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Flexibility of the built environment in healthcare: a systematic literature review

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ABSTRACT

This paper provides a comprehensive view of the concept of flexibility in healthcare design from a discussion on design strategies to achieve flexibility, ways of searching strategies, results achieved, theoretical approaches, and other analyses necessary for its understanding. Healthcare services are complex environments that must be flexible to meet the demands caused by emergency situations. For example, the COVID-19 pandemic showed that the lack of incorporation of the concept of flexibility prevented the efficient adaptation of space to support high demand, which caused high contamination rates in these environments. Towards a comprehensive view of the concept, the systematic literature review method was used in line with the Preferred Reporting Items for Systematic reviews and Meta Analyzes method. Based on that, the flexibility concept is divided into three levels, respectively: flexibility for adaptation (concentrated on the room scale), flexibility for conversion (focused on the building layout) and flexibility for expansion (coupled analysis of the buildings and land of the entire complex). Design requirements were structured at each level, however, more case studies are needed to collect quantitative data to facilitate its application in design, which is scarce in the literature. Collection of such quantitative data can boost the development of flexibility assessment tools in design, thus facilitating the application of this concept in healthcare environments.

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KEYWORDS
Healthcare facilities; built environment; design; flexibility; literature review

Highlights

- A systematic literature review on flexibility in healthcare design is presented;
- The paper offers a structured view of flexibility in healthcare design;
- Design requirements are presented for each of the three flexibility levels.

Introduction

Healthcare facilities have social significance due to the importance of health to humans (Dogan, 2018). Healthcare services are developed and delivered in buildings whose complexity results from the diversity of functional and technical requirements, as well as the expectations and concerns of their different users, such as patients, visitors, service providers, employees, and healthcare

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professionals (Caixeta & Fabricio, 2013; Codinhoto, Aouad, Kagioglou, Tzortzopoulos, & Cooper, 2009; Domingo, 2015). Due to this complexity, it is possible to understand the need to apply different concepts during the development of the healthcare environment: efficiency, flexibility, expandability, humanization, ease of cleaning, accessibility, circulation control, safety, and sustainability (Carr, 2009). Healthcare spaces have a great need to apply the concept of flexibility since these spaces are constantly changing, whether due to daily operational changes or changes in the way diseases are treated, which can generate a need not only to change use but also technological (Brambilla et al., 2021; França & Ornstein, 2021). Therefore, failure to apply this concept increases the chances that the healthcare space will not guarantee good functionality during its useful life (França & Ornstein, 2021).

Designs for contemporary healthcare facilities are based on the building's durability principle, so few structures can easily accommodate space changes (Brambilla et al., 2021), despite being a frequent demand. The problem of this rigidity of healthcare environments was even more evident during the COVID-19 experience, in which the demand increased and healthcare environments had difficulty incorporating it (Brambilla et al., 2021; Capolongo et al., 2020; Makram & El-Ashmawy, 2022). After this experience, the need to apply the concept of flexibility became even more evident so similar situations can be faced more efficiently (Alfowzan, Valipoor, & Portillo, 2024; Romano, Falegnami, Cagliano, & Rafele, 2022; Wexler & Oberlander, 2021).

Studies that explicitly address the topic generally present the strategies adopted in case studies or review those designed by other authors. Studies that aim to review strategies have a more restricted, poorly structured, and subjective approach, i.e. the application of some strategies must be clarified in the design of healthcare facilities (Brambilla et al., 2021; Carthey, Chow, Jung, & Mills, 2011; Jamshidi, Hashemi, & Valipoor, 2024). Moreover, Brambilla et al. (2021) e Carthey et al. (2011) do not relate the proposed classification of strategies and those used as references, hampering the understanding of the differences among classifications. Given this scenario, the research questions raised in the present study are: What are the criteria adopted for classifying flexibility in the healthcare built environment? What strategies are employed for designing flexible healthcare environments? The questions were addressed through a systematic literature review (SLR) on flexibility in healthcare built environments, in which the selected studies were analyzed regarding theoretical focus, techniques adopted, and results achieved.

Research method

Saieg, Sotelino, Nascimento, and Caiado (2018) identified five stages to organize the SLR method, namely: (i) formulation of questions; (ii) location of articles; (iii) selection and evaluation of articles; (iv) analysis and synthesizing; and (v) presentation of results. Towards a more efficient report on the article selection process, PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) method (Moher, Liberati, Tetzlaff, & Altman, 2010) was adopted in the present study, since it has been widely used in SLRs on healthcare services and design (Ransolin et al., 2022). PRISMA is divided into the following four steps: identification, screening, eligibility, and inclusion (Moher et al., 2010).

The first stage of an SLR consists of the definition of the research protocol, i.e. explanation of the premises that will guide the research, questions to be answered, keywords, databases, filters, and inclusion and exclusion criteria. The construction of keywords is not a linear process; the initial search string was defined in function of the interaction among the two groups of interest, flexibility, and built health environments, as follows:

- ("flexibility" OR "flexible" OR "adaptability" OR "adaptable" OR "convertibility" OR "expandability") AND
- ("healthcare facility" OR "hospital facility" OR "healthcare structures" OR "hospital structures" OR "healthcare retrofits" OR "hospital retrofits" OR "healthcare space" OR "hospital space" OR

"healthcare construction" OR "hospital construction" OR "healthcare architecture" OR "hospital architecture" OR "healthcare design" OR "hospital design" OR "healthcare building" OR "hospital building" OR "healthcare environment" OR "hospital environment").

Throughout the study, it was observed that if words 'health' and 'hospital' were not accompanied by terms related to the context of Architecture, Engineering, Construction, and Operation (AECO), a large part of the filtered articles would not be associated with the built environment, which is the focus of this research. A search for and an analysis of some articles and the referenced ones revealed the presence of words 'health care' and 'healthcare'. Due to such two forms of writing and the importance of mapping the entire scenario, the words in the group above were written in this second way and the final string is found in Table 1.

The search for articles was conducted in Scopus and Web of Science databases. Only journal articles published in English and Portuguese were selected. Inclusion and exclusion criteria were defined for the screening process. Table 1 summarizes the definitions.

