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Design strategies in hospitals to respond to epidemiological changes

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ABSTRACT

Hospital buildings are very complex in nature. Hospital requirements are changing rapidly because of medical, epidemiological, and technological changes. Also, future uncertainties of medical and diagnostic equipment in terms of its size, weight, the environment required for its function, and adjacencies to other functional areas are often a challenge for the hospital designer. Hospital buildings must be designed in a flexible way so as to address these future uncertainties and be able to adapt to changing requirements, the most important of which is epidemiological change. Therefore, the research aims to identify design strategies to achieve flexibility in hospitals and ensure that hospitals adapt to epidemiological changes. By defining flexibility assessment criteria and tools, analysing them, and applying those strategies during the design process to provide more flexible spaces. The research followed a three-part methodology: (1) A historical approach: collecting a theoretical background on the definition of resilience, its principles, and strategies in hospitals (2) Descriptive approach: identifying tools and criteria for assessing global resilience in hospitals (3) A comparative analytical approach: by analysing the global resilience assessment tools in hospitals and the collected theoretical background and making a comparison to identify points of strength and weakness, to apply them in the design and planning of future hospitals.

1. Introduction

As science, technology, and medicine evolve at an increasing rate, hospitals must ensure that they are able to meet ever-changing needs. Hospitals must keep up with all the new requirements and user needs [1]. Hospitals are facing enormous challenges with epidemiological changes in terms of hospital management, infection prevention and control, and operational requirements [2]. With the spread of epidemics, hospitals run out of space and resources, and the need to redesign hospitals becomes more urgent [3]. To be able to accommodate current demands, adapt to rapid adjustments, and respond to present and future needs. For the following reasons: Flexibility is described as the ability to shift and adjust with few and minor acts [4]. Becomes one of the fundamental requirements for healthcare facilities and one of the main themes, both during the designing process and after it is completed. It also becomes one

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of the key criteria for healthcare facilities and one of the primary topics, both throughout the design process and after it is completed [5]. Architectural design flexibility may be characterised as a building's capacity to adapt to changing space needs and functional solutions throughout short, medium, and long time periods [6]. This may be accomplished by using two design approaches: variable surface flexibility or constant surface flexibility. To provide the flexibility provided by the latter method, the approach of the open building must be used. John Habraken devised this design for home architecture in 1961 [7]. Constant surface flexibility is the ability to change and adapt to new requirements without increasing the overall capacity or expanding the overall structure. One method is the open building approach, which represents the flexibility of a constant surface [8]. The flexibility analysis matrix, which represents the flexibility of constant surface, variable surface flexibility, and operational flexibility, and the modified assessment tool, which represents constant surface flexibility with some criteria of variable surface flexibility [9].

1.1. Research problem:

With epidemiological changes, hospitals are witnessing great challenges in terms of running out of resources and space. The failure of hospitals to respond to these changes and the lack of reliable design solutions to help make flexible strategic decisions in hospital facilities [10]. There is a lack of operative tools for assessing the levels of flexibility in hospital buildings.

1.2. The aim of the research:

The research aims to compare the global resilience assessment tools and flexible design strategies in hospitals and to know the components of each tool with an analysis of the strengths and weaknesses of each of them to reach the best tool for assessing resilience in hospitals in light of the sudden changes, including the epidemiological changes. To identify and apply them later to obtain more flexible hospitals in future.

1.3. Research Methodology:

The study strategy consisted of three steps: (1) A literature review on the definition of flexibility, its levels, and types in hospitals (2) Knowledge of flexible assessment tools in hospitals from a survey of the literature (3) a comparison between global flexibility assessment tools and the collected theoretical background, analysing points of strength and weakness to benefit from them in planning and designing future hospitals.

