# Measuring Flexibility In Hospitals: Flexible Design Strategies And Decisions In Hospitals

**Monira Mohamed Abd-Alhady [1*], Mohamed Helmy Al-Hefnawy [2], Mohamed Atef Abu-Ashour [3], Ahmed Al-Menshawy [3]**

[a] MSc. Student , Architecture Department, Faculty of Engineering, Zagazig University, Zagazig,
b AssociateProfessor;Dept of Arch; Faculty of Fine Arts; Assiut University; Egypt
c Associate Professor; Dept. of Arch.; Faculty of Eng.; Zaqaziq University; Egypt

**Corresponding author: Monira Mohamed Abd-Alhady**,

**Moniraaklashour@gmail.com**

## Abstract

With the outbreak of the Corona pandemic, hospitals faced enormous challenges in terms of running out of resources and space and the inability to separate patients infected with the Corona virus from patients suffering from other diseases. The Corona virus starkly highlighted the lack of reliable design strategies to support strategic and flexible decision-making in hospitals, to be able to adapt and respond to all future requirements and rapid changes, and to respond to contemporary and future public health emergencies. Therefore, flexibility was the main component of hospitals' ability to meet these ever-changing needs. Therefore, the research aims to identify technical solutions to ensure flexibility in designing hospitals by studying and identifying flexibility assessment tools, conducting a critical review of them, and developing a new assessment tool for assessing hospitals flexibility. To determine in what measure hospitals follow the principles of flexibility. In this study, flexible assessment tools in hospitals were identified and compared, followed by a critical review of them, and then a new developed assessment tool was deduced to serve as a constant reference for hospital designers. Testing the new tool on international models to determine its effectiveness and identifying deficiencies in hospitals to avoid these design problems the new version of the AFAT framework (Advanced Flexibility Assessment Tool) consists of evaluation criteria that are classified under the four levels of flexibility (hospital complex, building, functional unit, and room) and are divided into measurable variables with scores ranging from 0 to 5. Testing case studies enabled the assessment and validation of the validity and reliability of the AFAT to support decision-makers in addressing flexibility in hospital design. To accommodate current hospital activities, adapt to time-sensitive physical changes, and respond to present and future public health emergencies, healthcare facilities must be planned and constructed using flexible design principles.

**Keywords**: Hospitals,Flexibility,Epidemiological Changes, Adaptability,The Ability To Change.

## Introduction:

Hospitals are complex buildings due to their multiplicity of functions and their overlapping, in addition to the fact that the designers and structural engineers designed them for the purpose of a specific function, which makes it difficult to make adjustments and development over time and to face rapid changes such as medical, technological, and epidemiological changes[1]. It is imperative that hospitals ensure that they are able to meet ever-changing needs as science, technology, and medicine develop at an ever-increasing pace. Hospitals have to keep up with all the new requirements and user needs[1].

Since the outbreak of the COVID-19 pandemic, hospitals have faced enormous challenges with regard to healthcare management, environmental contamination risks, and operational requirements for infection prevention and control [2]. Hospitals have been running out of space and resources to treat COVID-19 patients, and the need to redesign hospitals has become more pressing[3]. To be able to accommodate current demands, adapt to rapid adjustments, and respond to present and future needs, particularly while dealing with emergency concerns such as the COVID-19 pandemic. The stress caused by the pandemic has made the existing structural, organisational, and technological challenges of worn-out and ageing hospitals more pressing and heightened the sense of urgency to redesign hospitals. Hospital buildings must be planned and designed to be able to accommodate current needs, adapt to rapid transformations, and respond to contemporary and future needs, especially while facing emergency issues such as the COVID-19 pandemic[3].

For these reasons, flexibilitydefined as the ability to modify and change with a few actions[ becomes one of the basic requirements for hospital buildings, both during the design process and throughout the entire life cycle of the building [4,5]. Flexibility in architectural design is defined as the ability of a building to adapt to changing spatial requirements and functional solutions according to short-, medium-, or long-term points of view[6].

## Research problem

The coronavirus crisis has revealed that many modern hospitals lack the flexibility to accommodate sudden surges in patients, run out of space due to unexpected healthcare situations, and fail to adapt to these sudden changes, practical tools for assessing resilience in hospital buildings are lacking[7]. It is essential to develop reliable tools and assessment criteria to support hospital planners in addressing challenges that require rapid adjustments, such as the response to COVID-19.

## Research aim

The aim of this research was to modify and develop a flexibility assessment tool that provides guidance to hospital designers to improve their proposed designs and to bring it to existing hospitals to provide a deeper understanding of how facilities meet resilience criteria and concepts.

## Materials and Methods

The research plan followed a four-step process by collecting data through: (1) reviewing the literature on resilience principles and strategies; (2) identifying global resilience assessment tools; (3) critically reviewing resilience measuring tools, comparing them, and concluding and developing a new tool; and (4) testing the new tool for global models to ensure its effectiveness.