PRISMA was applied according to the steps displayed in Figure 1. Filters and keywords were used in the identification stage, resulting in 1,900 articles (Scopus and Web of Science), plus 4 manually added sources, totaling 1904 articles. By crossing the databases by StArt software, 249 duplicate articles were found, reducing the analysis universe to 1651 titles. Titles, abstracts, and keywords were read in the screening stage and the exclusion criteria were applied (Table 1). 1484 articles were then excluded, resulting in 167 ones. Eligibility, the next stage, involved the analysis of full articles, leading to the exclusion of 120. Finally, in the inclusion stage, 47 articles were selected for complete reading and analysis of the results.

Data analysis Meyhod

The analysis of the collected material was divided into three parts: general characterization, classification, and analysis of knowledge. During the analysis of the general characterization, presented in topic 'Publications overview', the following criteria were analyzed: year of publication, country of the main author's institution, and relevance in terms of contributions to understanding the concept of flexibility in the design of healthcare environments. In the second part, presented in section 'Analysis of theoretical approaches, research methods or techniques, and results', the studies were classified in relation to four aspects: theoretical focus, research methods and techniques, types of results, and

Table 1. Research protocol.

Main questions	What are the criteria adopted for classifying flexibility in the healthcare built environment? What strategies are employed for designing flexible healthcare environment?
Search keywords	("flexibility" OR "flexible" OR "adaptability" OR "adaptable" or "convertibility" or "expandability") AND ("healthcare facility" OR "hospital facility" OR "healthcare structures" OR "hospital structures" OR "healthcare retrofits" OR "hospital retrofits" OR "healthcare space" OR "hospital space" OR "healthcare construction" OR "hospital construction" OR "healthcare architecture" OR "hospital architecture" OR "healthcare design" OR "hospital design" OR "healthcare building" OR "hospital building" OR "healthcare environment" OR "hospital environment" or "health care facility" or "health care structures" or "health care retrofits" or "health care space" or "health care construction" or "health care architecture" or "health care design" or "health care building" or "health care environment" or "hospital infrastructure design" or "healthcare infrastructure design" or "health care infrastructure design")
Databases	Scopus; Web of Science
Filters	Time: no time interval has been defined Publication type: Journal Languages: English and Portuguese
Exclusion Criteria	– Outside the context of Flexibility in AECO. For example, mentions of adaptability (e.g, tool is adaptable), or mentions of flexibility (e.g, flexible framework) but not an aspect related to build environments – Not accessible even with University credentials
Inclusion criteria	– Fully accessible with credentials – Flexibility in the AECO area in healthcare

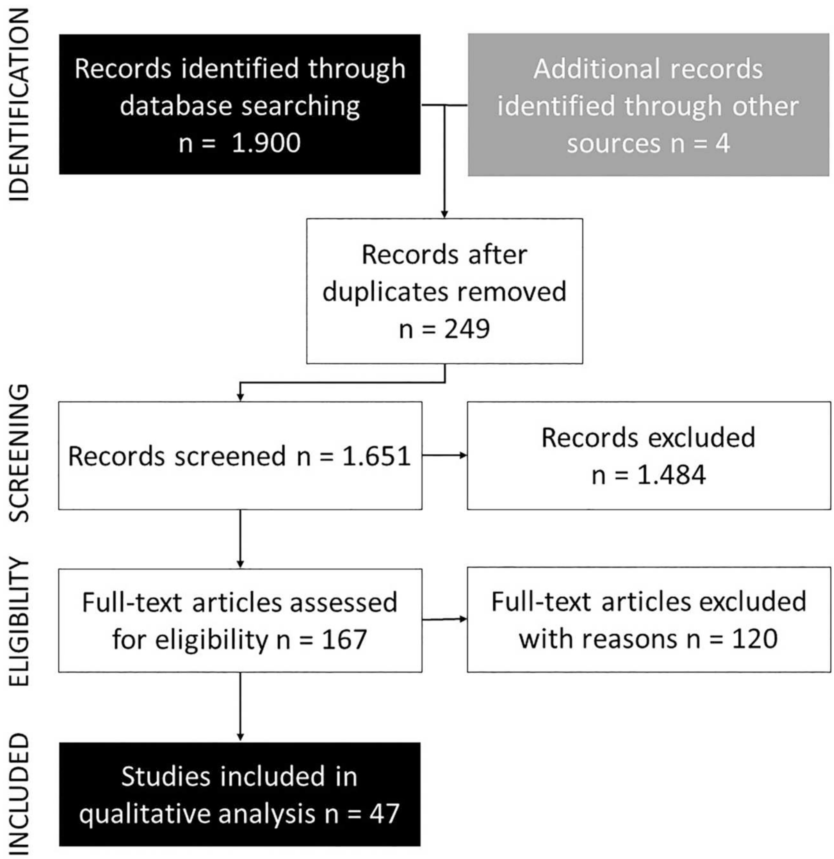

Figure 1. Steps for the selection of papers.

types of healthcare facility or building department focus of the case study. Table 2 presents the categories of each characterized aspect. In the third part, strategies that support the application of the concept of flexibility were analyzed, and the results are presented in sections ‘Flexibility to adapt’, ‘Flexibility to convert’, and ‘Flexibility to expand’. The note 1 present in the legend of some tables means that the supplementary material of the article should be consulted to identify the references linked to each number.

Results

Publications overview

According to the graph (Figure 2), the theme has been recurrent over the years, but with a small annual production, since the publication peaks were 5 (2022) and 4 (2004, 2013, 2016, 2024) articles annually.

Table 3, which defines the number of articles by country of the institution with which the primary author was associated at the time of publication, shows the country with the most publications is the United States, followed by Italy and Australia.

The articles were classified according to their contributions to the understanding of the flexibility concept, since those with different methodological rigors were filtered, thus impacting the quality of the evidence. The classification results in four categories were defined: very high, high, low, and very low (Table 4). According to Table 4, 57% of the selected articles were classified as

Table 2. Categories for the classification of articles according to theoretical focus, research methods or techniques, and results.

