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Hospital Architecture Adaptability: A Systematic Analysis of Concepts, Implementation, and Measuring Tools

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ABSTRACT

Keywords: architectural adaptability, hospital, systematic review, adaptability measuring instrument, building resilience.

This study aims to explore the concept of adaptability in hospital architecture through a systematic literature review. The methodology used is a Systematic Literature Review (SLR) with the PRISMA approach, utilizing the Watase Uake platform for the analysis of 26 selected articles published between 2015 and 2024. The results show that the need for adaptability of hospital architecture is driven by advances in medical technology, demographic changes, and learning from the COVID-19 pandemic. The findings reveal that the implementation of modular design, the separation of building systems into independent layers, and the integration of information technology can facilitate building adaptation. The development of measuring tools from a simple qualitative approach to comprehensive models such as GAAT, MEDICINE, and OFAT that are specifically designed for health facilities. However, its implementation still faces gaps, especially in different local contexts. This research contributes to the understanding of the importance of adaptability in hospital design and highlights the need for the development of more specific measuring tools for the Indonesian context.

Introduction

Buildings are dynamic objects that continue to change over time. As Sir Winston Churchill expressed in his speech at a meeting in the House of Lords (1943), "We shape our buildings, and after that, our buildings shape us," which hints that buildings continue to transform with the changes in their occupants (Aitchison, 2014). In his book, Stewart Brand also states that "First we shape our buildings, then they shape us, then we shape them again endlessly. Function changes form, continuously," emphasizing that the interaction between function and form of a building is a continuous process (Brand & Stewart, 1994). Stewart Brand, says that "All buildings are predictions. All predictions are wrong." This concept is especially relevant because society is facing unprecedented and accelerating trends, such as urbanization, political instability, terrorism activities, climate change, health, and technological transformation. Therefore, there is an interest in adaptability, especially since it is difficult to predict the changes that require adaptation.

The literature on building adaptability covers a wide range of sources and disciplines, including architecture, engineering, facilities management, and planning. However, there are still various interpretations of the types of changes covered by adaptability. In general, the three types of changes that are often mentioned are usage, physical layout, and size (Abd-Alhady et al., 2024). Building adaptability is essential to ensure optimal use despite changes in user or regulatory needs. Adaptive buildings offer adaptability to change functions and spatial layouts according to future needs (Langston & Smith, 2012). According to Stewart Brand in his book "How Buildings Learn," a building's ability to adapt to change is critical. He highlighted how various factors such as technology, business, and trends continue to influence changes in buildings. Meanwhile, James Douglas in the second edition of his book "Building Adaptation" specifically discusses building adaptation. Douglas explains that "Buildings designed to adapt will continue to follow changes over time so that the structure and facilities can be continuously updated without the need to make a complete change."

The concept of building adaptability has become the main focus of various cross-disciplinary research. Previous studies have revealed a significant correlation between building adaptability and sustainability aspects of the built environment. Adaptive buildings have the potential to extend the life of the structure through the reuse of space, elements, and materials, which in turn can minimize the need for demolition (Abd-Alhady et al., 2024). Recent research shows that a high level of adaptability can reduce the risk of building obsolescence and reduce long-term carbon costs. However, literature that discusses the concept of adaptability is still fragmented and spread across various scientific fields, including architecture, engineering, and environmental science. A comprehensive analysis of the factors affecting building adaptability is crucial to understanding the effectiveness of current strategies in facing global challenges as well as identifying potential opportunities.

The importance of adaptability in architecture can be seen from several aspects. First, in terms of sustainability, adaptive buildings tend to have a longer lifespan, reducing the need for repetitive demolition and reconstruction. This is in line with the principles of sustainable development put forward by (Kohler & Hassler, 2002). Second, from an economic perspective, adaptability can result in long-term cost savings by reducing the need for major renovations or relocations. Demographic changes, work patterns, and lifestyles demand spaces that can quickly adapt to changing needs. As argued by (Brand & Stewart, 1994) in their work "How Buildings Learn", buildings that cannot adapt tend to become obsolete faster, leading to the waste of resources and energy. In the context of climate change and natural disasters that are becoming more frequent, building adaptability is also important for resilience and safety. Adaptive design can allow buildings to respond better to changing environmental conditions. (Bosher et al., 2007) emphasizes the importance of integrating disaster resilience considerations in the architectural design process.

In general, changes in the function of space are common activities in building construction. Many factors can affect changes in the function of a space, such as changes in user needs, trends of the times, or applicable regulations by taking into account the typology of the building. Building typology is the study of the classification and characteristics of various types of buildings based on function, shape, and structure. In the context of architecture, typology serves as an analytical tool to understand the general and specific patterns of various types of buildings. According to (Ching, 2014), architectural typology can be divided into several main categories such as residential, commercial, institutional, industrial, and recreational. Each of these categories has a more specific sub-typology, reflecting the diversity of needs and functions within the built environment.

Recent developments in architecture have also given rise to new sub-typologies. According to (Hensel & Nilsson, 2016), sub-typologies have emerged that respond to contemporary issues such as green buildings, parametric architecture, and smart buildings. This reflects how architectural typologies are constantly evolving in response to technological and social changes. In the context of building typologies, hospitals as part of advanced healthcare facilities require an adaptive and evidence-based design approach. Hospitals are included in the institutional category (Ching, 2014) and are an important component of the health service system. The concept of flexible architecture put forward by (Kronenburg, 2007) is particularly relevant in modern hospital planning, given the need to accommodate changes in function without significant structural modifications. The structure of this study is arranged as follows: Part 2 describes the research methodology used to achieve the objectives of this study, as well as the research design applied to analyze the findings. Part 3 presents and discusses the main findings organized into three main themes. Part 4 presents a closing discussion and identifies research questions that are still open. Part 5 summarizes the overall findings and concludes the study. Through this systematic approach, this review is expected to make a significant contribution to the understanding and development of adaptability in hospital building design, as well as become a foundation for further research in this area.