## Flexibility definitions:

Pati et al. found that flexibility in healthcare design depends on the perspectives of patients, managers. discovered that the viewpoints of patients, managers and administrators, and professionals all influence flexibility in healthcare design[8]. Patients see flexibility in terms of more customised treatment, but nursing staff view it primarily in terms of operational efficiency. Managers and administrators value flexibility in personnel management, patient care management, and resource availability, among other things. Architects and engineers, for example, see flexibility in terms of space functioning and closeness to other spaces, patient well-being and comfort, light, ventilation, and structural grids, among other things. Pati and colleagues describe flexibility as having three components: adaptability, convertibility, and expandability[8]. Agre and Landstad, as well as Bjrberg and Verweij[9], 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 [10].

**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)[5]. For each scale, it is also feasible to identify different types 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[11].

Levels of hospitals Facilities (hospital complex, building, functional unit, and individual room), hospital complex: The collection of all the buildings and outdoor areas that constitute the healthcare institution as a whole is referred to as a hospital complex Building; a single building: that may be identified within the larger system In the event of a single-building healthcare facility, this level will share many characteristics with the hospital complex. Functional unit: a grouping of rooms with similar purposes, such as the wards, the surgical building, the heating station, the central, and so on. Individual room: A single area contained and bounded by walls that can be designated separately within a functional unit, such as a room in a suite, a doctor's consultation room, and so on.

Constant surface flexibility[12]: The facility should be able to develop without reforming its overall surface area (GFA), reacting to changes in its spatial organisation owing to demand development, medical science advancements, or function redevelopment. At this level, layout planning and space management capacity are given special consideration. Variable surface flexibility[1]: 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 in order to improve its operation via changes in various services.

## 2.Matrix of Flexibility Analysis

An analytical matrix was created to identify the most often employed methods in hospitals and to highlight different levels and types of resilience. The matrix is organised across four levels of flexibility depending on different scales: hospital complex, building, functional unit, and individual room **(Table 1)**. The following types of flexibility are defined at each level: constant surface flexibility, variable surface flexibility, and operational flexibility that highlights prospective spatial and managerial qualitative strategies that may be utilised and attained to secure and promote the future growth of hospitals [13].

**Table (1): Matrix for analysing hospital flexibility:**

| 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 expansion space as well as 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, Building with many levels |
| | 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 utilisation of movable interior walls and wall-mounted fixtures, Internal partitions that can be moved, The presence of service building infrastructure spaces |
| | Variable surface flexibility | Possibility of expanding the complete Functional Unit vertically/horizontally, Verandas/setbacks are provided. |
| | Operational flexibility | Plant with several uses |
| 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 utilisation of mobile furniture and vertical screens, as well as customisable humanization of the space |

Source: Capolongo, S. Architecture for Flexibility in Healthcare; Franco Angeli Milano: Milano, Italy, 2012; ISBN 882041502X.
22. Pilosof, N.P. Building for Change: Comparative Case Study of Hospital Architecture. HERD 2021, 14, 47–60.

## 3. Tools for assessing resilience in hospitals
### 3.1. Open Building Assessment Tool (OBAT):

It is the open building approach (OBAT)[14] , which represents the flexibility of the constant surface, that identified eight parameters for evaluation. They are: shape, structure, facade, building plant, expandability, restrictions, technologies, and exchangeability of large equipment, which can be used to determine the extent to which the building follows the principles of the open building approach[15]. The grading system presents for each parameter a score between 0 and 10 points [14].

### 3.2. Optimised Flexibility Assessment Tool (OFAT):

The modified assessment tool was developed by the researchers through a critical review of the OBAT framework to highlight the strengths and weaknesses of each of the parameters. The analysis resulted in a modified version of the tool, the Optimal Flexibility Assessment Tool (OFAT)[16]. The assessment tool is designed to determine the degree of adherence to the basic principles of the concept of resilience. The modified tool consists of nine evaluation parameters, with each parameter divided into measurable variables with a score range between 0 and 10, and they are: shape, structure, façade, building plant, expandability, restrictions, technologies, exchangeability of large equipment, and function.

### 3.3. Make a comparison between the collected theoretical background on resilience assessment tools (the resilience analysis matrix, the original assessment tool OBAT, and the modified optimal assessment tool OFAT)

The researcher made a detailed analytical comparison between the collected theoretical background on flexibility in hospitals, the flexibility analysis matrix, the original assessment tool, and the modified assessment tool. It was found that the original assessment tool or the open building approach represents constant surface flexibility only, which means the ability of hospitals to adapt to changes without increasing or changing the size, and the modified evaluation tool represents fixed constant surface flexibility as well, with some parameters of variable surface flexibility, such as adding a new analysis parameter, "An open corridor[17] and/or large spaces at the end of the building the availability of the adjacent plot of land. While the flexibility analysis matrix achieved flexibility strategies of its three types (flexibility of a constant surface, flexibility of a variable surface, and operational flexibility) at all levels (hospital complex, building, unit)[1]. Therefore, the researcher adopted the flexibility analysis matrix, but by applying it to global models, it found that the flexibility analysis matrix ignored some design criteria such as shape, structure, building restrictions, and the possibility of exchanging equipment[18].