Theoretical Focus	
	Contributes to the discussion of types of flexibility
	Contributes to the deepening of a specific strategy to achieve some level of flexibility
	Contributes to the understanding of the characteristics that provide flexibility to adapt to the design
	Contributes to the understanding of the characteristics that provide flexibility to convert to the design
	Contributes to the understanding of the characteristics that provide flexibility to expand to the design
Research methods or techniques	
	Design Reports
	Systematic Literature Review
	Literature review
	Case studies
	Interviews
Results	
	Conceptual, theoretical deepening
	Case reports
	Design guidelines
	Artifact proposition

those that indirectly address flexibility, i.e. they generally discuss important strategies for the design to improving the quality of the healthcare environment, involving flexibility as one of such points.

The country of origin of the authors of the studies included in the 'very high' classification was verified. Italy contributed most in a direct and structured way to the concept of flexibility, with five articles, followed by United States, with three and Australia, with two. The United Kingdom, India, Finland, Netherlands, Turkey and Israel contributed with one article each.

Settings for publication analysis

The definition of the categories of the theoretical approach is related to the research objective, i.e. the understanding of the classifications of flexibility and the strategies for achieving a flexible built environment. Carthey et al. (2011) and August-Brady (2000) revealed there was little consensus on terminologies in the area of flexibility and the first adopted the classification of Pati, Harvey, and Cason (2008). Presseler (2006), Capolongo (2012), Łukasik and Porębska (2022), Makram and El-

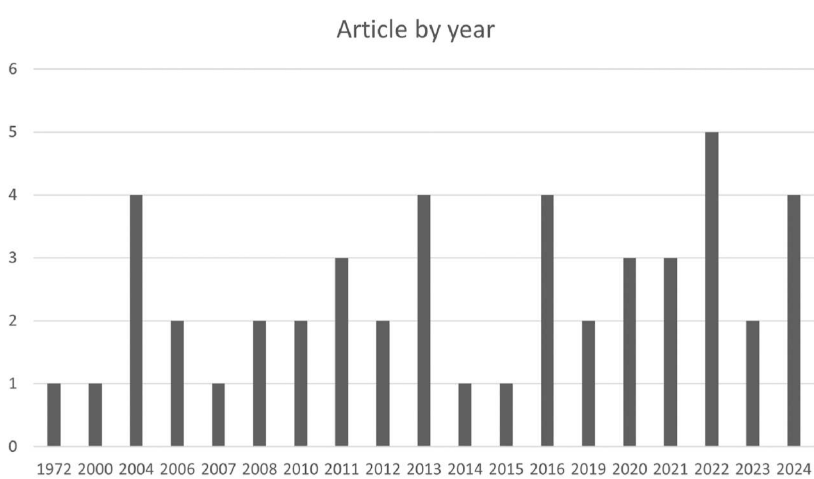

Figure 2. Number of articles per year.

Table 3. Number of articles according to country of primary author's institution.

Country of the lead author's institution	Quant.
United States	16
Italy	6
Australia	6
United Kingdom	4
Finland	3
Germany, Spain, Sweden, South Korea, Poland, Norway, Egypt, Israel, India, Ghana, Netherlands, Turkey	1
Total	47

Ashmawy (2022), Jamshidi et al. (2024), and Kyrö, Peltokorpi, and Luoma-Halkola (2019) defined types of flexibility, which converge to the classification proposed by Pati et al. (2008). August-Brady (2000) claimed flexibility might be related to adaptability and the building's ability to be expandable. Even though the authors presented different nomenclatures to present the types of flexibility, the proposal for Pati et al. (2008) was adopted in this study for analyses of the articles selected in the SLR.

The following definitions, which are in line with those of the aforementioned authors, are provided towards standardizing the classification of strategies regarding types of flexibility:

- flexibility to adapt: ability of the space to undergo operational changes and adapt to users´ needs within the workspace with no changes to construction systems; and
- flexibility to convert: ability to change the function of spaces with changes to construction systems; and
- flexibility to expand: a building's ability to expand its functionalities.

The contributions, research methods and results achieved by each work are presented below.

Analysis of theoretical approaches, research methods or techniques, and results

Table 5 shows two groups of articles separated according to their direct or indirect discussions on flexibility concepts – some of them discuss different design concepts, including flexibility, and the division aims to avoid misunderstandings about the theoretical approach adopted.

The extraction of data on the research method or technique (Table 6) and the results (Table 7) was conducted only in studies that directly contributed to the understanding of the flexibility concept for avoiding mistakes. This consideration was made because the objective of carrying out this extraction is to understand the analysis strategies of the concept of flexibility, however, in articles that address flexibility indirectly, the research methods and techniques, and the results focus on the themes that they addressed directly. Despite this, works using an indirect approach are analyzed because they are important to the timeline of the study and application of the concept of flexibility. Furthermore, the existence of these works indicates that the application of the concept of flexibility is important, but it requires greater depth in terms of its understanding, which is discussed in the present work.

Table 4. Number of articles according to the classification of relevance regarding contributions to the understanding of the concept of flexibility in healthcare environment design.

Classification of relevance regarding contributions to the understanding of the concept of flexibility in healthcare environment design	Quant.
VERY HIGH – Academic articles that directly discuss the concept of flexibility	17
HIGH – Academic articles that indirectly discuss the concept of flexibility	19
LOW – Non-academic articles that directly discuss the concept of flexibility	3
VERY LOW – Non-academic articles that indirectly discuss the concept of flexibility	8
Total	47

Table 5. Reference of articles according to the Theoretical Focus categories. Note 1.

Theoretical focus	Direct discussion of the concept of flexibility	Indirect discussion of the concept of flexibility
Contributes to the discussion of types of flexibility	[1]; [8]; [10]; [11]; [13] [16]; [17]; [26]; [30]; [33]; [36]; [44]; [46]	[2]; [37]; [39]; [40]; [42]
Contributes to the deepening of a specific strategy to achieve some level of flexibility		[5]; [6]; [15]; [21]
Contributes to the understanding of the characteristics that provide flexibility to adapt to the design	[8]; [10]; [11]; [12]; [16]; [17]; [25]; [30]; [33]; [34]; [36]; [44]; [45]; [46]; [47]	[3]; [7]; [9]; [14]; [15]; [19]; [20]; [21]; [22]; [23]; [24]; [27]; [32]; [37]; [38]; [39]; [41]; [43]
Contributes to the understanding of the characteristics that provide flexibility to convert to the design	[1]; [8]; [10]; [11]; [12]; [13]; [16]; [17]; [18]; [25]; [26]; [28]; [30]; [33]; [34]; [36]; [44]; [45]; [46]; [47]	[4]; [5]; [19]; [20]; [22]; [27]; [29]; [31]; [35]; [37]; [41]; [42]
Contributes to the understanding of the characteristics that provide flexibility to expand to the design	[10]; [12]; [16]; [17]; [18]; [25]; [30]; [33]; [36]; [44]; [45]; [46]	[7]; [20]; [31]; [37]; [39]; [40]; [42]

Table 6. Reference of articles according to the categories of methods or research techniques. Note 1.