Method

Literature Review Approach

This study uses the Systematic Literature Review (SLR) method to explore existing knowledge and identify gaps in the field of hospital architectural adaptability. SLR is a structured and transparent method, designed to identify, assess, and synthesize the results of various studies relevant to a particular topic, thus allowing researchers to obtain a holistic and comprehensive view of the existing literature.

This study uses Watase Uake as an online research collaboration platform to carry out a Systematic Literature Review (SLR). Developed by Lilik Wahyudi in 2018 and expanded in 2020, Watase Uake is designed to facilitate collaboration between researchers and support the principles of open science. The platform was chosen because of its ability to extract and classify data from various literature sources, which is crucial in the SLR process.

The authors utilize Watase Uake's automated feature to identify and categorize key information from each article, in line with recommendations (Okoli, 2015) to improve efficiency and consistency in the SLR process. The classification feature helps organize literature based on themes, methodologies, or other criteria relevant to the research question. One of the advantages of Watase Uake is its ability to facilitate real-time collaboration between researchers, improving the reliability of results through review and validation by several researchers. This feature allows for efficient cross-checking, discussion, and joint decision-making, even though the research team is spread across various geographic locations. Through Watase Uake, authors can conduct a more in-depth and comprehensive analysis of the literature. The model construction feature helps identify patterns and trends, while the gap analysis feature allows for the identification of under-explored areas.

This is in line with the main goal of SLRs to summarize existing knowledge and identify gaps for future research. To improve transparency and reporting quality, the authors adopted the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Using the PRISMA approach to article selection reporting, this review assesses the current state of knowledge about the adaptability of hospital buildings in the literature, the main drivers and associated obstacles, as well as previously suggested strategies in their implementation. The PRISMA approach involves a systematic search and synthesis of systematic research findings from various studies to produce a comprehensive summary of the findings. This approach consists of 27 checklists and a 4-phase flowchart to sift through articles and gather insights from a collection of articles. This diagram illustrates the number of records identified, duplicates removed, filtered records, full-text articles assessed, and studies that were ultimately included in the review.

The PRISMA approach method was chosen over other methods because of its strict structure that ensures the reliability and validity of the flow and review process. The authors also follow the recommendations of PRISMA 2020 in reporting on search strategies, eligibility criteria, data extraction processes, and bias risk assessments.

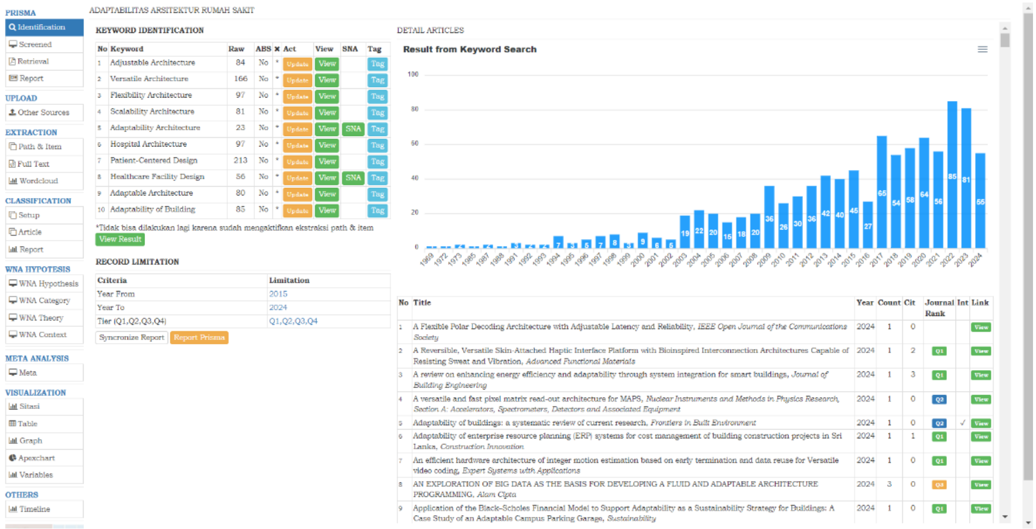
Stages of Systematic Literature Review

The initial stage of this SLR is to establish a solid foundation through the formulation of the background of the problem and the development of the rationalization of the selected theme. This research focuses on the issue of building obsolescence caused by multidimensional changes, a problem that has been comprehensively described in the introduction. The urgency of building adaptability and its relevance in dealing with changing dynamics has been elaborated, confirming the significance of this study.

Results and Discussion

Identification

The identification stage has been carried out in the process of reviewing the systematic literature regarding the adaptability of hospital architecture, using the Watase Uake platform, a systematic search was carried out on the Scopus database with a focus on indexed articles from Q1 to Q4. The keywords used (Figure 1), based on the theory of Schmidt III and Austin (2016), cover various aspects of architectural adaptability associated with hospital buildings.