## 4. Advanced Flexibility Assessment Tool (AFAT)

After extensive study, multiple readings, and literary review by the researcher over the past five years in everything related to flexibility in designing hospitals, research papers, theses, and books published in the time period from 2014 to 2023, the researcher collected a theoretical background on design flexibility standards and strategies, as well as The researcher collected all evaluation tools, from the oldest to the most recent (the flexibility analysis matrix, the original flexibility assessment tool, or the open building principles, the modified flexibility assessment tool), and the theoretical background of resilience thought and theories. The researcher deduced a sophisticated and advanced assessment tool that includes all criteria of flexibility for hospital design, and the researcher classified them on the four levels of flexibility[1] (hospital complex level, building level, functional unit level, and single room level). With a relative weight for each criterion based on each tool, each of the evaluation tools received a score of 1, except for the theoretical background, which received a score of 2. The combined criteria that are classified under the hospital complex are each of the following: shape, site capacity, flexibility of access systems, use of building automation and control systems (for overall management), reuse of the hospital complex, functional flexibility of the system, presence of networked information systems, and strategies to increase the size of individual buildings. The scores were calculated as follows:

| **Flexibility Levels** | **Combined Evaluation Criteria** | **Flexibility Measuring Tools** | | | | **Total** | **Total scores** |
|---|---|---|---|---|---|---|---|
| | | **Theoretical Background** | **Flexibility Analysis Matrix** | **Open Building Assessment Tool(OBAT)** | **Modified Flexibility Assessment Tool(OFAT)** | | |
| **Hospital complex** | **1-Shape** | **mentioned** | **Not mentioned** | **mentioned** | **mentioned** | **2+n** | **4** |
| | **2-Site Capacity** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **3+n** | **5** |
| | **3- Flexibility of access systems** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **1+n** | **3** |

*Source: researcher*

There are standards that are classified under the building level, which are: Structural flexibility[19] (structure system): floor height, loading capacity of floors, minimum internal structural walls[20]. Oversizing of load-bearing structures; separation of systems[20]; flexibility and automation of segregated pedestrian routes[1]; presence of spaces for building infrastructure; possibility of modular expansion [17]; façade; modular, replaceable and maintainable plant; the use of building automation and control systems (at a building level)[1]; Restrictions; standardisation of spaces; use of the service floor; setting a ratio for vertical mechanical equipment in the future; construction techniques; locating the plant for the building; grouped vertical circulation elements; the possibility of exchanging equipment; the idea of soft and non-soft spaces[17]; efficient programmed maintenance; natural lighting[21]; and the calculation of degrees was as follows in the illustrative example:

| **Flexibility Levels** | **Combined Evaluation Criteria** | **Flexibility Measuring Tools** | | | | **Total** | **Total scores** |
|---|---|---|---|---|---|---|---|
| | | **Theoretical Background** | **Flexibility Analysis Matrix** | **Open Building Assessment Tool(OBAT)** | **Modified Flexibility Assessment Tool(OFAT)** | | |
| **Building** | **1-Structural System** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **3+n** | **5** |
| | **2-Floor Hight** | **mentioned** | **Not mentioned** | **Not mentioned** | **mentioned** | **1+n** | **3** |
| | **3- Minimum of Structural Walls** | **mentioned** | **Not mentioned** | **Not mentioned** | **Not mentioned** | **n** | **2** |
| | **4- Facade** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **3+n** | **5** |

*Source: researcher*

There are standards that are classified under the level of the functional unit, which are partitions and standard internal walls; movable walls and partitions; internal partitions prepared with infrastructure; Presence of spaces for service building infrastructure[22]; standard prefabricated elements; an open-ended corridor; the possibility of extending the entire functional unit sideways; presence of verandas/setbacks[1]; plant with flexibility of use; multi-use spaces; and the scores were calculated as follows in the illustrative example:

| **Flexibility Levels** | **Combined Evaluation Criteria** | **Flexibility Measuring Tools** | | | | **Total** | **Total scores** |
|---|---|---|---|---|---|---|---|
| | | **Theoretical Background** | **Flexibility Analysis Matrix** | **Open Building Assessment Tool(OBAT)** | **Modified Flexibility Assessment Tool(OFAT)** | | |
| **Functional Unit** | **1-The use of internal dry partition walls** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **3+n** | **5** |
| | **2- The use of movable interior walls** | **mentioned** | **mentioned** | **Not mentioned** | **mentioned** | **2+n** | **4** |
| | **3-Open ended corridor** | **mentioned** | **Not mentioned** | **Not mentioned** | **mentioned** | **1+n** | **3** |
| | **4- Presence of verandas/setbacks** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **1+n** | **3** |