2. Flexibility definitions:

Pati et al. found that flexibility in healthcare design depends on the perspectives of patients, managers and administrators, and professionals. Patients perceive flexibility regarding improved personalised care, while nursing staff perceive it mainly in operational terms. Managers and administrators perceive flexibility regarding staff management, patient care management, resource provision, etc. Professionals such as architects and engineers perceive flexibility in terms of the space's functionality and its proximity to other spaces, patient well-being and comfort, light, ventilation, structural grids, etc [11]. Pati and colleagues define the three aspects of flexibility are adaptability, convertibility, and expandability. Agre and Landstad, as well as Bjrberg and Verweij [12], employ a similar categorization. "Adaptability or flexibility to adapt" refers to the hospital infrastructure's ability to handle changing healthcare requirements without modifying the environment. "Convertibility or flexibility to convert" refers to the capacity of the healthcare infrastructure to adapt to changing facility needs with small adjustments to the current structure at a fair cost. "Expandability or flexibility to expand" refers to the hospital infrastructure's ability to develop vertically or horizontally in response to changing healthcare needs. Flexibility must be addressed from both an architectural and a facility management standpoint [13].

2.1. Flexibility levels and types:

Previous research has found that "with a better understanding of the hospital facility, it is feasible to establish four levels of flexibility depending on the magnitude of the structure" (hospital complex, building, functional unit, or individual room). For each scale, it is also feasible to identify different sorts of flexibility (space or operational) accessible primarily through certain typological-spatial techniques". Furthermore, these levels must be split into three types of flexibility: constant surface spatial flexibility, variable surface spatial flexibility, and operational flexibility [14]. Levels of flexibility, as described. hospital complex: a combination of all the buildings and external spaces that define the healthcare facility as a whole, building: Individual buildings are identifiable within the broader system; in the case of healthcare facilities made up of individual single-block buildings, this level will have many features in common with the hospital complex's. Functional unit: combination of rooms grouped by similarity of functions, for example, wards, surgical blocks, central heating plants, etc. Individual room: individual space confined and delimited by walls, identifiable individually within a functional unit such as a room in a ward, a doctor’s consulting room, etc. These levels require the application of all types of flexibility.

Constant surface flexibility: The facility should be able to develop without reforming its overall surface area (GFA), reacting to changes in its spatial organisation. At this type, space management capacity is given special consideration [15]. Variable surface flexibility: the facility should be able to support scalability in terms of expansion or decrease based on demand without causing any disruption or impediment to facility activities. Operational flexibility: the hospital's functions should be able to react and adapt to improve its operation via changes in various services.

2.2. Flexibility Analysis Matrix:

An analysis matrix was created to identify the most commonly employed methods in hospitals and to highlight different levels and types of flexibility. The matrix is organised across four levels of flexibility depending on different scales: hospital complex, building, functional unit, and individual room (see Table 1). The following types of flexibility are defined at each level: constant surface, variable surface, and operational flexibility, which highlight prospective spatial and managerial qualitative strategies that can be applied and achieved to assure and support the future development of the healthcare facility [16]. As shown in Table 1.

Table 1. Matrix for analysing hospital flexibility [5].

Level of flexibility	Types of flexibility	Management-typological-spatial-strategies
Hospital complex	Constant surface flexibility	Access system flexibility, System functional flexibility, Reuse of the Hospital Complex, Plant space redundancy.
	Variable surface flexibility	Unused building land exists; strategies for expanding the volume of individual structures exist.
	Operational flexibility	Plant that is modular, interchangeable, and easy to maintain. Networked information systems are present. Building automation and control systems are used (for overall management), Building automation and control systems are used (for overall management), Support services are outsourced.
Building	Constant surface flexibility	The presence of shell space, structural flexibility, oversizing of load-bearing constructions, modifiability of the envelope, the presence of areas for constructing plant infrastructure flexibility and automation of separated pedestrian paths.
	Variable surface flexibility	Load-bearing structural oversizing, the usage of blank facades, modular expansion capability, tiered building.
	Operational flexibility	Plant that is modular, replaceable, and maintainable; building Control and automation systems are used (at a building level); efficient scheduled maintenance; the Life Cycle Cost
Functional Unit	Constant surface flexibility	The installation of interior dry partition walls; the use of moveable internal walls and wall-mounted fittings; internal partitions that can be moved; the presence of service building infrastructure spaces
	Variable surface flexibility	Possibility of expanding the complete functional unit upward/sideways; presence of verandas/setbacks.
	Operational flexibility	Plant with flexibility of use
Individual Room	Constant surface flexibility	The room's functional flexibility
	Variable surface flexibility	Extensions upward/sideways are possible.
	Flexibility of use	providing multipurpose spaces; multifunctional plant; multifunctional information systems services
	User adaptivity	The use of moveable furniture and vertical screening; customizable humanization of the room