Research methods or techniques	References
Design Reports	[1]; [8]; [12]
Systematic Literature Review	[16]; [33]; [36]; [44]
Literature review	[26]; [17]
Case studies	[10]; [11]; [13]; [16]; [17]; [18]; [25]; [28]; [34]; [36]; [46]
Interviews	[11]; [13]; [30]; [34]; [45]; [47]

Table 7. Reference of articles according to the categories of Results achieved. Note 1.

Results	References
Conceptual, theoretical deepening	[16]; [17]; [33]; [36]; [44]
Case reports	[1]; [8]; [12]
Design guidelines	[10]; [11]; [13]; [16]; [17]; [18]; [25]; [26]; [28]; [30]; [33]; [34]; [36]; [44]; [45]; [46] [47]
Artifact proposition	[17]; [28]; [36]; [46]

Regarding articles that explicitly addressed flexibility in the healthcare environments, those that conducted case studies analyzed hospital design or, more specifically, some departments included in a hospital's architectural design brief (Table 8). The hospitalization department was the one that received the most attention from researchers, among the studies that specified the department studied.

Protocol for analyzing of strategies that support the application of the flexibility concept

According to the SLR, several terminologies denote flexibility, thus hampering the understanding of the concept and the strategies to achieve a level of flexibility in the design. Therefore, the second objective of this study is to organize the strategies presented by all authors into a single classification, since, in principle, each author makes their classification independently. Firstly, the strategies were allocated into the levels of flexibility proposed in the present study from analyses of the

Table 8. Number of articles according to case studies. Note 1.

Case Studies	Quant.
Hospital	[1]; [8]; [10]; [11]; [12]; [16]; [17]; [18]; [25]; [28]; [34]; [36]
Inpatient units	[8]; [11]; [12]
Nursery	[1]
Clinic	[1]; [12]
Surgical department	[1]; [8]
Research and Teaching	[1]
Emergency departments	[8]; [46]
Imaging department	[8]

similarity between each author's classification and the proposed one. Second, each strategy was analyzed individually for a final classification by this research. Third, the strategies identified, their requirements and criteria were extracted. Requirements are characteristics that the building must possess so that its use can be satisfactory. The requirements are qualitative and should not impose the use of a specific construction system. Criteria are quantitative properties that the building, its systems or its elements must have to objectively meet a requirement. For example, the strategy of using rationalized prefabricated elements requires that most environments meet the modulation requirement. In turn, this requirement can be verified through the criterion that the construction elements coincide with a mesh of 1.33 m (Bachmanm, 1972). It is important to highlight that at least one requirement was extracted from each strategy, but there were few strategies from which it was possible to extract criteria.

Subsections 'Flexibility to adapt', 'Flexibility to convert', and 'Flexibility to expand' discuss both requirements and criteria for the level of flexibility to adapt, convert, and expand, respectively. Each subsection begins by defining the requirements for each level and, after an in-depth analysis of the concept, some specific requirements are either reallocated to another level, differently from what is suggested by the literature, or grouped into a single requirement. At the end of each subsection, a summary table of the requirements and criteria for each level is presented.

Flexibility to adapt. Flexibility to adapt means assurance of ease of change in an environment with no changes to the construction. Therefore, an intervention in spatial organization and facilities is required. The following requirements must be applied towards a spatial organization with ease of adaptation: adaptable spaces, and furniture that enables easy movements. Furthermore, the system must incorporate universal installations and new technologies to achieve flexibility to adapt. Table 9 shows the references that helped define such requirements.

Some authors consider the standardization strategy as a strategy of flexibility to adapt (Carthey et al., 2011; Kyrö et al., 2019; Pati et al., 2008). However, as we consider standardization facilitates changes through the division of environments or the grouping of different environments (Reijula, Reijula, & Reijula, 2016), this research classifies this strategy in the group of flexibility to convert, and therefore it will be further discussed in the next section.

Those interviewed by Kyrö et al. (2019) reported generality or multifunctionality is an efficient way to achieve adaptability and, according to the authors, extra capacity is related to multifunctionality that aims the use of the same room by different users. Linked to these concepts, the concept of acuity-adapted rooms usually appears, which aims to produce a room equipped to allow treatment for different clinical conditions, reducing the number of transfers (Drexler & Cimini, 2013; Hendrich, Fay, & Sorrells, 2004). Even though Presseler (2006) inserts the 'acuity-adapted room' strategy into a type of flexibility that is at the level of 'flexibility to convert' (classified by the author as 'long-term flexibility'), the present study understands that this strategy is related to the level of flexibility to adapt as it is related to daily adaptations. Those interviewed by Kyrö et al. (2019) and Kwan (2011) reported the application of adaptable rooms was not so efficient, but their concept promoted other developments, such as the emergence of the concept of universal and individual rooms. Based

Table 9. Reference to articles that helped to define the level of flexibility to adapt requirements. Note 1.

Requirements	References
Spatial organization	
Requirement 1: Having adaptable spaces	[3]; [6]; [7]; [8]; [9]; [10]; [11]; [12]; [14]; [15]; [16]; [17]; [19]; [20]; [21]; [22]; [23]; [24]; [27]; [30]; [33]; [34]; [36]; [37]; [39]; [41]; [44]; [45]; [46]; [47]
Requirement 2: Having furniture that enables easy movements	[10]; [11]; [17]; [19]; [24]; [25]; [32]; [33]; [36]; [38]; [43]; [44]; [47]
Facilities System	
Requirement 1: Having universal installations	[7]; [11]; [16]; [17]; [30]; [33]; [36]; [41]; [44];
Requirement 2: Having new technologies incorporated into the facilities	[14]; [17]; [19]; [25]; [30]

on the understanding of what constitutes the concept presented and from practical experiences, the requirement was stated as: presence of adaptable spaces, thus facilitating the comprehension of what should be applied and verified to the design.

