place, transparency, lightning, noise, color, nature, and artwork) by importance, as shown in Fig. 11.

The second section deals with direct questions about the design requirements of the modular pandemic hospitals.

5.3. Procedure

First, participants (architects and urban designers) were requested to specify their background experience, gender and position as shown in Table 2.

Second, the respondents were asked to determine the importance of the four aspects, which influenced the modular pandemic hospital designs. A four-point rating scale was used for ratings ranging from 1 "not at all" to 4 "very much" as given previously in Fig. 10.

Third, the respondents should arrange the patient's psychological needs, Fig. 11, by importance [1 = least important and 6 = most important] and participants remarks if any.

Forth, in the last part of the questionnaire, the respondents were asked direct questions about the best placement of the modules of the hospital, the circulation they preferred and the best construction system of the hospital units, as shown in Figs. 12–14.

5.4. Questionnaire results

The research had concluded the following results based on the response of participants on the questionnaire.

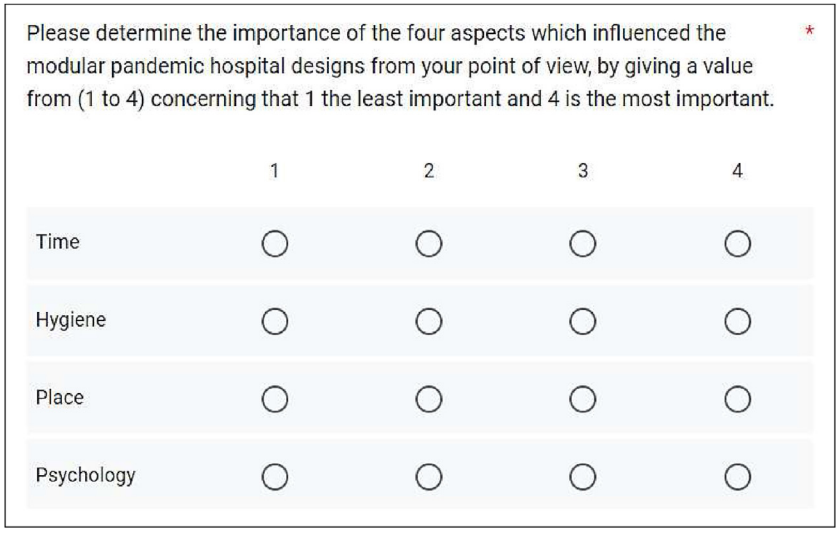


Fig. 10. Part one of the questionnaire. Ref: Authors.

(1) Hygiene, Fig. 15, had shown to have the top priority followed by psychological aspects, whereas time and space came next. These results have a very important line of consideration in architectural design.

Patient needs have, therefore, to be fully considered in patients' rooms design (Mokhtar, 2021). However, from the emergency point of view, both time and space are of urgent need. In this respect, the role that architects and construction engineers can act in the design and construction is vital.

(2) Participants also arranged psychological aspects based on the following:

Sense of place, transparency, nature and artwork were the top priority then comes next: noise, color and lightning, as shown in Fig. 16. The results were surprisingly contravene and not unique. This is logic as the relative importance of each aspect from one to another one depends on participant view point and his psychological behavior.

(3) The majority of participants (40%) preferred a mixture of more than one option when asked whether placement for the hospital modules (beside one another, beginning to end, stacked in several levels, and combination of two alternatives) would be preferable. Close behind is side by side receiving 32.5%, then stacked in several stories and end to end, as shown in Fig. 17.

These results depicted that the construction (the structural frame and body) of each module and its architectural design should be able, beside its functional design requirements, to be safely and rigidly assembled in different placements and combinations.

(4) With reference to the preferred circulation while designing hospitals (either horizontal or vertical circulation), 74.4% of participants prefer horizontal circulation and the rest prefer vertical circulation, as shown in Fig. 18.

An expected result, horizontal circulation makes movement easier and creates more green areas.

(5) The best construction system that can be used in modular hospitals (prefabricated system, mobile system, 3D printing, shipping containers, inflatable system and combination of systems) 57.5% voted combination of systems, 22.5% chose prefabricated systems and 17.5% suggested

Table 2. Experts' experience information.