3. Hospital flexibility assessment tools

3-1. Original Flexibility Assessment Tool: OBAT (open building assessment tool)

It is introduced to provide a more comprehensive debate and assessment of adaptive and flexible design. An open building approach [17], which represents the flexibility of a constant surface, it proposed eight assessment parameters that can be used to measure how closely a building adheres to the principles of an open building. It consists of eight analysis parameters: shape, structure, façade, building plant, expandability, constraints, technologies, and equipment exchangeability. The shape of the building has a significant impact on the project's flexibility and the possibilities for functional and spatial reorganisation: the more compact the volume, the more it fits the open building concept (Fig.1).

Instead, the structure is a fixed element that should be created with the dimensions and needs of all hospital services in mind, as well as the necessity to be able to readily shift them. The regularity, form, scale, and modularity of the structural grid are consequently critical to ensuring that the open building principles are observed (Fig.2). To that extent, employing materials capable of providing for future needs, such as bigger bearing elements to withstand the weight of a hypothetical extra floor or hollow pillars to house the plumbing and wiring, can be highly beneficial [8].

Fig. 1: The compact shape of a new Karolinska Solna Hospital with the provision of internal courtyards due to the importance of lighting and natural ventilation for patients and users.

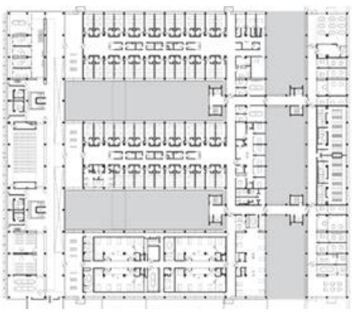

Fig. 2: A regular square structural grid (7.20*7.20) for Clemente Alvarez Emergency Hospital, Argentina, 2007, which contributes to creating more flexible spaces.

The façade is a significant aspect both visually and technologically since it provides shelter and weather protection to the surrounding region. It should be made up of modular panels and be as independent of the interior arrangement as feasible, enabling changes to the latter without affecting the former (Fig.3) (Fig.4).

Fig. 3: The facade consists of a double layer. The inner wooden facade is protected from the weather by the outer facade of sheets of glass "scales". The primary system is, in effect, a low-tech building for high-tech content. INO Project in Bern, Switzerland.

Fig. 4: Facades consisting of curtain walls that can be easily changed and replaced whenever required. Karolinska Hospital, Stockholm, Sweden.

Building plant selection should be based on the necessity for future requirements adaptability, decisive considerations include the distribution, size, and location of the technical shaft and all the features of the single elements (Fig. 5 and Fig. 6).

Fig. 5: New Martini Hospital in Groningen. Central stations such as steam boilers, refrigeration stations, compressed air, etc. are located on the rear facade which extends to the roof through insulated pipes. The fixtures are placed in a central column for each building block, which consists of 80% public spaces and 20% specific spatial destinations, and the insulated pipes outside help to maintain the best arrangement of the future space [8].

Fig. 6: Efficient maintenance of equipment as air ducts, spray tubes, medical gases and branches for patient rooms are constructed and placed symmetrically on each floor. In the future, maintenance personnel will know exactly where to work.

Given that the Open Building approach is an example of constant surface flexibility, expandability must be found inside the building itself, arranging spaces such that they may respond to the need for change and functional reorganisation in different time frames [18]. (Fig.7and Fig.8).