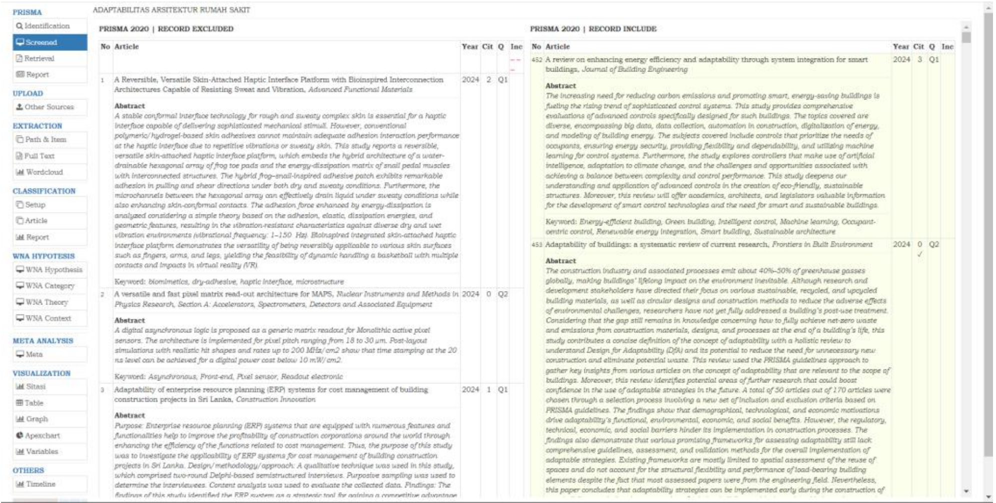
Picture 1
Results of the Identification Stage
Source: Watase Uake Platform, 2024

This identification process is limited to English-language publications from 2015 to 2024, to capture the development of the concept of adaptability over the past decade. The Watase Uake platform provides a variety of features that facilitate comprehensive analysis, including visualization of annual publication histograms, Social Network Analysis (SNA) to map relationships between keywords, and keyword frequency analysis.

As a result of this identification stage, the authors obtained (n=982) articles from 10 keywords "adjustable architecture", "versatile architecture", "flexibility architecture", "scalability architecture", "adaptability architecture", "hospital architecture", "patient-cent"ered design", "healthcare facility design", "adaptable architecture", "adaptability of building". Then the platform deletes the raw article which is duplicated as many as (n=157) articles so that there is no double review of the article. A total of (n=310) articles are automatically deleted because they do not meet the period set by the author, namely 2015 to 2024. Then the platform automatically deletes as many as (n=21) articles that do not include the Scopus Q1, Q2, Q3, and Q4 index rankings. Finally, the platform removed as many (n=15) articles that were not accompanied by an abstract. From these results, it is relevant to proceed to the screening stage as many (n=479) articles will be discussed at the screening stage. The platform displays the results in the form of a histogram of the publication year of article discovery based on keywords (Figure 1) with the most occurrences in 2022 as many as (n=85) articles that discuss keywords. The discovery of the results of the identification stage has been automatically recorded at the reporting stage with the PRISMA method.

Filtering

After carrying out the identification stage, the next stage is screening. The screening criteria applied include conformity with the main topic of adaptability of hospital architecture, both in the context of emergencies and long-term planning.



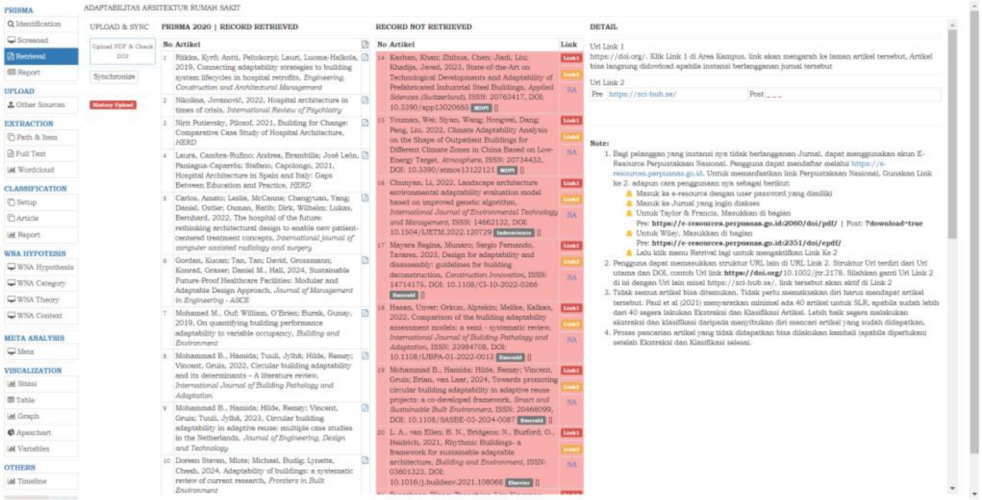
Picture 2
Results of the Screening Stage
Source: Watase Uake Platform, 2024

Articles that pass this stage must meet several specific criteria, including the use of key concepts such as "adaptability", "flexibility", and "resilience", as well as following the IMRAD structure (Table 1.2). This screening also considers technical aspects such as the length of the title and the clarity of the language. This process is carried out systematically, with each article being evaluated and categorized as "relevant" or "irrelevant" based on predetermined criteria.

The results obtained after the identification stage were (n=479). Then start reviewing the article by looking at the title, abstract, and keywords according to the rules that have been set (Table 1.2). At this screening stage, the author stated that as many (n=451) articles were irrelevant, and as many (n=28) articles were declared relevant (Figure 2). Articles that have been declared relevant are automatically eligible for the retrieval stage which will be presented after this screening stage and the results will be automatically recorded at the reporting stage using the PRISMA method.

Retrieval

After carrying out the screening stage, the next stage is retrieval. The recruitment criteria include the context of the built environment, the type of intervention, the research methodology, and the scope of the relevant field. The use of Digital Object Identifiers (DOIs) facilitates direct access to article sources, while additional URLs for databases such as the National Library improve accessibility, especially for open-access articles.