*Source: researcher*

There are criteria that are classified under the level of individual room, which are: functional flexibility of the room; generic/universal rooms[17]; prefabricated rooms[23]; a multifunctional factory; the use of movable furniture; the provision of multifunctional rooms; humanising the room[1]; and the calculation of grades was as follows in the illustrated example:

| **Flexibility Levels** | **Combined Evaluation Criteria** | **Flexibility Measuring Tools** | | | | **Total** | **Total scores** |
|---|---|---|---|---|---|---|---|
| | | **Theoretical Background** | **Flexibility Analysis Matrix** | **Open Building Assessment Tool(OBAT)** | **Modified Flexibility Assessment Tool(OFAT)** | | |
| **Individual Room** | **1- Functional flexibility of the room** | **mentioned** | **mentioned** | **Not mentioned** | **mentioned** | **2+n** | **4** |
| | **2- Generic/universal rooms** | **mentioned** | **Not mentioned** | **Not mentioned** | **mentioned** | **1+n** | **3** |
| | **3- Fabricated rooms** | **mentioned** | **Not mentioned** | **Not mentioned** | **Not mentioned** | **n** | **2** |
| | **4- Use of moving furniture and vertical examination** | **mentioned** | **mentioned** | **Not mentioned** | **mentioned** | **2+n** | **4** |

*Source: researcher*

### 4.1. Test global case studies using the advanced flexibility assessment tool (AFAT) and determine their effectiveness:

A group of hospital buildings known for their flexibility around the world were chosen to be a test for the new tool and to determine its effectiveness. Recently completed, promising, and vetted case studies were selected across diverse geographies and scales and evaluated with a critical lens focused on flexibility. The five selected case studies were Case Study 1 (CS1): New Martini in Groningen, Netherlands. Case Study 2 (CS2): Hospital University Akershus, Oslo, Norway. Case Study 3 (CS3): Miami Valley, USA. Case Study 4 (CS4): Sunshine Coast University Hospital, Bertinea, Australia. Case Study 5 (CS5): New Karolinska Hospital, Stockholm, Sweden. Testing the advanced flexibility assessment tool for global case studies:

The evaluation of global case studies using the Advanced Flexibility Assessment Tool was as follows, as shown in the table:

| **Flexibility Levels** | **Flexibility Measuring Tools** | | | | | | | **Global Case Studies** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Combined Evaluation Criteria** | **Theoretical Background** | **Flexibility Analysis Matrix** | **Open Building Assessment Tool)OBAT)** | **Modified Flexibility Assessment Tool)OFAT)** | **Total** | **Total scores** | **Cs1** | **Cs2** | **Cs3** | **Cs4** | **Cs5** |
| **Hospital complex** | **1-Shape** | **mentioned** | **Not mentioned** | **mentioned** | **mentioned** | **N+2** | **4** | **3.2/ 4** | **3.2/ 4** | **4/4** | **3.6/ 4** | **3.2/ 4** |
| | **2-Site Capacity** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **N+3** | **5** | **3.3/ 5** | **3.7/ 5** | **3/5** | **4/5** | **4/5** |
| | **3-Flexibility of access systems** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **N+1** | **3** | **2.5/ 3** | **3/3** | **2.5/ 3** | **3/3** | **3/3** |
| | **4-The use of Building Automation and Control systems** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **N+1** | **3** | **0/3** | **3/3** | **0/3** | **3/3** | **3/3** |
| | **5-Reuse of the Hospital complex** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **N+1** | **3** | **2/3** | **3/3** | **1/3** | **1/3** | **3/3** |
| | **6-Functional flexibility of the system** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **N+1** | **3** | **3/3** | **3/3** | **3/3** | **3/3** | **3/3** |
| | **7-Presence of networked information systems** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **N+1** | **3** | **3/3** | **3/3** | **3/3** | **3/3** | **3/3** |
| | **8-Strategies for increasing the volume of individual buildings** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **N+3** | **5** | **3.4/ 5** | **4/5** | **0/5** | **4/5** | **3.9/ 5** |
| **Building** | **1-Structural flexibility** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **N+3** | **5** | **4.4/ 5** | **4.2/ 5** | **4.4/ 5** | **4.3/ 5** | **4/5** |
| | **2-floor height** | **mentioned** | **Not mentioned** | **Not mentioned** | **mentioned** | **N+1** | **4** | **3/3** | **3/3** | **3/3** | **3/3** | **3/3** |
| | **3- Minimum of internal structural walls** | **mentioned** | **Not mentioned** | **Not mentioned** | **Not mentioned** | **n** | **2** | **2/2** | **2/2** | **2/2** | **2/2** | **2/2** |
| | **4-Systems separation** | **mentioned** | **Not mentioned** | **mentioned** | **mentioned** | **N+2** | **4** | **4/4** | **4/4** | **4/4** | **4/4** | **4/4** |
| | **5-Flexibility and automation of segregated pedestrian routes** | **Not mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **1+0** | **1** | **0/1** | **1/1** | **0/1** | **0/1** | **1/1** |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6-Presence of spaces for building plant infrastructure | | mentioned | mentioned | mentioned | mentioned | N+3 | 5 | 5/5 | 5/5 | 4.5/5 | 5/5 | 4.5/5 |
| | 7-Possibility of modular expansion | | mentioned | mentioned | Not mentioned | Not mentioned | N+1 | 3 | 1.5/3 | 3/3 | 0/3 | 3/3 | 2/3 |
| | 8-Facade | | mentioned | mentioned | mentioned | mentioned | N+3 | 5 | 3.8/5 | 4.2/5 | 3.8/5 | 4/5 | 5/5 |
| | 9- Modular, replaceable and maintainable plant | | mentioned | mentioned | Not mentioned | Not mentioned | N+1 | 3 | 3/3 | 0/3 | 3/3 | 0/3 | 0/3 |
| | 10-The use of Building Automation and Control systems at building level | | mentioned | mentioned | Not mentioned | Not mentioned | N+1 | 3 | 0/3 | 3/3 | 0/3 | 0/3 | 3/3 |
| | 11-Restrictions | | Not mentioned | Not mentioned | mentioned | mentioned | 2+0 | 2 | 2/2 | 1.8/2 | 1.2/2 | 1.6/2 | 1.6/2 |
| | 12- Standardisation of spaces for functional units in the building | | mentioned | Not mentioned | Not mentioned | mentioned | N+1 | 3 | 1.5/3 | 3/3 | 1/3 | 2/3 | 2.5/3 |
| | 13- The possibility of expanding spaces inside the building | shell spaces | mentioned | mentioned | mentioned | mentioned | N+3 | 5 | 0 | 0 | 0 | 0 | 0 |
| | | already equipped spaces | Not mentioned | Not mentioned | mentioned | mentioned | 2+0 | 2 | 1.2/2 | 1/2 | .9/2 | 1/2 | .9/2 |
| | | volumes hanging from the façade | Not mentioned | Not mentioned | mentioned | mentioned | 2+0 | 2 | 2/2 | 0/2 | 0/2 | 0/2 | 0/2 |
| | | open ended corridor | mentioned | Not mentioned | Not mentioned | mentioned | N+1 | 3 | 3/3 | 3/3 | 0/3 | 1/3 | 1.5/3 |
| | 14- Use of the service floor (mechanical floor) | | mentioned | Not mentioned | Not mentioned | mentioned | N+1 | 3 | 3/3 | 3/3 | 3/3 | 3/3 | 3/3 |
| | 15-Opportunity for vertical mechanical equipment shafts in the future. . Fix a % of total surface area | | mentioned | Not mentioned | mentioned | Not mentioned | N+1 | 3 | - | - | - | - | - |
| | 16-Construction techniques | | mentioned | Not mentioned | mentioned | mentioned | N+2 | 4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 |
| | 17- Location of building plant | | Not mentioned | Not mentioned | mentioned | mentioned | 2+0 | 2 | 1.6/2 | 1.4/2 | 1.8/2 | 1.4/2 | 1.6/2 |
| | 18-Grouped vertical circulation elements | | mentioned | Not mentioned | Not mentioned | mentioned | N+1 | 3 | 3/3 | 3/3 | 3/3 | 3/3 | 3/3 |
| | 19-The possibility of exchanging large equipment | | Not mentioned | Not mentioned | mentioned | mentioned | 2+0 | 2 | 1.2/2 | 1.2/2 | 1.1/2 | 1.1/2 | 1.6/2 |
| | 20- The idea of soft and non-soft spaces | | mentioned | Not mentioned | Not mentioned | Not mentioned | n | 2 | 2/2 | 2/2 | 2/2 | 2/2 | 2/2 |
| | 21-Natural light | | mentioned | mentioned | Not mentioned | Not mentioned | N+1 | 3 | 3/3 | 3/3 | 3/3 | 3/3 | 3/3 |
| Functional Unit | 1-The use of internal dry partition walls | | mentioned | mentioned | mentioned | mentioned | N+3 | 5 | 5/5 | 5/5 | 5/5 | 5/5 | 5/5 |
| | 2-The use of moveable internal partitions | | mentioned | mentioned | Not mentioned | mentioned | N+2 | 4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **3- Internal partitions panels set up with plant infrastructure or The use of moveable internal walls and walls with wall-mounted fittings** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **N+3** | **5** | **5/5** | **5/5** | **5/5** | **5/5** | **5/5** |
| | **4- Possibility of extending the entire Functional Unit sideways** | **Not mentioned** | **mentioned** | **mentioned** | **Not mentioned** | **1+0** | **1** | **1/1** | **1/1** | **0/1** | **0/1** | **0/1** |
| | **5-Presence of verandas/setbacks** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **N+1** | **3** | **3/3** | **3/3** | **0/3** | **3/3** | **0/3** |
| | **6-Prefabricated items** | **mentioned** | **Not mentioned** | **mentioned** | **mentioned** | **N+2** | **4** | **4/4** | **4/4** | **4/4** | **4/4** | **4/4** |
| | **7-Plant with flexibility of use** | **mentioned** | **mentioned** | **mentioned** | **mentioned** | **N+3** | **5** | **5/5** | **4/5** | **5/5** | **4/5** | **4/5** |
| | **8-Multifunctional spaces** | **mentioned** | **mentioned** | **Not mentioned** | **mentioned** | **N+2** | **4** | **-** | **-** | **-** | **--** | **-** |
| **Individual Room** | **1- Functional flexibility of the room** | **mentioned** | **mentioned** | **Not mentioned** | **mentioned** | **N+2** | **4** | **3.5/4** | **3.8/4** | **4/4** | **3.5/4** | **3.5/47** |
| | **2-Generic/universal rooms** | **mentioned** | **Not mentioned** | **Not mentioned** | **mentioned** | **N+1** | **3** | **-** | **-** | **-** | **-** | **-** |
| | **3-Prefabricated rooms** | **mentioned** | **Not mentioned** | **Not mentioned** | **Not mentioned** | **n** | **2** | **0/2** | **0/2** | **2/2** | **0/2** | **0/2** |
| | **4- Information systems services for multifunctionality** | **Not mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **1+0** | **1** | **-** | **-** | **-** | **-** | **-** |
| | **5-The use of moveable furniture and vertical screening** | **mentioned** | **mentioned** | **Not mentioned** | **mentioned** | **N+2** | **4** | **4/4** | **4/4** | **4/4** | **4/4** | **4/4** |
| | **6-Customisable humanization of the room** | **mentioned** | **mentioned** | **Not mentioned** | **Not mentioned** | **N+1** | **3** | **3/3** | **3/3** | **3/3** | **3/3** | **3/3** |
| | **the total** | | | | | | | **112.6** | **117.7** | **98.2** | **109** | **112.3** |
| | **Total scores** | | | | | | | **145** | **145** | **145** | **145** | **145** |
| | **percentage** | | | | | | | **77.6 %** | **81 %** | **67.7 %** | **75 %** | **77 %** |