Fig. 7: The cancer centre has large balconies and verandas, which can be easily equipped to be used in different ways.

Fig. 8: INO Hospital is characterised by its ability to expand, thanks to the great care shown during the design process that led to the creation of already equipped areas as well as shell spaces.

Two factors have a significant impact on this procedure: the project's restrictions and the technology employed throughout the construction process (Fig. 9). The former is important for understanding how many changes are feasible to make, while the latter, together with material selection, has a significant influence on how fast and easily these changes can be accomplished [19].

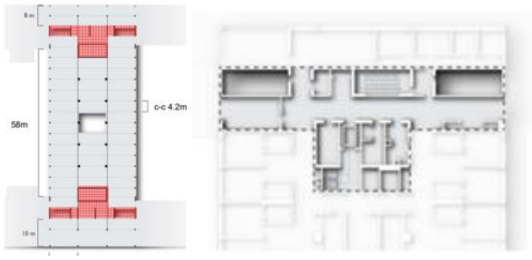

Fig. 9: Fixing the proportion of the service part of the building in a standard manner in the structural structure, leaving the rest of the space for other functional elements.

Another critical issue in the evaluation is the exchangeability of heavy equipment, because their size and the frequency with which they must be updated can make the procedure extremely difficult and costly, even leading to partial demolitions [20]. The following table shows the OBAT analysis parameters: Table (2).

Table 2. Evaluation Sheet Open Building Approach (Original Evaluation Tool) [8].

Evaluation tool			
Evaluation Parameters	Points	options	score
shape	10	100% Compact	Total score /10
	8	70% Compact or Vertical	
	6	50% Compact or Linear	
	4	Articulated	
	2	Horizontal	
	0	Detached buildings	
Structure	1	Span < 7 m	
	2	Span > 8 m	
	4	7 m ≤ Span ≤ 8 m	
	+1	Regular	
	+1	Squared	
	+1	Oversized elements	
	+1	Slabs of concrete with a detachable part for vertical circulation	
	+1	Wiring and plumbing pillars in the form of hollow pillars	
	+1	Predalles	
Facade	+6	Curtain Wall	
	+4	Modular Panels	
	0	Ventilated façade	
	0	Traditional brickwall	
Building plant	+2	Plant infrastructure is spread out in a false ceiling.	
	+1	Infrastructure for the condensed plant (varying height of false ceiling)	
	+1	Technical interfloor	
	+1	Distribution in raised floors	

	+1	In view, when advisable	
	+1	Plant tower	
	+1	Size of service shafts: shafts total surface/floor surface ≥ 0,01	
	4	The distance between service shafts.: d ≤ 35 m	
	2	The distance between service shafts.: 35 m < d ≤ 70 m	
	0	The distance between service shafts.: d > 70 m	
Expandability	+5	Internal: already equipped spaces	
	+3	Internal: shell spaces	
	+2	External: "hanging" volumes from the façade	
Restrictions	8	Only fixed vertical items are allowed (connections and service shafts)	
	6	Up to 10%	
	4	Up to 30%	
	2	Up to 50%	
	0	Up to 50%	
	+2	Drain pipes are installed in service shafts.	
	+1	Drain pipes go alongside pillars	
Technology	4	Dry assembly technique	
	2	Mixed assembly technique	
	0	Wet assembly technique	
	+2	Internal partitions; modular panels	
	+2	Internal partitions; panels set up with plant infrastructure	
	+2	Internal partitions; prefabricated panels	
	+1	Internal partitions; dry walls built in situ	
Exchangeability of large equipment	8	Only the façade panels need to be disassembled.	
	4	Dismantling of facade panels and interior partitions	
	0	Partial demolitions	
	+2	Large equipment is located on the ground floor.	