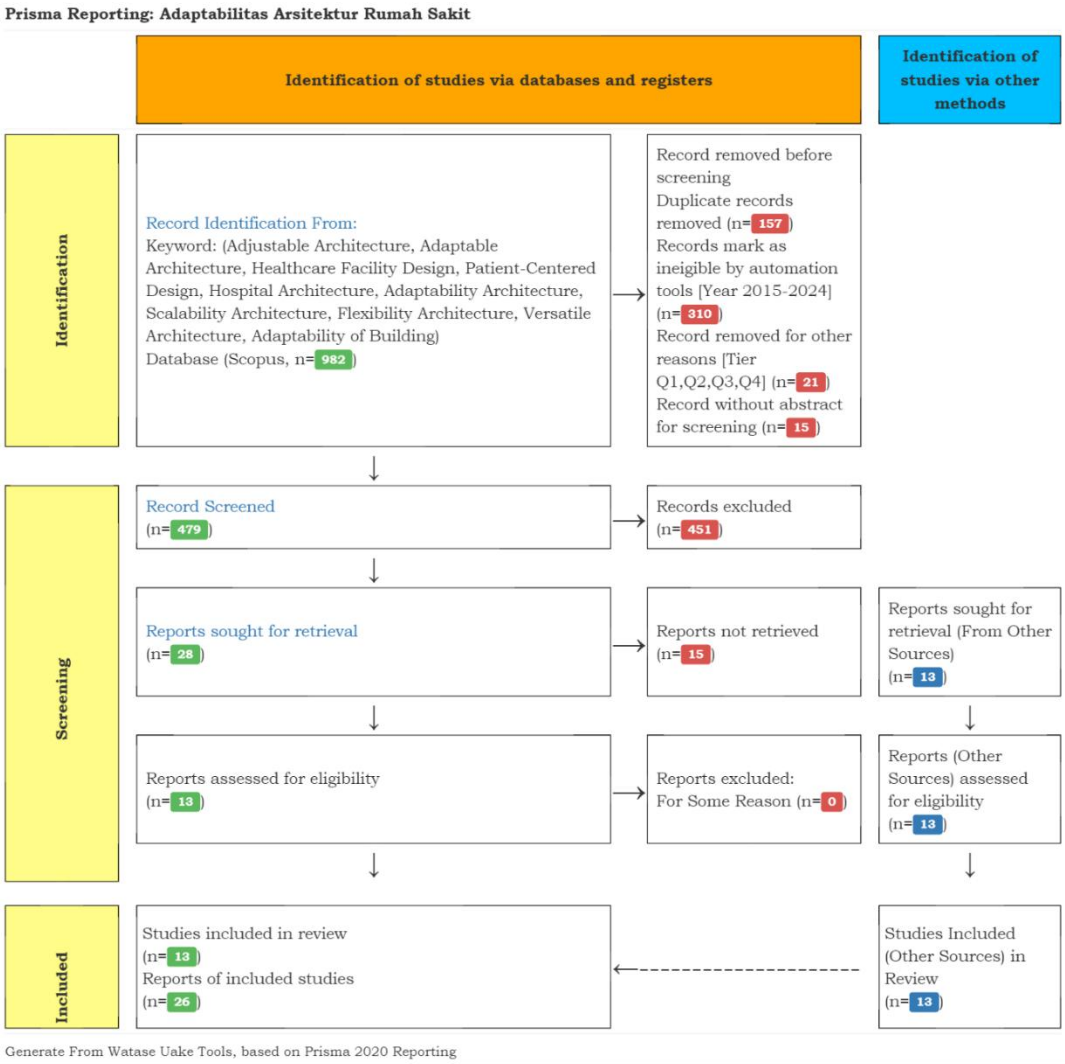


Picture 3
Results of the Recruitment Stage
Source: Watase Uake Platform, 2024

In this collection stage, there are 2 stages, namely the collection stage from Watase Uake and the extraction stage from other sources (*other sources*). The results obtained by the author after carrying out this stage of collection are as many as (n=13) worthy articles and as many as (n=15) unworthy articles. Then the author along with this stage, the author adds articles that have gone through identification and filtering from outside the platform as much as (n=13). These results have been automatically recorded at the reporting stage with the PRISMA method.

Reporting

After doing the previous stage, the next stage is reporting. At this stage, the author does not do it manually but has been automatically recorded by the platform, so this can make it easier for the author to know the results of the processing that has been done from the previous stage and reduce errors in the results that have been found. The PRISMA method was chosen because of its ability to present a transparent and structured literature selection flow, allowing readers to understand the article selection process from the initial identification stage to the final inclusion. This visualization includes the number of articles identified, filtered, and ultimately included in the review, providing a clear picture of the rigor and depth of the selection process.

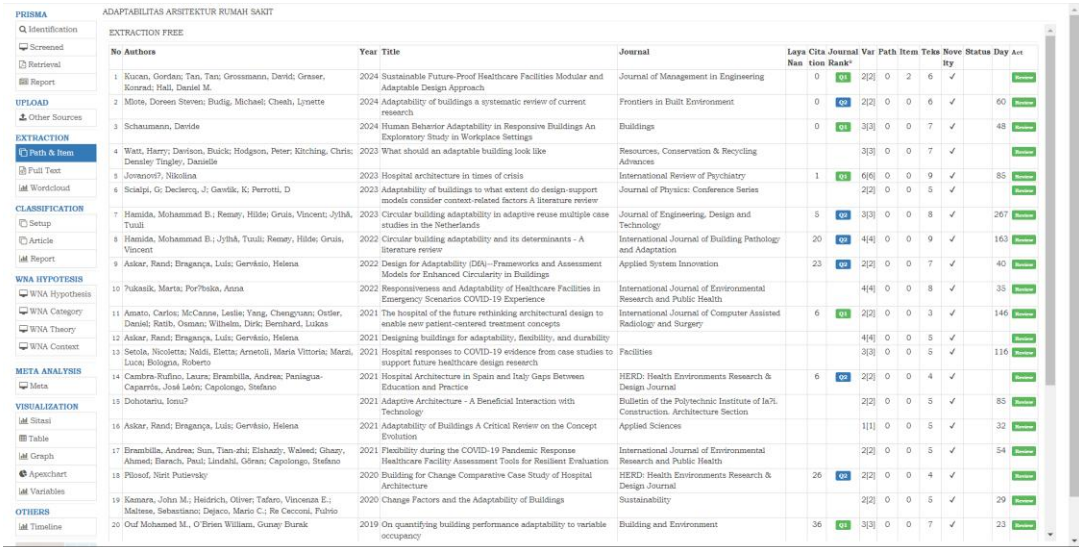


Picture 4 Results of the Reporting Stage (Report)
Source: Watase Uake Platform, 2024

The results of the reporting stage are the results of automated reporting provided by the platform from the identification, filtering, and retrieval stages. From this stage, the author gets articles with a total of (n-26) articles. The results will be extracted at the data extraction stage to review each article.