*Source: researcher*

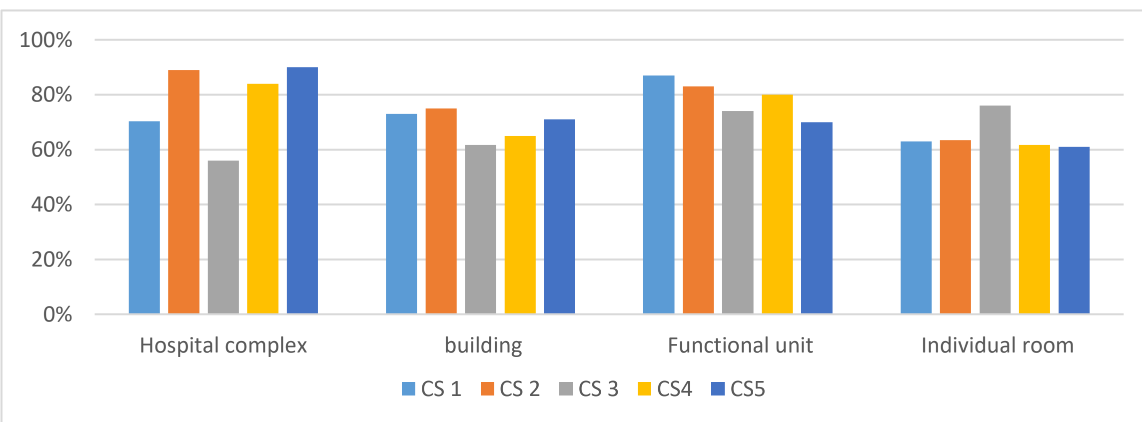


**Figure (1): Graph with percentage of evaluation criteria used the horizontal x axis lists the parameters included in the assessment tool for levels of flexibility (hospital complex, building, functional unit, single room), while on the vertical y axes, it is seen that each parameter is met based on the analysed case studies.**

### 4.2. Comparison between the original tool and the advanced tool and determining its effectiveness Advanced Flexibility Assessment Tool (AFAT)

The Advanced Flexibility Assessment Tool is designed to determine the degree to which the core principles of the concept of resilience are met. It was developed to assess resilience in healthcare facilities during the design and planning phases and provides a standard of control for hospital designers to enhance their proposals. Its application to the existing facilities helps to estimate the extent to which the building meets the standards and concepts of flexibility and what needs to be modified if necessary. The new tool consists of assessment parameters. Assessment parameters are categorised under four levels of flexibility, with each parameter divided into measurable variables with a score range of 0 to 5 (see table). Each rating parameter achieves a certain score that reflects the level of application of the principles of resilience, which helps determine the resilience of the building.

### 4.3. Comparison results between the original tool and the advanced tool

We tested the original tool (OBAT) on two hospitals selected from case studies previously assessed with the advanced tool (Martini Hospital and Karolinska Hospital). We validated the new instrument and simultaneously compared the scores for each evaluation parameter using both versions of the original and new instruments. For each of the two case studies, we aggregated the results from the newly created assessment along with the results of the original assessment. We also rated the building according to its rating score to determine whether and to what extent it met the open building criteria.

The new Assessment Tool was applied to Martini Hospital, and the overall assigned score was 77.6% (64/85); hence, it is classified as a flexible building, but with some aspects that need to be improved. The final results show that the total score assigned from the original assessment tool was 75%, and using the advanced tool, it was 77.6%. The new assessment tool was applied to New Karolinska Hospital, and the overall score assigned was 74.6 (63/86); hence, it is classified as a resilient building, but with some aspects to be improved. The final results show that the total score assigned from the original assessment tool is 74.6 using the modified score of 77.2. As shown in the following table:

| **Evaluation Parameters** | **CS1** | **CS5** |
|---|---|---|
| **Shape** | **6/10** | **6/10** |
| **Structure** | **6/9** | **4/9** |
| **Facade** | **4/10** | **10/10** |
| **Building Plant** | **8/9** | **7/8** |
| **Expandability** | **7/10** | **5/10** |
| **Restrictions** | **10/10** | **8/10** |
| **Technology** | **8/8** | **8/8** |
| **Exchangeability** | **8/10** | **8/10** |
| **Summary** | **57/76** | **56/75** |
| **Total score** | **75%** | **74.6%** |