The application of universality of rooms of the principle leads to an increase in the dimensions of healthcare environments; consequently, nurses would need to travel greater distances to serve them if the nursing station were centralized, which is not interesting for the caring of patients (Scalise, Thrall, Haugh, & Runy, 2004). Decentralized nursing stations can reduce the distances covered (Carthey et al., 2011; Drexler & Cimini, 2013; Eagle, 2007; Hendrich et al., 2004; Memari, Kocaturk, Lozanovska, Andrews, & Tucker, 2022; Noble & Lee, 2010; Pati et al., 2008; Presseler, 2006; Scalise et al., 2004). However, care must be taken to ensure decentralization does not cause the isolation of professionals (Scalise et al., 2004). This issue of distancing was not introduced in the requirements at this level for two reasons: firstly, it is a question of functionality, and secondly, multifunctionality must be applied in spaces of low complexity: clinics, hospitalizations, and offices (Kyrö et al., 2019), thus the inclusion of the requirement would direct to an analysis only of hospitalization rooms.

According to the classification of Capolongo (2012), the level of flexibility called 'single room' covers the type of flexibility called 'user adaptability', in which the 'personalized humanization of the room' is a spatial typology strategy related to the use of automation for controlling thermal and lighting parameters. The topic is associated with the insertion of new technologies into the installation system for providing space automation and guaranteeing adaptation flexibility. Therefore, the 'to have new technologies incorporated into the facilities' requirement was inserted in the facilities area for representing that strategy. The literature reports no quantitative properties that facilitate both application and verification of requirements related to the area of installations.

Regarding universal rooms, Eagle (2006, 2007) suggested they should have an area of approximately 20m^2. Despite Carthey et al. (2011) arguing there is no consensus on an exact area for those spaces, they agree a comfortable area would be 20–25 m^2 for ensuring the room accommodates the diversity of equipment necessary for various levels of severity, regardless of the type of disease. No other information was found about the other spaces that are interesting to be adaptable.

Gashoot (2022) highlighted the importance of furniture having wheels. Table 10 summarizes the requirements (qualitative characteristics) and criteria (quantitative properties) relating to the following design areas: spatial organization and facilities system to achieve flexibility for adaptation.

Flexibility to convert. The flexibility to convert level is related to the building's ability to change its use or expand it internally through an intervention focused not only on the spatial organization and facilities, but also on the sealing system (building partitions that divide the internal environment or separate the internal environment from the external environment) and structural system. A spatial organization with ease of conversion must involve standardization of spaces, design of low complexity spaces close to complex ones, zoning, and a vertical grouped circulation body (stairs, ramps, and elevators) in the center. Installations must have sufficient ceiling height for their horizontal distribution on the floor and a standardized distribution of the shafts and the elements to be grouped. The internal sealing system must be easy to remove and the external one must be independent. The structural system must reach large spans and should be standardized. Finally, interaction between vertical elements must be guaranteed through columns grouped with shafts and vertical

Table 10. Requirements with their respective criteria for each construction area.

Requirements	Criteria
Spatial organization	
Requirement 1: Having of adaptable spaces	$20m^2 < x < 25m^2$
Requirement 2: Having furniture that enables easy movements	Not defined in the literature
Facilities System	
Requirement 1 Having universal installations	Not defined in the literature
Requirement 2: Having new technologies incorporated into the facilities	Not defined in the literature

Table 11. Reference to articles that helped to define the flexibility level requirements for conversion. Note 1.

Requirements	References
Spatial organization	
Requirement 1: Having standardization of spaces	[1]; [4]; [5]; [8]; [11]; [13]; [16]; [18]; [19]; [20]; [22]; [25]; [27]; [29]; [30]; [33]; [36]; [37]; [41]; [45]; [46]; [47]
Requirement 2: Having non-complex spaces close to complex spaces	[8]; [10]; [12]; [16]; [26]; [27]; [28]; [30]; [31]; [33]; [36]; [37]; [41]; [42]; [44];
Requirement 3: Having zoning	[16]; [19]; [34]; [37]; [47]
Requirement 4: Having a vertical grouped circulation body (stairs, ramps, and elevators) in the center	[16]; [26]; [33]; [37]
Sealing System	
Requirement 1: Having an easily removable internal sealing system	[1]; [8]; [10]; [13]; [17]; [18]; [25]; [27]; [28]; [33]; [35]; [36]
Requirement 2: Having facades independent of the layout	[17]; [25]; [28]; [33]; [36]
Structural system	
Requirement 1: Having flexible span	[12]; [13]; [18]; [25]; [26]; [28]; [33]; [34]; [36]; [37]
Requirement 2: Having a standardized structure	
Facilities system	
Requirement 1: Having sufficient ceiling height for a horizontal distribution of installations on the floor	[1]; [11]; [13]; [16]; [18]; [26]; [27]; [28]; [30]; [33]; [36]; [37]; [42]; [44]
Requirement 2: Having a standardized distribution of the shafts and the elements to be grouped	[8]; [17]; [18]; [28]; [30]; [33]; [34]; [38]; [8]; [36]; [37]
Interaction between vertical elements	
Requirement 1: Having columns grouped with shafts and vertical circulation	[8]; [28]; [33]; [36]
Requirement 2: Having shafts grouped with vertical circulation	

circulation and shafts grouped with vertical circulation. Table 11 shows the references that contributed to define the requirements of this level of flexibility.