Position title	Participants No. (%)
Gender	
Male	20 (44.44%)
Female	25 (55.55%)
Position	
Urban Designer	17 (37.77%)
Architects	28 (62.23%)
Work experience	
0–5 years	9 (20%)
5–10 years	7 (15.55%)
10–15 years	8 (17.77%)
15–20 years	11 (24.44%)
More than 20 years	10 (22.22%)

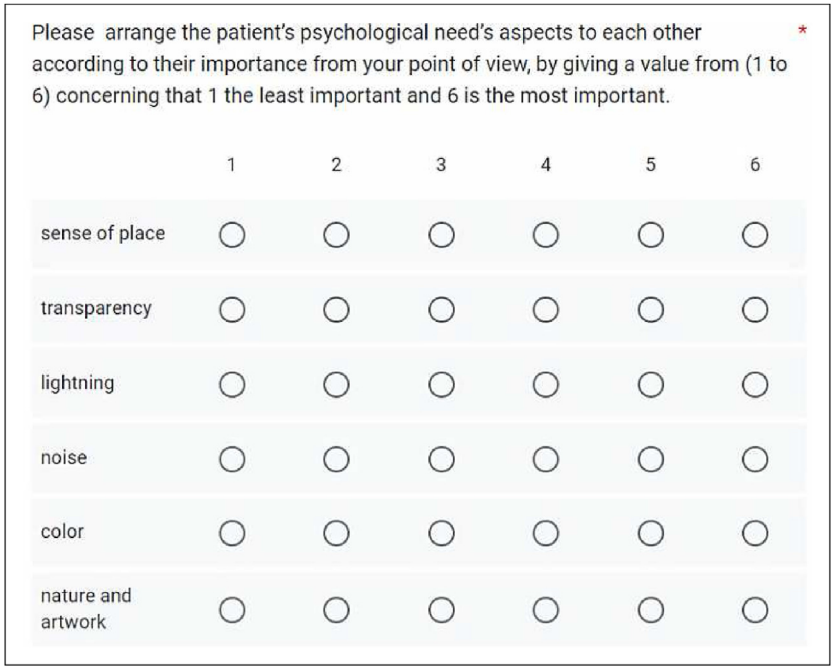


Fig. 11. Part two of the questionnaire. Ref: Authors.

future trend of 3D printing while other systems have the least votes, as shown in Fig. 19.

Although there was no distinct construction and manufacturing selected technique, it is evident that the ultimate adoption of a specific technique of construction and manufacturing depends on the facilities available and economic considerations. This, surely, would bear a burden on both architects and construction engineers. Each construction system has its rules and codes of design which have to be taken into account in the design process.

6. Guidelines of the conceptual modular hospital design

The following are the primary key guidelines of thinking of the conceptual modular hospital design that may be drawn from the current questionnaire results.

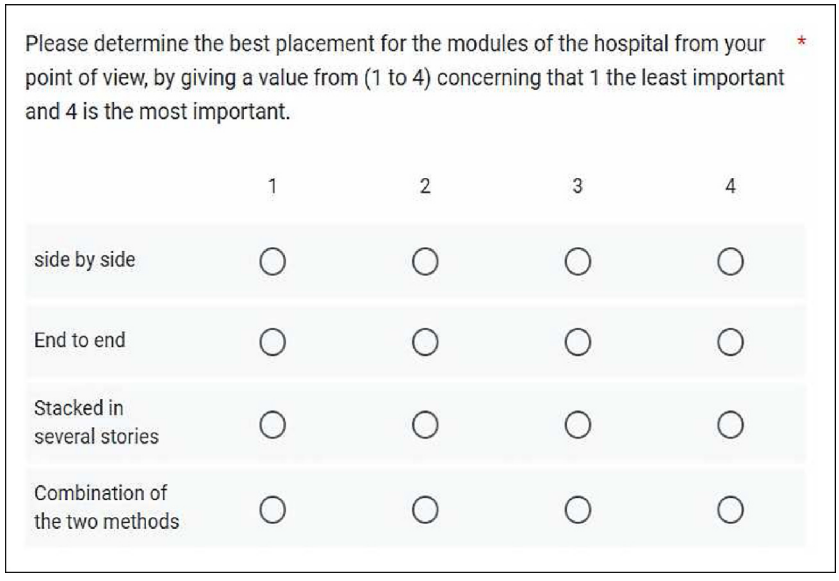


Fig. 12. The best placement for the modules of the hospital. Ref: Authors.