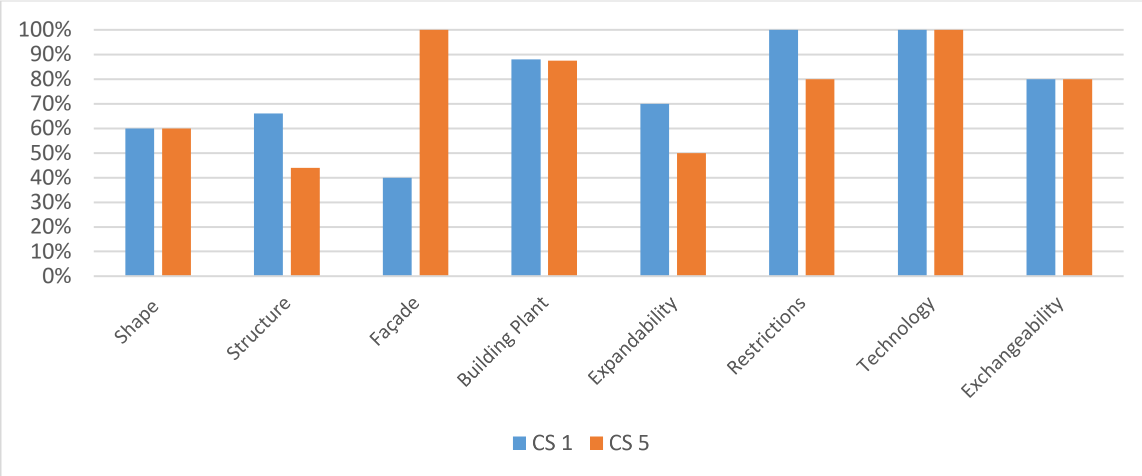


Figure 4: Percentage of original assessment criteria (OBAT) applied to two case studies

## 5. Results and Discussion

Hospitals are complex structures with a mixture of social, cultural, economic, technological, and architectural aspects. For healthcare facilities to fulfil their roles, it is essential that they should be planned and designed for the present and the future. Hospitals should be flexible with changing needs. While emphasising the importance of the building's flexibility, it is important to highlight other areas for improvement. Hospital buildings should have the capability to accommodate alterations in functions and not just be designed rigidly to serve a specific purpose. In fact, such approaches can only be addressed if participatory design and multidisciplinary cooperation between different fields, disciplines, and professions are in place[24].

We have made it clear by using the flexibility analysis matrix that it is the best for evaluating hospitals for their interest in the three types of flexibility (constant surface flexibility, variable surface flexibility, and operational flexibility) for the four levels of flexibility. Therefore, the researcher adopted the flexibility analysis matrix, but the researcher found that it neglected some important design criteria that achieve flexibility, including shape, restrictions, and the possibility of exchanging large equipment and technology, so the researcher deduced a new assessment tool (AFAT).

The new and advanced flexibility assessment tool consists of evaluation criteria classified under the four resilience levels. The global models were evaluated using the new advanced flexibility assessment tool (AFAT). The results were as follows: Martini Hospital scored 77.6%, Hospital University Akershus scored 81%, Miami Valley scored 67.7%, Sunshine Coast University Hospital got 75%, and New Karolinska Hospital got 77%. The researcher carried out a re-evaluation of two case studies, Martini Hospital and New Karolinska Hospital, using the original resilience assessment tool (OBAT) to determine the effectiveness of the new tool. The new assessment tool (AFAT) is designed to improve the degree to which core resilience principles are met in both the design and operational phases. We found that in two case studies, the AFAT app resulted in a more comprehensive assessment when compared to the older tool.

## 6.Conclusions

We used a five-step research methodology that included reviewing the literature on flexibility and levels of flexibility, reviewing flexibility assessment tools and comparing them, and then deducing an advanced assessment tool, which the researcher called the Advanced Flexibility Assessment Tool (AFAT), and testing the advanced tool and determining its effectiveness by evaluating five international studies. And the comparison between the results of the advanced flexibility assessment tool for case studies and the results of the original tool.

Indeed, the emerging changes in technology and the continuous improvement of scientific and medical knowledge require hospitals to adapt over time to their formal and functional structures. There is an urgent need to increase flexibility and create buildings that are not very complicated but flexible in the short, medium, and long term. More is needed. Through long-term research, our findings led to the development of an assessment tool to assess the extent to which a healthcare facility meets the resilience principles.