3.2. Modified Flexibility Assessment Tool (OFAT)

Researchers created the modified assessment tool after conducting an analysis of the OBAT framework. To emphasise the advantages and disadvantages of each characteristic. The modified flexibility assessment tool (OFAT) was created as a consequence of the investigation. The evaluation tool is intended to examine the degree to which the basic principles of flexibility are followed. It was created to test medical facility resilience throughout the design and planning phases. Its application to existing facilities contributes to the extent to which the building fulfils flexibility criteria and principles. The modified assessment tool has nine assessment parameters, each of which is divided into measurable variables with a score range of 0 to 10. They are: shape, structure, façade, building plant, extension potential, restrictions, interchangeability of heavy equipment, and function. The table below illustrates the modified tool for each rating criterion.

Table 3. Modifications suggested for each evaluation criterion in the new modified assessment tool [9].

Evaluation Parameter	Modifications
Shape	Merged and uncorrelated morphological categories of "70% compact with vertical" and "50% compact with linear" need to be separated.
	Splitting the merged classifications results in an increase in the number of analytic parameters from six to eight, allowing for a more precise and well-defined evaluation. As a result, the scores are revised to reflect the new changes.
Structure	A 20% tolerance is added to the regular grid evaluation parameter to avoid rigid assessments that may have a detrimental influence on the overall evaluation. As a result, the (+1) is allocated to the 80% to 100% regular grid instead.
	The former instance is likewise applied to the squared grid analysis parameter, with a tolerance of 20%. As a result, the (+1) is assigned to the 80% to 100% squared grid instead.
	The large structural parts will be redefined to include not just the structure's capacity to accept more medical equipment, but also the building's vertical growth if necessary. There is no specific proportion of oversizing for vertical expansion, but it will depend on each particular scenario based on the building height regulations of the project area.
	The analytical parameter "predalles" is not included in the evaluation since it is not an instrumental approach to structural flexibility.
	According to the literature and healthcare design guidelines, a new analytical parameter, "ceiling height 4 m," is included since it has a critical influence on the flexibility of the healthcare facility to permit future convertibility. It has been given a +1 score.
Facade	The curtain wall analysis parameter is divided into three categories: 100% curtain wall, 75% curtain wall, and 50% curtain wall, with

	scores of (+6), (+4), and (+2), respectively.
Building Plant	Because they are deemed separate strategies that serve the same aim, the analysis parameters "distribution in raised floor" and "in view when advised" (changed to: exposed installations, when necessary) are to be integrated into one analysis parameter.
	A new analytical parameter "mechanical floor" is included to allow for unrestricted transition between functions with varied spatial organisation and technical/structural constraints (for example, bed tower and operating block). As a result, a (+1) score is awarded.
	The maximum score for distances between shafts has been decreased from (+4) to (+2). Despite the fact that it is critical to giving the required flexibility to the building plant, however, there are other factors that are as important.
	According to the literature and design rules, a new analytical criterion "redundancy of building plant" is included to handle future renovations and additions to the building. It has a (+2) rating.
	According to the literature and design rules, a new analytical criterion "redundancy of building plant" is included to handle future renovations and additions to the building. It has a (+2) rating.
Expandability	Another new analytical element is added: "soft spaces: to be converted into service areas if needed," which enhances the building's flexibility to adapt to functional future demands. A (+1) score is awarded in this situation.
	Internal: the score for previously equipped spaces has been decreased from (+5) to (+4), and the score for shell spaces has also been reduced from (+3) to (+2).
	Another new analytical parameter is included, "availability of neighbouring plot," which ensures the potential for physical growth. A (+1) score is awarded in this situation.
	External: 'hanging' volumes from the façade" score is to be evaluated using the third evaluation technique, "alternative points," rather than the second assessment method. In this instance, a (+1) score is assigned.
Restrictions	Instead of five categories, the " percentage of fixed elements" analytical parameter is divided into four: fixed vertical elements (connections and service shaft), fixed elements of building plant: fixed elements of building plant: up to 25%, fixed elements of building plant: up to 50%, and fixed elements of building plant: up to 75%
	Because of the reclassification of the previous analytical parameter, the score of each parameter has been modified to (+6), (+4), (+2), and (zero) for a more accurate evaluation.
	Because they are considered different techniques that serve the same purpose, the analysis parameters "drain pipes placed in service shafts" and "drain pipes run next to pillars" are to be merged into one analysis parameter. As a result, the same (+1) score is awarded.