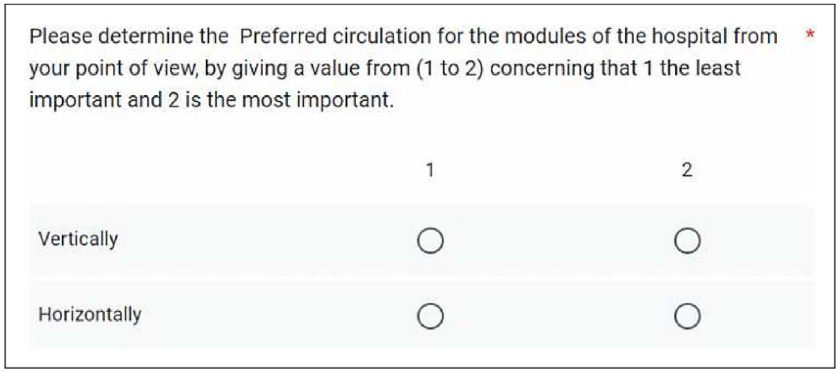


Fig. 13. The preferred circulation of the modules of the hospital. Ref: Authors.

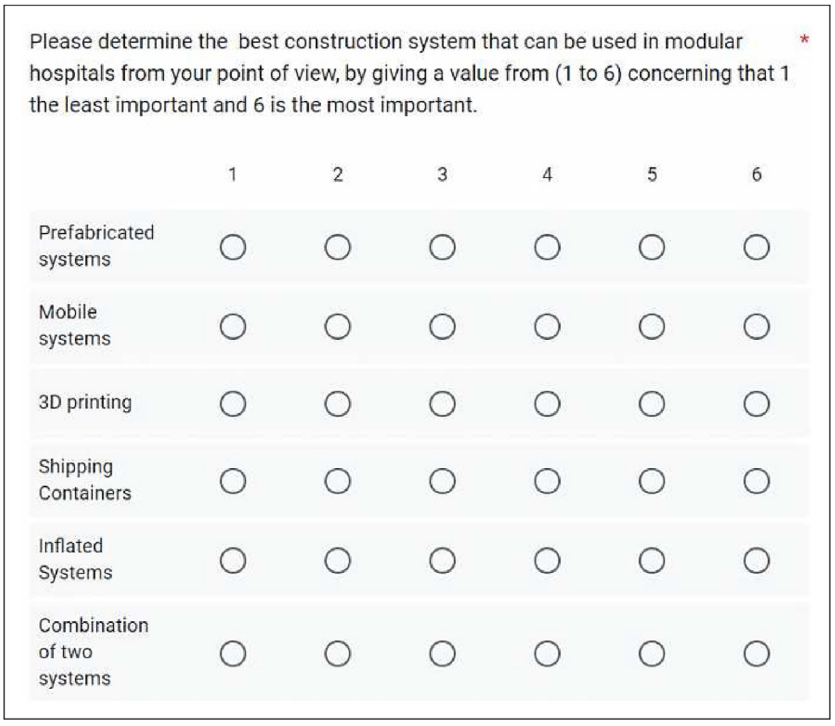


Fig. 14. The best construction system that can be used in modular hospitals. Ref: Authors.

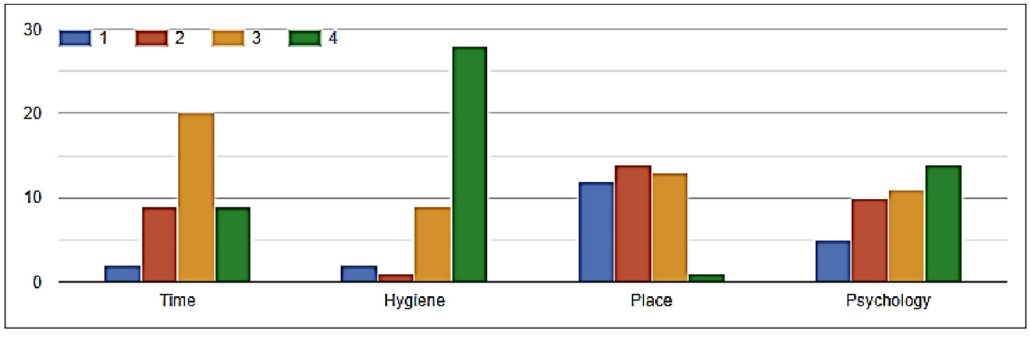


Fig. 15. The four proposed aspects that can help to achieve the new concept of future emergency hospitals.