**References:**

1- Astley, S. Capolongo, M. Gola, and A. Tartaglia, "Adattabilità operativa e progettuale nelle strutture sanitarie," *Techne*, vol. 9, pp. 162–170, 2015, doi: 10.13128/Techne-16118.
2- Y. Liu *et al.*, "Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals," *Nature*, vol. 582, no. 7813, pp. 557–560, 2020, doi: 10.1038/s41586-020-2271-3.
3- S. Capolongo, M. Gola, A. Brambilla, A. Morganti, E. I. Mosca, and P. Barach, "COVID-19 and healthcare facilities: A decalogue of design strategies for resilient hospitals," *Acta Biomed.*, vol. 91, no. 1, pp. 50–60, 2020, doi: 10.23750/abm.v91i9-S.10117.
4- P. M. Di Battista V, Fontana C, *Flessibilità e riuso*. Firenze, 1995.
5- S. Caplango, *Architecture for flexibility in healthcare.*, FrancoAnge. Milano, 2012.
6- M. Buffoli, D. Nachiero, and S. Capolongo, "Flexible healthcare structures: analysis and evaluation of possible strategies and technologies.," *Ann. Ig.*, vol. 24, no. 6, pp. 543–552, 2012.
7- G. Jane Carthey, BArch, MPM,Vivien Chow, BArch, MPD, Susan Mills, BA, "Flexibility: Beyond the Buzzword—Practical Findings from a Systematic Literature Beview," *HERD Heal. Environ. Res. Des. J.*, vol. 4, no. 4, pp. 89–108, 2011.
8- C. C. Debajyoti Pati, Tom Harvey, "Inpatient Unit Flexibility: Design Characteristics of a Successful Flexible Unit," *Environ. Behav.*, vol. 40, no. 2, pp. 205–232, 2008, [Online]. Available: https://doi.org/10.1177/0013916507311549.
9- M. Bjørberg, S.,&Verweij, "Life-cycle economics: cost, functionality and adaptability," *Invest. Hosp. Futur.*, pp. 145–166, 2009.
10- J. Van Der Zwart and Theo J. M. Van Der Voordt, "Adding Value by Hospital Real Estate: An Exploration of Dutch Practice," *HERD Heal. Environ. Res. Des. J.*, vol. 9, no. 2, pp. 52–68, 2016, [Online]. Available: https://doi.org/10.1177/1937586715592649.
11- T. Del Gatto, M. L., Morena, M., & Truppi, "Organizational models for the flexible management of hospitals," *TECHNE-Journal Technol. Archit. Environ.*, pp. 147–154, 2015.
12- P. A. Prugsiganont, S., & Jensen, "dentification of space management problems in public hospitals: the case of Maharaj Chiang Mai Hospital," *Facilities*, vol. 37, no. 7, pp. 435–454, 2018.
13- J. Maben, J., Griffiths, P., Penfold, C., Simon, M., Anderson, J. E., Robert, G., ... & Barlow, "One size fits all? Mixed methods evaluation of the impact of 100% single-room accommodation on staff and patient experience, safety and costs," *BMJ Qual. Saf.*, vol. 25, no. (4), pp. 241–256,

2016.
14- M. Capolongo, S., Buffoli, M., Nachiero, D., Tognolo, C., Zanchi, E., & Gola, "Open building and flexibility in healthcare: strategies for shaping spaces for social aspects," *Ann. Ist. Super. Sanita*, vol. 52, no. 1, pp. 63–69, 2016.
15- G. Guenther, R., & Vittori, *Sustainable healthcare architecture*. John Wiley & Sons, 2008.
16- A. Brambilla *et al.*, "Flexibility during the covid-19 pandemic response: Healthcare facility assessment tools for resilient evaluation," *Int. J. Environ. Res. Public Health*, vol. 18, no. 21, 2021, doi: 10.3390/ijerph182111478.
17- L. Thomas, "Flexibility & Adaptability in Hospital Design & Construction," no. November, 2010, [Online]. Available: https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/ dist/a/3723/ files/2013/09/ Flexibility -adaptability-in-hospital-design-construction-1twhvzo.pdf.
18- R. Guenther and G. Vittori, *Sustainable healthcare architecture*, John Wiley. New York, 2008.
19- A. H. Babbu, "'Flexibility': A key concept in Hospital Design," *Int. J. Appl. or Innov. Eng. Manag.*, vol. 5, no. 5, pp. 24–28, 2016.
20- S. H. Kendall, P. Investigator, T. D. Kurmel, and J. A. Becker, "Healthcare Facilities Design For Flexibility : A Report On Research For The National Institute of Building Sciences," no. December, pp. 1–10, 2012.
21- J.-Y. Lee and K.-D. Song, "The daylighting effects in hospital for healing patients," *Proc. Int. Conf. Sustain. Build. Asia*, pp. 869–874, 2007.
22- A. Gigantesco and and M. Giuliani, "Quality of life in mental health services with a focus on psychiatric rehabilitation practice," *Ann Ist Super Sanità*, vol. 47, no. 4, pp. 363–372, 2011, doi: 10.4415/ANN.
23- "Miami Valley Hospital a New Chapter on Efficiency."
24- N. Azzopardi-Muscat, A. Brambilla, F. Caracci, and S. Capolongo, "Synergies in design and health. The role of architects and urban health planners in tackling key contemporary public health challenges," *Acta Biomed.*, vol. 91, no. 7, pp. 9–20, 2020, doi: 10.23750/abm.v91i3-S.9414.