Data Extraction

The last stage of SLR is data extraction including the identification and categorization of various key elements such as key variables, hypotheses, research methodologies, study contexts, and significant findings. This process follows pre-defined protocols, as outlined in Table 1.5, to ensure consistency and thoroughness in information collection.



No	Authors	Year	Title	Journal	Laya Nan	Cita tion	Journal Rank*	Var	Path	Item	Teks	Nove lty	Status	Day	Act
1	Kucan, Gordan; Tan, Tan; Grossmann, David; Graser, Konrad; Hall, Daniel M.	2024	Sustainable Future-Proof Healthcare Facilities Modular and Adaptable Design Approach	Journal of Management in Engineering		0	Q1	2[2]	0	2	6	✓			
2	Mlote, Doreen Steven; Budig, Michael; Cheah, Lynette	2024	Adaptability of buildings a systematic review of current research	Frontiers in Built Environment		0	Q2	2[2]	0	0	6	✓		60	
3	Schaumann, Davide	2024	Human Behavior Adaptability in Responsive Buildings An Exploratory Study in Workplace Settings	Buildings		0	Q1	3[3]	0	0	7	✓		48	
4	Watt, Harry; Davison, Buick; Hodgson, Peter; Kitching, Chris; Densley Tingley, Danielle	2023	What should an adaptable building look like	Resources, Conservation & Recycling Advances				3[3]	0	0	7	✓			
5	Jovanovi?, Nikolina	2023	Hospital architecture in times of crisis	International Review of Psychiatry		1	Q1	6[6]	0	0	9	✓		85	
6	Scialpi, G; Declercq, J; Gawlik, K; Perrotti, D	2023	Adaptability of buildings to what extent do design-support models consider context-related factors A literature review	Journal of Physics: Conference Series				2[2]	0	0	5	✓			
7	Hamida, Mohammad B.; Remøy, Hilde; Gruis, Vincent; Jylhä, Tuuli	2023	Circular building adaptability in adaptive reuse multiple case studies in the Netherlands	Journal of Engineering, Design and Technology		5	Q2	3[3]	0	0	8	✓		267	
8	Hamida, Mohammad B.; Jylhä, Tuuli; Remøy, Hilde; Gruis, Vincent	2022	Circular building adaptability and its determinants - A literature review	International Journal of Building Pathology and Adaptation		20	Q2	4[4]	0	0	9	✓		163	
9	Askar, Rand; Bragança, Luís; Gervásio, Helena	2022	Design for Adaptability (DfA)--Frameworks and Assessment Models for Enhanced Circularity in Buildings	Applied System Innovation		23	Q2	2[2]	0	0	7	✓		40	
10	?ukasik, Marta; Por?bska, Anna	2022	Responsiveness and Adaptability of Healthcare Facilities in Emergency Scenarios COVID-19 Experience	International Journal of Environmental Research and Public Health				4[4]	0	0	8	✓		35	
11	Amato, Carlos; McCanne, Leslie; Yang, Chengyuan; Ostler, Daniel; Ratib, Osman; Wilhelm, Dirk; Bernhard, Lukas	2021	The hospital of the future rethinking architectural design to enable new patient-centered treatment concepts	International Journal of Computer Assisted Radiology and Surgery		6	Q1	2[2]	0	0	3	✓		146	
12	Askar, Rand; Bragança, Luís; Gervásio, Helena	2021	Designing buildings for adaptability, flexibility, and durability					4[4]	0	0	5	✓			
13	Setola, Nicoletta; Naldi, Eletta; Arnetoli, Maria Vittoria; Marzi, Luca; Bologna, Roberto	2021	Hospital responses to COVID-19 evidence from case studies to support future healthcare design research	Facilities				3[3]	0	0	5	✓		116	
14	Cambra-Rufino, Laura; Brambilla, Andrea; Paniagua-Caparrós, José León; Capolongo, Stefano	2021	Hospital Architecture in Spain and Italy Gaps Between Education and Practice	HERD: Health Environments Research & Design Journal		6	Q2	2[2]	0	0	4	✓			
15	Dohotariu, Ionu?	2021	Adaptive Architecture - A Beneficial Interaction with Technology	Bulletin of the Polytechnic Institute of Ia?i. Construction. Architecture Section				2[2]	0	0	5	✓		85	
16	Askar, Rand; Bragança, Luís; Gervásio, Helena	2021	Adaptability of Buildings A Critical Review on the Concept Evolution	Applied Sciences				1[1]	0	0	5	✓		32	
17	Brambilla, Andrea; Sun, Tian-zhi; Elshazly, Waleed; Ghazy, Ahmed; Barach, Paul; Lindahl, Göran; Capolongo, Stefano	2021	Flexibility during the COVID-19 Pandemic Response Healthcare Facility Assessment Tools for Resilient Evaluation	International Journal of Environmental Research and Public Health				2[2]	0	0	5	✓		54	
18	Pilosof, Nirit Putievsky	2020	Building for Change Comparative Case Study of Hospital Architecture	HERD: Health Environments Research & Design Journal		26	Q2	2[2]	0	0	4	✓			
19	Kamara, John M.; Heidrich, Oliver; Tafaro, Vincenza E.; Maltese, Sebastiano; Dejaco, Mario C.; Re Cecconi, Fulvio	2020	Change Factors and the Adaptability of Buildings	Sustainability				2[2]	0	0	5	✓		29	
20	Ouf Mohamed M., O'Brien William, Gunay Burak	2019	On quantifying building performance adaptability to variable occupancy	Building and Environment		36	Q1	3[3]	0	0	7	✓		23	