The previous topic about flexibility to adapt discussed standardizing spaces would best fit the flexibility to convert group. Two concepts, namely, modulation (Acehan & Sarikaya, 2024; Alfowzan et al., 2024; Arsenault, 2004; Astley, Capolongo, Gola, & Tartaglia, 2015; Buffoli, Nachiero, & Capolongo, 2012; Carthey et al., 2011; Eagle, 2013; Hollander, 2020; Kyrö et al., 2019; Makram & El-Ashmawy, 2022; Memari et al., 2022; Pati et al., 2008) and standardization of spaces (Bachmanm, 1972; Brambilla et al., 2021; Corben, 2013; Hollander, 2020; Holmdahl, Lanbeck, Axel Munthe, & San Michele, 2013; Kyrö et al., 2019; Lavikka, Kyrö, Peltokorpi, & Särkilahti, 2019; Memari et al., 2022; Olsson & Hansen, 2010; Pati et al., 2008; Presseler, 2006; Reijula et al., 2016; Reiling et al., 2004; van Heel, Pretelt, Herweijer, & van Oel, 2024) frequently are used in the discussion. Some authors such as Hollander (2020), and Kyrö et al. (2019) use the two terminologies as synonyms, this occurs because, in these works, both terms are related to the repetition of dimensions in different spaces of the same building. Furthermore, it is important to highlight that the term 'standardization' was not used in the context of 'technical standardization'. As both terms are related to the repetition of dimensions in different elements of the building, in this work the term 'space standardization' will be used to facilitate understanding. Thus, an example of how to achieve standardization of spaces is to design all, or most of the spans, so that they are multiples of the same common distance.

Some studies have addressed the importance of having strategies such as 'soft spaces are spaces located adjacent to technically sophisticated spaces' or 'larger spaces and hot spots', empty spaces, presence of verandas/setbacks, and 'open corridors' (Astley et al., 2015; Capolongo, 2012; Carthey et al., 2011; Hollander, 2020; Kyrö et al., 2019; Makram & El-Ashmawy, 2022; Memari et al., 2022, 2023; Reijula et al., 2016) for facilitating internal transformations in the building. Among the authors who cited the strategies listed above and presented a flexibility classification, only Carthey et al. (2011) classified them as a 'flexibility to expand' level in the present research (classified by the author as 'expandability'). Although Brambilla et al. (2021) provided no flexibility classification, they claimed each evaluation parameter (shape, structure, functionality, expandability, among others) has its characteristics to achieve flexibility and when the authors deal with expandability, the strategy of 'open corridors' is found. Capolongo (2012) classified the 'presence of verandas/setbacks' strategy as a type of flexibility placed at the 'flexibility to expand' level in this research (the author's classification type is 'variable surface flexibility'). This discussion about balconies are important to the expansion of the functional unit, nonetheless, Capolongo et al. (2016) separated the expansion group into internal and external types. Internal expansion strategies can be included in the flexibility to convert level, because they relates with the change of construction systems, which is one of the characteristics of the aforementioned level. The analysis of the concepts revealed balconies, recesses, and corridors are spaces of low complexity that can be converted to another use. Therefore, those concepts are encompassed in the 'having less complex spaces close to complex spaces' requirement. No quantitative data on this requirement was found, the literature only indicates examples of low complexity spaces and complex spaces. Examples of the first type of space are administrative areas, employee locker rooms, storage rooms, clinical spaces/offices, waiting rooms, and hospitalization rooms, and the examples of complex spaces are diagnostic departments, surgery units, image, emergency, treatment and facilities service rooms (Babbu, 2016; Carthey et al., 2011; De Neufville, Lee, & Scholtes, 2008; Hollander, 2020; Kyrö et al., 2019; Noble & Lee, 2010; Presseler, 2006).

Among the authors who cited the 'integrated installations' strategy and presented a flexibility classification, only Presseler (2006) classified it equivalently to 'flexibility to adapt'. Since such an integration of systems is important for reducing the number of obstacles in the plan and facilitating the transformation of the space through modifications of construction elements, it can be included at the flexibility to convert level. Capolongo et al. (2016) and Brambilla et al. (2021) classified buildings as elements that cause restrictions, i.e. elements that do not change location easily (e.g. shafts, columns, stair bodies, and elevators). Therefore, the plan with the smallest area of those restriction spaces (fixed elements) in relation to the floor area is more flexible. Brambilla et al. (2021) and Hollander (2020) highlighted the importance of grouping the vertical elements of each construction system, reinforcing the need for a small number of those elements, which represent obstacles in the plan. Despite concerns over reductions in number of barriers generated by vertical elements, internal alterations may be complex in some situations, even with a few elements, due to their spread from different construction systems in the plan. As previously discussed, vertical elements are associated with structure, facilities, and spatial organization; therefore, requirements were developed for those areas related to the principles of having few vertical elements grouped. As an example, the vertical circulation body (staircase and elevator) can be grouped together and with installations and columns. Such situations were considered in requirements in the areas of spatial organization and interaction between vertical elements. A requirement was inserted in the installations area for verifying number of shafts and another in the interaction between vertical elements area for verifying grouping with columns and vertical circulation elements. The literature indicates the importance of following a grid in the structural system, which, in the authors view, includes the principle of having few vertical elements. Since the grouping of this system with other elements from other areas was considered, no new requirement was added.

In addition to vertical distribution, the papers discuss horizontal distributions that can occur on intermediate floors or through the ceiling (Babbu, 2016; Bachmanm, 1972; Brambilla et al., 2021; Buffoli et al., 2012; Capolongo et al., 2016; Capolongo et al., 2016; Carthey et al., 2011; Hollander, 2020; Jamshidi et al., 2024; Kyrö et al., 2019; Memari et al., 2022, 2023; Olsson & Hansen, 2010). Carthey et al. (2011) addressed the use of intermediate floors as an expansibility strategy because their classification incorporates strategies to convert and to expand in the expansibility group. As state before, the present research work differentiates between the flexibility to convert and flexibility to expand, thus the use of intermediate floor and other horizontal distribution strategies are considered as a flexibility to convert strategy. The horizontal distribution through intermediate floor or ceiling are distribution strategies for the horizontal distribution of facilities which 'having a high distance between floors' is the requirement.