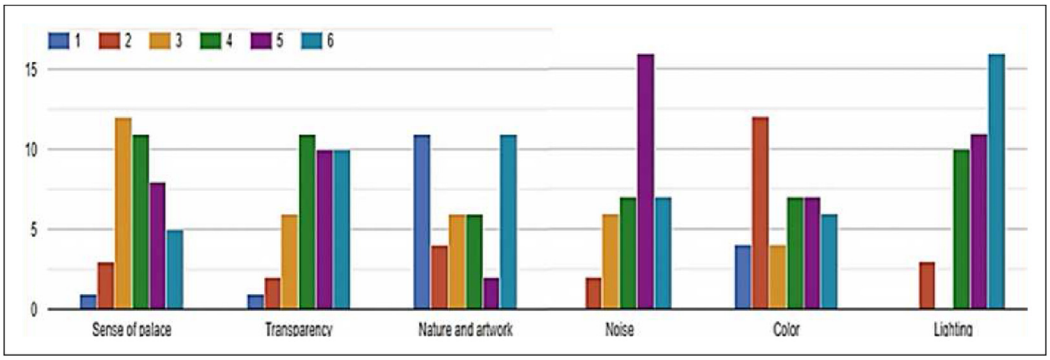


Fig. 16. Patient's psychology.

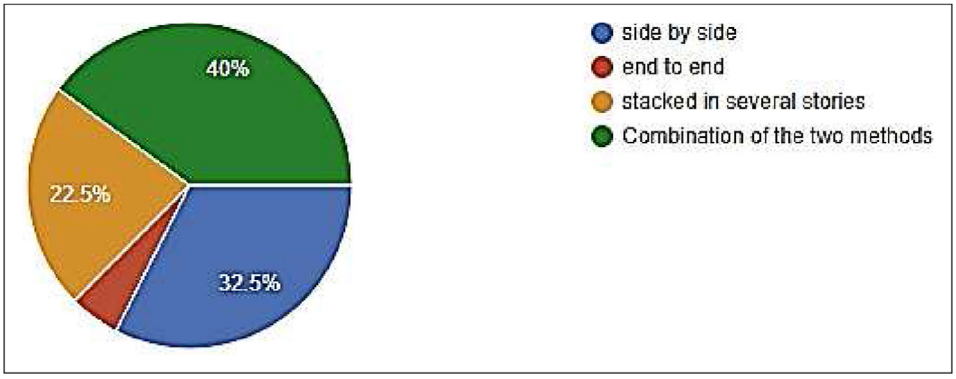


Fig. 17. The best placement for the modules of the hospital.

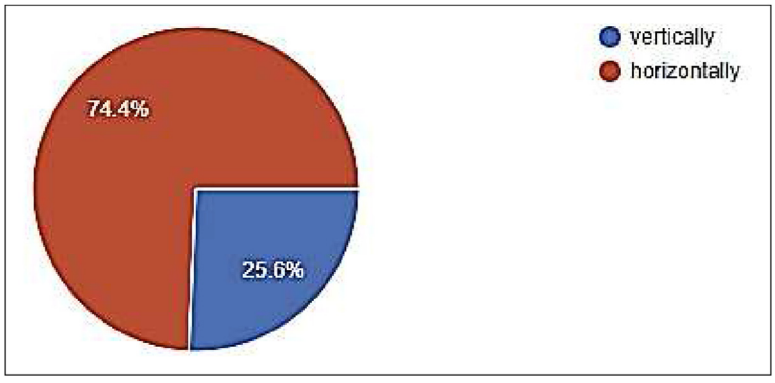


Fig. 18. Preferred circulation.