Picture 5 Results of the Data Extraction Stage
Source: Watase Uake Platform, 2024

Through systematic data extraction, this study aims to uncover patterns, trends, and relationships between concepts in the literature on the adaptability of hospital architecture. The results of this stage will form the basis for in-depth analysis and synthesis of findings, which in turn will allow for a more comprehensive understanding of the state of the art in this field, as well as identify knowledge gaps and potential directions for future research.

Why do we need adaptable buildings?

Based on the results of the literature, the need for adaptive buildings has emerged in response to various contemporary challenges in the built environment. Stated that the construction industry contributes to 40-50% of global greenhouse gas emissions, so a more sustainable approach to building design is needed. Adding non-adaptive buildings tend to experience premature obsolescence, resulting in premature demolition and waste of resources. This is supported by findings showing that up to 60% of building demolition is caused by obsolescence, not structural damage (Askar et al., 2021).

Adaptive buildings allow for the reuse and recycling of building components, which contributes to environmental sustainability and resource efficiency. Adding a circular economy dimension, where building adaptability facilitates a closed material cycle and reduces construction waste. Meanwhile, it states that adaptive design can balance the short-term carbon reduction needs with the long-term durability of buildings. It also underscores the importance of adaptability in the face of increasingly rapid lifestyle and technological changes. This is in line with the view that predictions needs of buildings are often inaccurate, so adaptability is key in dealing with such uncertainty (Andrade & Bragança, 2019); (Gosling et al., 2013); (Hamida et al., 2023). In particular, adaptability in hospital design, especially emergency rooms, is becoming increasingly important given the changing dynamics of health services. Hospital designs are designed as a collection of individual departments, with limited communication and collaboration between medical sub-specialties that actually hinder service efficiency and capacity, thus harming patients. This was evident during the COVID-19 pandemic, where it was found that many healthcare facilities had difficulty responding to the surge in patients due to limited spatial flexibility (Amato et al., 2022).

Rapid advances in technology and medical procedures have put great pressure on health facilities, especially emergency rooms which are at the forefront of services. Added that emergency rooms must be able to adapt quickly to various crisis scenarios, ranging from pandemics to natural disasters. Reinforcing this argument by stating that modular and adaptive design approaches can improve the resilience of healthcare facilities in the face of unexpected future challenges. Therefore, adaptability in emergency room design is not only about operational efficiency but also about the ability to provide optimal service in various emergency conditions.

What factors make building adaptation necessary?

Adaptable buildings are needed to avoid obsolescence and sustainability of the building life cycle, so it is necessary to know what factors make building adaptation necessary. There are several factors that drive the need for building adaptation.

Factors such as rapid technological advancement and innovation in medical practice pose challenges to the construction and management of facilities. This is especially relevant for healthcare facilities, where obsolescence occurs faster due to technological developments before their physical life cycle ends. From demographic and social aspects, changes in building occupancy patterns occur due to trends such as (Kyrö et al., 2019) Teleworking, co-working, and home-sharing, which changed the way space is used. Economic factors also play an important role, where non-adaptive buildings tend to experience premature obsolescence, leading to high vacancy rates and premature demolition which has implications for increased costs. From an environmental perspective, the construction sector contributes significantly to greenhouse gas emissions and waste generation, so the adaptation of existing buildings is preferable to demolition and new construction. Finally, crises such as the COVID-19 pandemic have shown the importance of building adaptability in responding to public health emergencies. All these factors emphasize that building adaptability is not only about building systems but also a response to various external factors that affect the function and use of buildings in the long term.

In the specific context of hospitals, especially Emergency Departments (ERs), building adaptation has several interrelated factors. Experience from the COVID-19 pandemic has shown that healthcare facilities must be able to adapt quickly to unexpected patient surges and the need to separate the flow of infectious patients. In addition, the ever-evolving development of medical procedures and healthcare technology requires that emergency rooms have the flexibility to accommodate new equipment and changes in clinical workflows. The aspect of operational efficiency is also an important consideration, where the layout of the emergency room must be modifiable to optimize response time and medical staff workflow. Emphasized that the design of an adaptive emergency room should consider the need for isolation of specific areas, ease of access, and the ability to change the capacity of the space as needed. These factors show that emergency room adaptability is not only about responding to emergencies but also about ensuring the sustainability and effectiveness of long-term health services.

What things make building adaptation easy to do?

Building adaptation can be easily done when several key factors have been considered from the initial design stage. The separation of the building system into layers (layers) is one of the important strategies that allows modifications to one part without affecting the other. The modular design and the use of standard components also contribute to the ease of adaptation, as it allows disassembly and reassembly with minimal damage. According to, the flexibility of the space configuration, especially the area free of structural elements, as well as the spare capacity in the building system are the main supporting factors for adaptability. Complete and accurate documentation of the building, including information on the materials and systems used, also facilitates the process of future adaptation (Mlote et al., 2024); (Gosling et al., 2013). (Hamida et al., 2023) emphasized that the ease of adaptation is also determined by the use of mechanical connections that can be disassembled, the accessibility of building components for maintenance and replacement, and the design that allows vertical and horizontal expansion. Information technology support such as Building Information Modeling (BIM) and effective facility management systems also play an important role in facilitating adaptation. In addition to the technical aspect, it was revealed that non-technical factors such as organizational willingness, availability of funds, and policy support also greatly determine the ease of building adaptation. The integration of all these factors from the planning stage will result in buildings that are more adaptable to changing needs in the future.