Capolongo et al. (2016) created a tool for analyzing the concept of open buildings, understood here as a synonym for flexibility, and, according to their criteria relating to facades, the use of a curtain wall system promotes greater flexibility to the building. Brambilla et al. (2021) pointed out that curtain walls allow the building to be independent. The independence between the internal and external environments facilitates internal changes without the need for major modifications to the facade, which would increase the cost of the intervention, especially if it were necessary to use scaffolding (Hollander, 2020). Just like facades that have a curtain wall, those that have balconies and terraces also allow a degree of independence in relation to the layout (Capolongo et al., 2016). In this way, 'having facades independent of the layout' can be defined as a requirement to have flexibility to convert.

After the definition of requirements based on the literature strategies for flexibility, it is important to define the evaluation criteria for these requirements. In the literature review, there are only criteria for requirements related to spatial organization, structural system, and facilities. Regarding the spatial organization, Bachmanm (1972) claimed a 1.33 m grid applies to all spaces, whereas, according to Arsenault (2004), a 9 × 11 module size for examination rooms and offices is most suitable. This shows that even there are evaluation criteria, there is no consensus about it in the literature. Regarding the structural system, Noble and Lee (2010), Buffoli et al. (2012), Astley et al. (2015), Babbu (2016), and Capolongo et al. (2016) presented a structural grid dimension that fits the one proposed by Hollander (2020) which can vary from 7.20 to 8.40 m, which is the value of the criteria considered for the 'having flexible spans' requirement. In relation to the facilities, according to Babbu (2016) and Brambilla et al. (2021), the distance from floor to floor must be equal to or greater than 4 meters, which is the value of the criteria considered for the 'having sufficient ceiling height for the horizontal distribution of installations on the floor' requirement. Although no criteria for sealing systems have been found in the literature, there is an indication for the use of dry assembly technical solutions as strategy to achieve flexibility (Astley et al., 2015; Buffoli et al., 2012). This strategy is intrinsically related with the use of prefabrication and standardized elements, which contributes to achieve four requirements: 'Having an easily removable internal sealing system', 'Having standardization of spaces', 'Having a standardized structure' and 'Having a standardized distribution of the shafts'. These requirements were already discussed based on other strategies and are shown in Table 12, which summarizes the requirements (qualitative characteristics) and criteria (quantitative properties) to achieve the 'flexibility to convert' relating to the following design areas: spatial organization, sealing system, structural system, facilities system, and interaction between vertical elements.

Flexibility to expand. This level is related to the building's ability to expand externally and in two directions, i.e. horizontally and vertically (Hollander, 2020; Makram & El-Ashmawy, 2022), and the requirements are related to spatial organization, empty space on the ground, and oversizing of the structure. Table 13 shows the references that helped to define the requirements.

Kyrö et al. (2019) classified the 'empty chair' strategy (unoccupied space on the land) equivalently to 'flexibility to convert' level (the author's classification type is flexibility). But this strategy is related to external expansion. As stated elsewhere, strategies associated with external expansion are placed at the level of flexibility to expand. Therefore, the 'having empty spaces on the land' requirement was formulated.

The literature reports no criteria that facilitate the application and verification of spatial organization and structure requirements. Table 14 summarizes the requirements (qualitative characteristics) and criteria (quantitative properties) to achieve the 'flexibility to expand', relating to the following design areas: spatial organization and structural system.

Discussion

This review has two main objectives: to analyze existing classifications of flexibility types and to identify design strategies to achieve a flexible healthcare environment. From the data collected in

Table 12. Requirements with their respective criteria for each construction area.

Requirements	Criteria
Spatial organization	
Requirement 1: Having standardization of spaces	Not defined in the literature
Requirement 2: Having non-complex spaces close to complex spaces	Not defined in the literature
Requirement 3: Having zoning	Not defined in the literature
Requirement 4: Having a vertical grouped circulation body (stairs, ramps, and elevators) in the center	Not defined in the literature
Sealing System	
Requirement 1: Having an easily removable internal sealing system	Not defined in the literature
Requirement 2: Having facades independent of the layout	Not defined in the literature
Structural system	
Requirement 1: Having flexible span	7,20 < x < 8,40m
Requirement 2: Having a standardized structure	Not defined in the literature
Facilities system	
Requirement 1: Having sufficient ceiling height for the horizontal distribution of installations on the floor	x > 4,00m
Requirement 2: Having a standardized distribution of the shafts and the elements to be grouped	Not defined in the literature
Interaction between vertical elements	
Requirement 1: Having columns grouped with shafts and vertical circulation	Not defined in the literature
Requirement 2: Having shafts grouped with vertical circulation	Not defined in the literature

Table 13. References that helped to define the flexibility level requirements for expansion. Note 1.

Requirements	References
Spatial organization	
Requirement 1: Having empty spaces on the land	[7]; [12]; [16]; [17]; [18]; [25]; [30]; [31]; [33]; [36]; [39]; [40]; [42]; [44]; [45]; [46]
Structural system	
Requirement 1: Having an oversized structure	[10]; [17]; [20]; [30]; [33]; [37]

Table 14. Requirements with their respective criteria for each construction area.

Requirements	Criteria
Spatial organization	
Requirement 1: Having empty spaces on the land	Not defined in the literature
Structural system	
Requirement 1: Having an oversized structure	Not defined in the literature

the literature, it is possible to identify contributions and points for improvement, discussed in the following paragraphs.

First, some authors understand the terms adaptability, convertibility, and expansability as types of flexibility, while others, such as Jamshidi et al. (2024) and Kyrö et al. (2019), understand them as levels of flexibility. The main difference between these two understandings is related to the interaction between the concepts. When considering a classification into types, a well-defined relationship between the terms is not established, however, when considering a classification into levels, it is assumed that to achieve a following classification must have fit into all other previous classifications. Hollander (2020) reinforces the importance of understanding the classification into levels, stating that the connection of an expansion construction with the existing complex must be preceded by the conversion of the existing internal space. Therefore, designing for conversion requires the application of adaptability strategies, and designing with the objective of carrying out an expansion also requires the application of adaptability and convertibility strategies. To illustrate this, considers a situation in which the designers of a new healthcare enterprise must occupy only part of the land for construction, to allow the unoccupied area to be used for future undefined expansions. To make the expansion process more effective, faster, and less costly, the design of the initial building must be carried out considering that the internal space must be easy to adapt and convert, especially on the border that is on the expansion line. For example, a zoning study is necessary (flexibility strategy for conversion) so that less complex services are located in this space (for example, administrative or teaching and research areas) and that these spaces are designed to be adaptable (strategy of flexibility to adapt) equipped with universal infrastructure to be capable of a change of use (flexibility to adapt strategy) and constituted with lightweight partitions (flexibility to convert strategy) to facilitate the disassembly of the space. As illustrated in this example, the present work understands that the application of the concept of flexibility is gradual, in which the flexibility to expand level is the most complex as it requires applications of strategies from the previous levels. This understanding of the concept of flexibility makes its application more viable in healthcare building design.