(1) The master plan must consider the personal needs and desires of patients, staff, management, and the local community.
(2) Modular systems are recommended in pandemic hospitals.
(3) For pandemic hospitals, horizontal circulation is preferred, and module connections can be a mix of side-to-side and end-to-end connections, as shown in context with adjacent structures and open spaces, and making the best use of the site's topography, orientation, site boundaries, sun paths, views and landscape.
(4) Control of disinfection of surfaces and circulating air is a must. Patients' hygiene and psychological needs have to be met, as this can affect their length of stay.

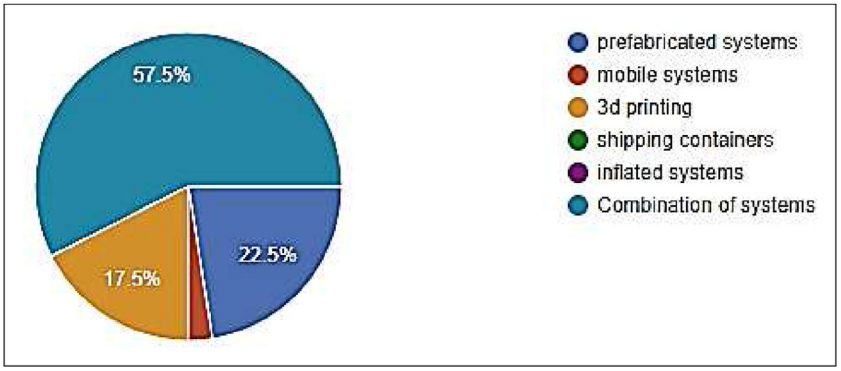


Fig. 19. The best construction system that can be used in modular hospitals.

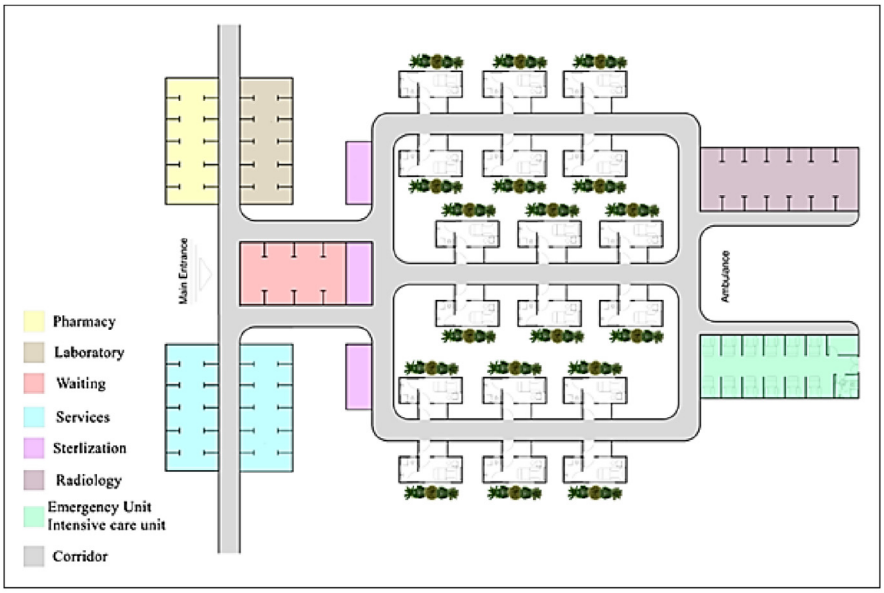
7. Modules required in a hospital

With a view of the medical and clinical needs in hospitals design and based on the outcomes from the questionnaire, the following hospital modules are expected to be essential.

(1) Specialized services modules:

Intensive care unit, imaging and sterilization, emergency and operation units.

(2) Diagnostics services modules:



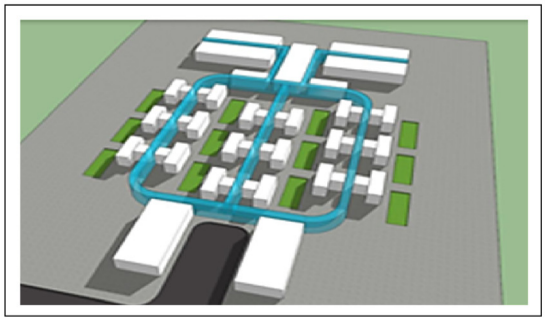


Fig. 20. Diagram showing an example of a layout for the arrangement of modules in a hospital. Source: Authors.