In the context of hospital building adaptation, especially emergency rooms, the ease of adaptation depends on several important aspects. states that the layout adopts the concept of (Amato et al., 2022) Patient Hub, where all critical functions occur on the same floor, can facilitate adaptation as it reduces waiting times and patient transfers. Studies by show that the modular design and use of prefabricated systems allow for quick changes to the emergency room configuration as needed, especially when dealing with patient surges. added that the systematic separation between clinical and non-clinical areas, as well as the flexibility in zoning facilitate the adaptation of emergency rooms to various emergency scenarios. Ease of adaptation is also supported by a clear circulation system, separate access for different types of patients, and the integration of information technology that allows for the monitoring and management of the space in a timely manner.

How to measure the success of building adaptation?

Discussions on measuring the success of building adaptation are important in the context of global challenges to environmental sustainability, functional obsolescence, and changing social and technological needs. The success of building adaptation can be measured through various aspects that are integrated with each other. According to , these measurements include functional evaluations that assess the extent to which buildings can meet user needs after the adaptation process. The economic aspect is also an important indicator, where property values and post-adaptation rates of return on investment are key considerations. In addition, environmental sustainability is a crucial parameter in measuring the success of adaptation, which can be seen from energy efficiency, carbon emission reduction, and more optimal use of resources.

The technical quality of post-adaptation buildings also needs to be evaluated, including the structural strength, safety, and reliability of the building system. emphasizing the importance of assessing the economic life of buildings that are extended through adaptation. The socio-cultural aspect is no less important, where the success of adaptation can be measured by the level of user acceptance, suitability to the local context, and the preservation of historical values where relevant.

Evaluation of building adaptation success must also consider long-term flexibility and adaptability. This includes the building's ability to accommodate future changes in function without requiring major modifications. This measurement of success should be carried out comprehensively and continuously, taking into account feedback from building users and regular monitoring of building performance to ensure the effectiveness of the adaptations that have been made.

From these various approaches, it can be concluded that the success of building adaptation can be measured through a comprehensive evaluation that includes physical aspects of the building, operational efficiency, transformation capabilities, and responsiveness to user needs. However, it is reminded that the measurement of adaptation success needs to consider local contexts and non-physical factors such as policy, economic, and socio-cultural factors that can influence the implementation of building adaptation strategies (Askar et al., 2021).

How is the development of the adaptation measuring tool in buildings?

Adaptation measuring instruments in buildings have undergone significant development. Initially, the development of adaptability was still qualitative and limited to the physical aspects of the building. But over time, the evaluation approach has become more comprehensive by considering various factors. Building adaptation measuring instruments are as follows.

1. Adaptive Reuse Potential (ARP) is an approach that uses a formula to measure the extent to which obsolescence can reduce the useful life of a building; (Langston & Shen, 2007)
2. The Adaptable Building Design Framework (ABD) (ALLAHAIM et al., 2010) examines a building's ability to adapt to future uncertainties, including market changes;
3. iconCUR (Langston & Smith, 2012) is a conceptual framework that evaluates the obsolescence of a building to understand the potential for adaptation of a building;
4. adaptSTAR (Conejos et al., 2013) is a star-based scoring system that considers factors related to buildings and the context in which they were built;

5. A building adaptation Causal Loop Diagram (CLD) (Gosling et al., 2013) is a graphical model that depicts the relationships between variables in a system to show the building adaptation process;
6. The Preliminary Adaptation Assessment Model (PAAM) is a checklist to assess ongoing adaptations; (S. Wilkinson, 2014)
7. Flex 4.0 (Geraedts, 2016) is a set of indicators that take into account development factors and environmental contexts;
8. Triple-bottom-line retrofit optimization (McArthur & Jofeh, 2016) is a system for evaluating the benefits of different types and levels of adaptation;
9. The Learning Building Framework (LBF) (Ross, 2017) is a quantitative framework that provides guidance in new designs based on weighted criteria, including operational costs and potential adaptation;
10. The Conversion Meter (Geraedts et al., 2017) is a checklist used to assess the context of a building in detail down to financial feasibility analysis and risk assessment;
11. The Transformation Capacity Tool (TCT) is a set of rules to evaluate a building's capacity to adapt, based on factors related to the building itself;
12. Spatial Assessment of Generality and Adaptability (SAGA) (Herthogs et al., 2019) is a method that compares the adaptability of various spatial layouts;
13. The Adaptive Reuse Assessment Model (ARAM) (Yazdani Mehr & Wilkinson, 2021) focuses on the potential for adaptation and reuse of historic buildings.
14. The Original Building Assessment Tool (OBAT) focuses on an open building approach with eight assessment parameters including shape, structure, façade, utility system, expandability, limitations, technology, and ease of equipment replacement (Capolongo et al., 2016).
15. The General Adaptability Assessment Tool (GAAT) is an assessment tool that uses 9 parameters (including 7 parameters of flexibility such as airflow, patients, personnel and resources, modification, conversion, and scalability, as well as 2 parameters related to EBD and Design-for-all, namely comfort and surrounding environment) to evaluate the adaptability and response of health facilities in various operational scenarios.
16. Modified Flexibility Assessment Tool (OFAT) which is an enhancement of UBAT. OFAT adds a new parameter, namely functionality, as well as modifies existing assessment criteria to accommodate constant and variable surface flexibility (Brambilla et al., 2021). In addition, a more comprehensive (Abd-Alhady et al., 2023) Flexibility Analysis Matrix was developed by considering three types of flexibility (constant surfaces, variable surfaces, and operational) at four building levels ranging from hospital complexes to individual rooms

Recent developments show that adaptability measurement tools not only focus on the physical aspects of buildings, but also consider contextual factors such as social, economic and environmental. This is reflected in the development of new models that integrate empirical data related to market demand, user needs, and building performance.