	A new analytical parameter, "adjustability of service shafts," is included since it increases the building's ability to react to changes in technical and clinical needs. In this situation, a (+2) is assigned.
	A new analytical parameter, "grouped vertical circulation elements," is included to maximise future planning so that the rest of the floor space is continuous and open. As a result, a (+1) score is awarded.
Technology	A new analysis parameter called "internal partitions: movable/retractable" is included to ensure that spaces may be modified simply by moving parts. They provide many flexible methods of utilising space by varying the degree of connectivity between nearby rooms. In this situation, a (+1) score is awarded.
	A new analysis parameter "internal partitions: framed construction" is included to allow partition walls to be changed for maintenance or alteration. As a result, a (+1) is assigned.
	The scoring of "internal partitions: modular panels" and "internal partitions: panels set up with plant infrastructure" is decreased from (+2) to (+1) as a consequence of the addition of two additional analysis parameters.
Exchangeability of large equipment	A new analysis criteria called "equipment spaces with redundancy" has been included to ensure that spaces may be modified to future needs and accommodate additional equipment. In this situation, a (+1) score is awarded.
	The score of "big equipment on ground level" has been updated to (+1) as a consequence of the addition of the previous analysis parameter. Also, this characteristic is redefined to cover "equipment on floor with direct contact with the outside".
Functionality	When having generic/universal rooms, the highest score (+4) is awarded since it promotes avoiding excessive variation in related components when the change in functionality may be handled in one standard design.
	A lower (+2) score is attributed to the existence of space standardisation, which is attributed to definition, specification, quality, and error reduction due to repetition, in addition to permitting adaptation to future transformation and the demands of the facility's users.
	The double function receives a score of (+1), as it allows for changes in operating mode via space sharing (Fig.10) [23].
	Overflow design receives a (+1) because it maximises the space's ability to accommodate multiple functions with non-overlapping time schedules. It is extremely useful in times of disaster.
	While loose fit is given a (+1) since it is a concept in which spaces effectively react to today's operational policy while also having the inherent flexibility to adapt to a variety of alternatives
	In terms of furniture/equipment flexibility, completing either one or both gets a (+1) since it allows mobility into other regions for function flexibility.

Fig. 10: Miami Valley Hospital, USA, 2011. Multi-functional rooms.

3.3. Comparison between the flexibility analysis matrix, the original assessment tool OBAT, and the modified assessment tool OFAT

The researcher made a detailed analytical comparison between the collected theoretical background on resilience in hospitals and the flexibility analysis matrix, which represents constant surface flexibility, variable surface flexibility, and operational flexibility, and between the original evaluation tool (OBAT), which represents constant surface flexibility only, and the modified evaluation tool (OFAT), which represents constant surface flexibility and some parameters of variable surface flexibility in the table below.