Radiology, laboratory and impatient units, patients' rooms and isolation rooms.

(3) General services modules:

Pharmacy, laundry, kitchen, cafeteria, WC and shower units.

(4) Staff and management modules:

Management and reception, doctors' room, staff and personnel units.

(5) Treatment modules:

Sterilization unit, medical gas and compressors unit, water purification and waste water unit.

(6) Auxiliary modules:

Power source unit, storage unit and mechanical, electrical and control unit.

The size of these modules is selected to be according to the standards of shipping containers, so that they can be easily transported and deployed within hours. They range between 2.5 m in width and 6 m−8 m in length. Modules can be arranged in various arrangements and they can be connected by corridors, tunnels, stairs, etc. Fig. 20 gives an example of a layout showing an arrangement of modules representing different functional requirements in a hospital. Any other layouts for the arrangement of modules can be designed for a pandemic hospital depending on the requirements.

The design of each module has to satisfy the main directions; namely, clinical and medical requirements, architectural features and constructional details.

Table 3 is considered a guideline for architects to follow when designing emergency pandemic hospitals.

8. Proposed framework for pandemic hospitals modular units design

The present study illustrated hospitals modular units as potential anchors to rethinking of future designing hospitals in a pandemic era. Yet, the study

Table 3. Spaces in hospital and architectural requirements.

Space	Unit	Architectural requirements
Specialized Services Areas	Intensive Care Unit	All the intensive care units should be housed at the same place or at least on the same floor.
	Emergency Unit	The Emergency Unit should be located on the ground floor and accessible by two separate entrances: one for ambulance patients and the other for ambulant patients.
	Imaging and Sterilization Unit	For minimizing distance for transportation & also for saving time, it should be located as near main user areas as possible like intensive care and emergency unit etc. Therefore, it should be on the same floor or the floor immediately above or below.
Diagnostic Services Area	Radiology Unit	This service requires a direct access from the emergencies for lying patients. It must be situated on the ground floor or at the first.
	Laboratory Unit	Is an independent Unit. It may be located in a service zone within the healthcare facility and very close to the emergency unit.
General Services Area	Pharmacy	Should be centralized in the hospital and connected to key departments through close adjacency.
	Laundry Unit	Should be located in an area that has ample daylight and natural ventilation. It should be on the ground floor and connected to the water and power tank unit.
	Kitchen Unit	Should ensure that any noise from the departments do not cause any inconvenience to the other departments. At the same time the location should involve the shortest possible time in delivering food.
Treatment Area	Sterilization Unit	The room should have 2 doors, one for entry and one for exit as well as ventilation in the opposite direction to minimize the risks of recontamination.
	Medical Gas Unit	The output system must be arranged in the most favorable position for patients and medical staff when operating.
Inpatient Area	Quarantine Rooms	It could be in large halls.
	Isolation Rooms	Should be equipped with negative pressure isolation systems and exceed the Airborne Infection Isolation (AII) system requirements and controls all three elements of indoor air quality: particles, biological, and gas phase