Second, Table 7 shows a high number of studies which has contributed to the level of flexibility to adapt and convert, which may be associated to levels with a greater concern over short-term flexibility through the development and application of strategies for meeting users' daily demands. Such a lack of discussion on flexibility to expand is related to a shallow understanding of the flexibility level, whose success is associated simply with the oversizing of structural elements. Therefore, common sense would indicate a need for an increase in building construction costs towards a practical application of requirements. On the other hand, there are possibilities to design applying the concepts of flexibility to expand through an instrumentation strategy and monitoring of structural and foundation elements at low investments. The approach would reduce uncertainties inherent to the construction process, promoting post-construction analyses towards future expansions. Another possibility is to think about spaces on lower floors so that they can contemplate uses that generate greater structural load or require smaller deformations of the structure. However, the SLR indicated the scientific community of structural engineering does not include that approach in their research work, since strategies for the application of flexibility for expansion are related to the ability of structural systems to resist loads from expansion and their analysis requires specific studies. It is noted that to deepen knowledge in the field of flexibility, it is necessary to develop future multidisciplinary research to present the strategies in more detail and facilitate their practical application.

Third, the literature presents several case studies (Table 6), but a limited amount of quantitative data (Tables 10, 12, and 14) to support the identified strategies. This lack of quantitative data highlights the lack of depth in the strategies, which makes it difficult to apply them effectively in design. This creates inflexible spaces, which made it difficult for some healthcare spaces to make changes to their infrastructure to accommodate the high demand generated during the pandemic, hence the need to seek more flexible spaces (Acehan & Sarikaya, 2024; Alfowzan et al., 2024). The fact that only four studies found propose ways to verify the application of the concept is also a reflection of the lack of quantitative data regarding flexibility in healthcare buildings. Jamshidi et al. (2024) understand the benefits of tools for this area, this importance is evidenced in facilitating communication between designers and design stakeholders by facilitating the understanding of the resources necessary to apply the desired degree of flexibility and thus improving the basis for decision making. Furthermore, the tools are not only important for the design phase, but also for checking existing buildings. For example, during emergencies, resource management is important to be able to provide efficient service to a greater number of people in a shorter time. This way, a verification tool would be able to inform the emergency managers which is the spaces that, easier, accommodate a specific demand. In this way, it would be possible to define a plan for distributing resources according to the characteristics of each health building and respond to emergencies efficiently and with quality to people who are in a more fragile state. Based on this, it is possible to see the importance of developing future research to generate quantitative data, to boost the development of new verification tools, preferably associated with design tools, to assist designers in understanding requirements with design solutions (Kiviniemi, 2005). The tools of the Building Information Modeling (BIM) methodology allow creating a link between requirements and the model (Koutamanis, 2017), thus being a field to be explored in the context of flexibility.

Finally, the presentation of strategies at each level showed that spatial organization is the design area repeated at all levels of flexibility. This fact helps to understand why there is no consensus on the classification of strategies to achieve flexibility. This occurs because when working in general on each design area, it is possible to work in relation to more than one level of flexibility described in this work, in the case of the area of spatial organization, for example, it would be possible to work on all three levels. However, when detailing the design area in requirements, it is observed that each requirement fits into a different level, making it possible to work on them individually. In turn, requirements can be broken down into criteria, to facilitate the application of strategies and verify, during the design process, their effectiveness. Furthermore, by systematizing the application of strategies to achieve flexibility, research into specific flexibility topics is encouraged, as their isolated analysis is facilitated.

Conclusions

This article explores in a structured way the literature on the concept of flexibility in healthcare design with the aim of systematizing ways to achieve a flexible healthcare environment. The key points observed after the bibliometric analysis were the following: an increasing number of publications from 2020 onwards, which may be associated with the COVID-19 pandemic, since more than half of the articles collected after this period were related to the pandemic, which shows that this episode highlighted the need to deepen the concept; the countries with the highest volume of articles published were the United States, Italy and Australia; the hospitalization department cited in the hospital architectural design brief was the most discussed sector in the papers.

This article contributes to a holistic and structured view of the topic to facilitate the feedback of knowledge in search of design solutions to make flexible environments. Structured design strategies are important not only for designers and researchers in healthcare environments but also for construction stakeholders, as it promotes a global understanding of what should be applied in the design and the development of cost and risk analyses. The organization proposed here was based on the analysis of strategies to achieve flexibility. From this analysis, three levels of flexibility were defined (adapt, convert, and expand) and requirements (qualitative characteristics) and criteria (quantitative characteristics), that flexible healthcare buildings must have, were extracted. Therefore, some practical implications and future work can be mentioned below.

Implications for practice

- The discussion on the types of flexibility allows the understanding that the division: flexibility to adapt, flexibility to convert, and flexibility to expand is satisfactory and thus contributes to the adoption of a common language in this area.
- From the analysis of the strategies, it was possible to understand that the concept of flexibility can be applied gradually. This means, flexibility to adapt is found at the room scale, flexibility to convert at the building scale, and flexibility to expand at the complex scale. This makes it easier for stakeholders to understand the level of strategies that need to be considered. This facilitates cross-referencing with other design disciplines, which allows for more informed decision-making.
- Structured knowledge encourages other studies to update knowledge and consequently increases the chances of its practical application, which increases the quality of built healthcare environments.

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Future research

- Development of multidisciplinary studies are necessary to better detail strategies and consequently improve implementation in design.
- Development of case studies for the extraction of quantitative data for each requirement listed.
- Development of propositional studies for the design of tools that evaluate how much the concept of flexibility is considered by the design according to the desired level.

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