Table 4: Comparison of assessment tools

Combined theoretical background for flexibility criteria in hospitals	The Open Building Assessment (OBAT)	Modified Assessment Tool(OFAT)	Flexibility analysis matrix
Geometric shape[21]	✓	✓	×
The main hub of the hospital	×	×	×
Site capacity [21]	×	×	✓
Use of building automation and control systems (comprehensive management)	×	×	✓
The presence of building areas for the infrastructure of the facility	×	×	✓
Strategies for increasing the volume of individual buildings	×	×	✓
Existence of networked information systems	×	×	✓
Reuse of the Hospital complex	×	×	✓
Modular Structural System [22]	✓	✓	✓
The height of the floor to the other floor from the finishing level is not less than 16 feet[22]	×	✓	×
Minimum internal structural walls. Minimal internal structural walls	×	×	×
Oversizing of load-bearing structures	×	×	✓
Modular and flexibility plant	✓	✓	✓
Using the service floor or called a mechanical floor	✓	✓	×
Redundancy of building plant	×	×	✓
Opportunity for vertical mechanical equipment shafts in the future. Fix a % of total surface area[21]	✓	✓	×
The façade ideally should be replaceable in the [21].	✓	✓	✓
Grouped vertical circulation elements	×	✓	×
Equipment spaces with redundancy	×	✓	×
Relatively simple building techniques	✓	✓	×
The idea of soft and non-soft spaces	×	✓	×
Provide shell spaces	✓	✓	✓
Possibility of modular expansion	×	×	✓
Open ended corridor [22]	×	✓	×
Presence of verandas/setbacks	×	×	✓
Modular Fixed partitions and walls	✓	✓	✓
The use of moveable internal partitions	×	✓	✓
The use of moveable Internal walls and walls with wall-mounted fittings	✓	✓	✓
Providing multi-use spaces	×	✓	✓
General& universal rooms [22].	×	✓	×
Functional flexibility in rooms	×	✓	✓
The use of m le furniture and vertical screening	×	✓	✓
Customizable humanization of the room	×	×	✓

3.4. Results of the comparison between the theoretical background and flexibility assessment tools

After making a table to compare the collected theoretical background, and flexible assessment tools (the flexibility analysis matrix, the original assessment tool, and the modified assessment tool), we found that some of the flexibility criteria mentioned in the theoretical background were achieved by the original assessment tool (OBAT), and were not achieved by the modified assessment tool(OFAT) and the flexibility analysis matrix, and some flexibility criteria were achieved by the modified assessment tool and were not achieved by the original assessment tool and the flexibility matrix, and some criteria of flexibility were achieved by the flexibility matrix, but were not achieved using the two flexibility assessment tools. There are criteria that the three assessment tools contributed to achieving.

The original assessment tool only represented constant surface flexibility. Constant surface flexibility means that there are no strategies to increase the size of the buildings or the possibility of expansion, in contrast to the flexibility analysis matrix, which represents constant surface flexibility, variable surface flexibility, and operational flexibility. While the modified assessment tool achieved constant surface flexibility and some variable surface flexibility criteria through strategies to increase the volume of buildings and expand outside the building, like open-ended corridors or large spaces on the building's end and the availability of neighbouring plots, the modified assessment tool with the flexibility analysis matrix emphasised the importance of the function through the importance of functional flexibility for rooms, space standardisation, and furniture and equipment flexibility, as shown at table 3. The Flexibility Analysis Matrix was distinguished from the other two assessment tools (OBAT and OFAT) as it focused on criteria for achieving operational flexibility at the four levels of the hospital (hospital complex, building, functional unit, and individual room), as shown in Table 1.

As mentioned earlier, flexibility means (the ability to adapt, the ability to change or transform, and the ability to expand), and the original assessment tool did not achieve the ability to expand and increase the size of buildings; it only achieved the ability to adapt through an open building approach, which represents constant surface flexibility, as shown in Table 2, while the modified assessment tool achieved the possibility of adaptation and some expansion strategies and increased the size of buildings, as shown in Table 3. The flexibility analysis matrix has achieved the ability to transform, adapt, and expand on the four levels of the hospital (hospital complex, building, functional unit, and room), as shown in Table 1. Therefore, we find that the flexibility analysis matrix is the best for assessing flexibility in hospitals and responding to and adapting to rapid changes and transformations, which include epidemiological changes.

4. Conclusions:

We used a three-step research methodology that included reviewing the literature on defining resilience and its principles and strategies in hospitals, identifying and analysing global resilience assessment tools in hospitals, and then conducting a comparison to identify the strengths and weaknesses of each tool to use as a design reference for use in designing and planning hospitals. The idea was to create hospitals that are easy, adaptable, transformable, and expandable and are able to meet new requirements and rapid changes without affecting the activities of users or medical staff. Therefore, flexibility is the main requirement for the hospital of the future.

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