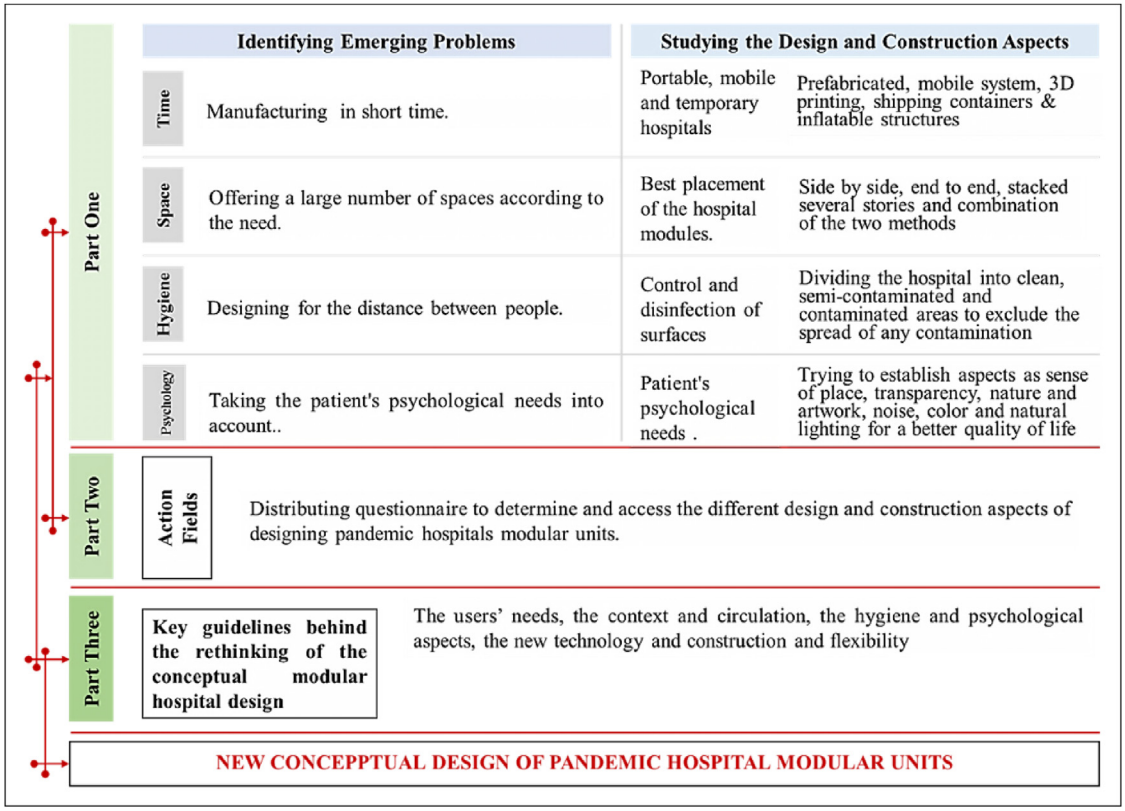


Fig. 21. Proposed framework for pandemic hospital modular units Ref.: Authors.

also showed the several problems that face the rethinking of this building type in general and focused on those problems facing the pandemic hospitals in particular. Hence, a framework for the future designing hospitals modular units, especially in the pandemic time is proposed and herein presented.

The proposed framework was developed using the theoretical and empirical research presented in the study. It deals with three parts; the first is concerned with the main emerging problems facing the designing of hospitals in the pandemic time, the second deals with the action fields that need to be taken to determine and access the different design and construction solutions, and the third part focuses on the key guidelines for the new conceptual design of pandemic hospital modular units, as shown in Fig. 21.

8.1. Conclusion

The paper highlights the significant role of the hospitals' design in the pandemic time and highlights the emerging problems that arose at the interface of COVID-19.

The sheer volume of patients became a greatest challenge in hospital design after COVID 19. A new way of thinking of temporary hospitals with the suitable number of isolation rooms is essential. Considering the urgency in introducing an architectural framework taking into account the time, space, hygiene and psychological factors, the present work explores the hospitals design and construction aspects through a questionnaire. A conceptual design of pandemic hospital modular units has been proposed.

The problem of erecting lots of rooms to cope with the high number of patients and the speed by which these numbers can be constructed could be herein highlighted by proposing a framework for pandemic hospitals modular units' design. Modular temporary hospitals, as that herein proposed, with designed simple patient rooms for isolation are the future for healthcare designs.

These patient modular rooms are simply constructed, aesthetically designed, easily manufactured and satisfying patients' medical and psychological needs.

Through an online questionnaire a group of urban designers and architects agreed on giving hygiene

the highest priority followed by psychological aspect, whereas time and space came next. These results have a very important line of consideration in architectural design.

Next, a proposed framework was created based on the theoretical and the outcomes from the questionnaire. It revealed the key guidelines for the new conceptual design of pandemic modular hospitals.

Authors contribution

Both *Dr. Mona Shedid* and *Dr. Eman Mokhtar* conceived of the presented idea and the design of the work. They developed the theoretical formalism through collecting and analyzing data. They designed and constructed the questionnaire then analyzed the data and results.

All authors read and approved the final manuscript.

Conflict of interest

Declaration of Conflicting interests statement: The author declared that there are no potential conflicts of interest with respect to the research authorship or publication of this article.

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