Nonetheless, most of the existing measuring tools are still in an academic context and have not been extensively tested on real projects. The challenge ahead is to develop measuring tools that can be integrated with information technology such as (Kamara et al., 2020) (Rockow et al., 2019) Building Information Modeling (BIM) to improve interoperability and ease of use in the adaptive building design and evaluation process. The development of adaptability measurement tools in the context of hospital health facilities in the form of components such as emergency rooms is a gap in future research that can be filled.

What is the gap in the adaptation measurement tool when applied to different contexts and objects?

The gap analysis of the building adaptation measuring tool shows some limitations when applied to different contexts and objects. The majority of existing measuring instruments are developed and tested on commercial or institutional buildings in developed countries with specific climatic and socio-cultural characteristics. This can pose challenges when applied to different building typologies such as residential or industrial, especially in developing countries with different tropical climatic conditions and socio-cultural contexts. Some models such as ARP and iconCUR rely heavily on complete building historical data, which may not be available in many local contexts. Meanwhile, measuring tools such as adaptSTAR and Flex 4.0 require adjustment of weights and assessment criteria to be relevant to local priorities and standards. Another gap lies in the focus of most measuring instruments on physical and economic aspects, while the socio-cultural and environmental aspects are less comprehensively accommodated. Newer models such as ARAM try to ove rcome this by incorporating heritage value considerations, but are still limited to historic buildings.

In the context of hospitals in the form of components such as emergency rooms, there are adaptation challenges that become more complex because they have to consider special aspects such as sterility, patient flow, and evolving medical needs. The application of measuring tools such as ARP and iconCUR in healthcare facilities faces obstacles because the parameters used are more oriented towards economic value and physical obsolescence, while the functional and operational aspects that are important for healthcare facilities are less accommodated. The adaptSTAR assessment system, although more comprehensive, still has limitations in assessing the specific technical aspects that hospitals need such as MEP systems (Langston & Smith, 2012) complex and special requirements related to infection control.

To address the gap, some researchers have developed more specific measurement tools for healthcare facilities. According to Łukasik & Porębska (2022), GAAT has limitations because it only assesses adaptability in general based on 9 basic parameters. This can create gaps when applied to different contexts and objects because it does not take into account location-specific factors, local culture, rapidly evolving aspects of technology and digitalization, and assessment scales that are too simple to accommodate the complexity of different types of facilities. As the researchers state that this tool is still in the development stage, has not been comprehensively validated, and is only intended as a decision-making support and introduction to site-specific research (Łukasik & Porębska, 2022).

Similar to MEDICINE and OFAT, it is an example of a measuring instrument designed with the special characteristics of the hospital in mind. Both of these measuring tools pay more attention to the aspects of functionality and flexibility that are very important for healthcare facilities. However, there is still room for improvement, especially in integrating aspects of sustainability and resilience to the pandemic that are becoming increasingly relevant.

Based on the gap analysis of building adaptation measuring instruments that have been presented, it can be concluded that the application of measuring instruments to different contexts and objects still has some significant limitations. The majority of measurement tools such as ARP, iconCUR, adaptSTAR, and Flex 4.0 developed in developed countries face challenges when applied to different contexts, especially in terms of data availability, adjustment of criterion weights, and accommodation of local socio-cultural aspects. In the context of healthcare facilities, more specific metrics such as GAAT, DIA, and OFAT have been developed taking into account the specific characteristics of hospitals, but further development is still needed to integrate aspects of sustainability and resilience to the pandemic, as well as more comprehensive validation to ensure the effectiveness of their application in various local contexts.

Conclusion

The application of Systematic Literature Review (SLR) with the PRISMA approach in this study has allowed a comprehensive and structured analysis of the current literature on the adaptability of hospital architecture. This method facilitates the identification, selection, and synthesis of relevant sources in a systematic manner, improving the reliability and reproducibility of findings. The use of Uake's Watase platform has enriched the analysis, allowing for the visualization of trends and relationships between concepts. For future research, it is recommended to integrate more sophisticated quantitative analysis methods, such as meta-analysis, in order to increase the validity of the findings. In addition, expanding database coverage and improving inclusion/exclusion criteria can deepen the understanding of hospital architecture adaptability.

This systematic literature study reveals that the adaptability of hospital architecture is an important aspect in facing various contemporary challenges. The need for adaptive buildings is driven by factors such as advances in medical technology, demographic changes, environmental sustainability considerations, and learning from the COVID-19 pandemic. Hospital building adaptation can be facilitated through the implementation of modular design, separation of building systems into independent layers, and the use of integrated information technology. Measuring adaptation success involves a multidimensional evaluation covering functional, economic, environmental, and social aspects. The development of adaptability measurement tools has evolved from a simple qualitative approach to more comprehensive models, such as GAAT, MEDICINE, and OFAT designed specifically for healthcare facilities. However, the application of the measuring tool still faces significant gaps, especially in different local contexts.

For further research, it is recommended to: (1) develop more specific adaptability measurement tools for emergency rooms by considering local characteristics and aspects of resilience to the pandemic, (2) conduct empirical validation of existing measurement tools in the context of hospitals in Indonesia, (3) integrate Building Information Modeling (BIM) technology in the evaluation and implementation of adaptability strategies, and (4) study more deeply about socio-cultural aspects and policies which affects the adaptability of hospitals at the local level. Practical implementation requires collaboration between various stakeholders to develop standards and guidelines that are appropriate to the Indonesian context.

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