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Editorial board

Fabio Bitencourt
Jorgeny Catarina Gonçalves
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Editor

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Graphic Design

Nathalia Duran

Translation

Spanish Martin y Claudia Cadillo
English Marina Jarouche

Cover Image

São Bernardo do Campo Emergency Hospital
Architecture Angelo Bucci (SPBR Arquitetos)
Photographer Nelson Kon

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Mailing address

IPH - Instituto de Pesquisas Hospitalares Arquiteto Jarbas Karman
Rua Piracuama, 21 térreo - sala 02
Sumaré, São Paulo - SP
CEP 05017-040
telefone (11) 989059107
e-mail revista@iph.org.br
endereço eletrônico www.iph.org.br/revista

Summary

Editorial 314

Marcio Nascimento de Oliveira

Article 317

Hospital building maintenance: Challenges, critical variables, and guidelines for workforce sizing

Aline Neves Gomes, Prof. Marcelo J. Meiriño and Prof. Fábio Aquino

Article 332

The contribution of digital technologies to develop projects that ensure the necessary information to run and maintain hospital assets

Adriana Tonani Mazzieiro

Article 353

Circular economy in healthcare facilities

Antonio Pedro Alves de Carvalho and Jair de Jesus Lima

Article 382

Natural lighting and design process employed by Siegbert Zanettini: Ermelino Matarazzo Hospital

Danielly Marcianny Silva Eulário, Paulo Sergio Scarazzato and Ludmila Cardoso Fagundes Mendes

Article 401

Hospital managers perceptions of the incorporation of emerging technologies and their impact on the physical infrastructure of hospitals in Santa Catarina

João Paulo Lucchetta Pompermaier, Lizandra Garcia Lupi Vergara and Patrícia Biasi Cavalcanti

Article 423

Emergency Hospital of São Bernardo do Campo: context and project

Sérgio Luiz Salles Souza and Ângelo Bucci. Curator of images and diagrams: Gabriela Pedini

Editorial

IPH Magazine reaches its 23rd edition reaffirming the historical commitment of IPH – Institute of Hospital Research Architect Jarbas Karman with the production and dissemination of technical-scientific knowledge focused on healthcare establishments' architecture, engineering, management and operation. In the current context of rapid technological transformation, increasing sustainability demands, and lifelong need of improving Brazilian hospital infrastructures, the works gathered in this issue are relevant to deepen the discussions regarding the future of health environments.

The chosen articles form an interconnected net by addressing different dimensions of hospital buildings' life cycle, from the planning and design to the operation, maintenance and adaptation of physical structures in the face of new care and technological demands. This edition highlights the importance of integrating multidisciplinary knowledge, strategic management and innovation to ensure more efficient, resilient and humanized environments.

Opening this issue, the article "Hospital building maintenance: challenges, critical variables and guidelines for workforce sizing" discusses one of the most sensitive topics for the operational sustainability of hospitals: the maintenance of physical and technological infrastructure. In a context in which the complexity of hospital building systems grows continuously, the study underlines the need for more precise methodologies to size technical teams, considering operational variables, criticality of systems and the requirements for follow-up care.

Next, the article “The contribution of digital technologies to develop projects that ensure the necessary information to run and maintain hospital assets” shows how digital tools have been transforming the processes of designing and managing assets. The incorporation of methodologies based on structured information, interoperability and digital models represents a significant step towards the efficiency of hospital operation throughout the life cycle of buildings.

The debate on sustainability gains particular emphasis in the article “Circular economy in healthcare facilities”, by Antonio Pedro Carvalho and Jair de Jesus Lima, presenting important reflections on the rational use of resources, waste management, and new strategies to reduce environmental impacts in the health sector. The incorporation of circular economy principles into healthcare facilities points to a necessary shift in paradigm considering contemporary environmental challenges.

Also adding to this edition, the study “Natural lighting and Siegbert Zanettini’s design process: Ermelino Matarazzo Hospital”, by Danielly Eulário and collaborators, revisits the work of one of the main names in contemporary Brazilian architecture, analyzing the relationship between natural lighting, environmental comfort and spatial quality in hospital design. The work puts in evidence how architectural solutions oriented towards climate and human well-being remain fundamental even in the face of advancing construction technologies.

The transformations caused by emerging technologies in the hospital environment are addressed in the article “Perception of hospital managers on the incorporation of emerging technologies and their impacts on the physical infrastructure of hospitals in Santa Catarina”, by João Paulo Lucchetta Pompermaier and collaborators. The study reveals the challenges faced by managers to adapt existing buildings to new operational, digital and care requirements, stressing the need for greater flexibility and upgradability of healthcare buildings.

Closing this issue, the article “Healthcare architecture – Public Emergency Hospital, São Bernardo do Campo”, by guest authors Sergio Salles and Ângelo Bucci, presents a reflection on contemporary hospital architecture from the perspective of a public hospital building of great relevance, emphasizing the relationship between architectural features, functionality, urbanity and humanized care.

We hope that the works published here will contribute to broaden the technical and scientific debate on the direction of hospital architecture and infrastructure in Brazil, prompting new research, innovative practices and solutions capable of responding to the present and future challenges of health environments.

We thank the authors, researchers, reviewers and collaborators who made it possible to publish this edition of IPH Magazine. Moreover, we invite our readers to continue actively participating in this network of knowledge built throughout the Institute's trajectory.

Arch. Marcio Nascimento de Oliveira, MSc.

Editor

Article

Hospital building maintenance: Challenges, critical variables, and guidelines for workforce sizing

Authors

Aline Neves Gomes Fluminense Federal University

Prof. Marcelo J. Meiriño, D.Sc Fluminense Federal University

Prof. Fábio Aquino, D.Sc. Federal Center for Technological Education

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Abstract

Hospital building maintenance is a strategic macro-process essential for patient safety and the continuity of healthcare services. Despite its relevance, a significant gap exists in the scientific literature, especially in the Brazilian context. This study conducted a systematic review and bibliometric analysis of 185 publications indexed in the Scopus database (1989–2023), using the R software and the Bibliometrix package, a widely used tool for scientific mapping and quantitative analysis of academic production. The results showed that most studies are concentrated in developed countries, while the national literature remains limited. Critical variables for sizing the workforce in hospital building maintenance were identified, including system complexity, maintenance frequency, physical area, number of assets, and team training level. Based on these findings, the study proposes guidelines based on work orders, operational indicators, and technical standards applicable to the sector. Strengthening maintenance management is essential for promoting safer, more efficient, and sustainable hospital environments.

Keywords

hospital building maintenance; workforce sizing; hospital infrastructure management.

1.Introduction

Building maintenance aims for the building to perform its functions in a way that does not hinder use or occupancy, ensuring the functionality, safety, and well-being of the users of a building. In the hospital environment, the consequences of failures in building maintenance can be serious and irreparable, besides causing hospital infection, accident or worsening of the condition of a debilitated patient. Therefore, the responsibility, discipline and technical knowledge of the team become vital elements. Each intervention requires meticulous planning, with the rigorous application of protection and signage measures. Separating dirty or contaminated and clean materials is crucial, preventing the spread of risks. The execution process should be carried out with the least possible disruption to hospital routines, minimizing any impact on patients, companions, physicians, and staff. (EBSERH, 2022).

Planning hospital building maintenance from the beginning is crucial to ensure the longevity, efficiency, and safety of the hospital building, ensuring that it continues to fulfill its fundamental mission: to care for human life (Karman, Fiorentini, and Karman, 1995).

In countries such as the United States and the United Kingdom, where healthcare systems are highly developed, investment in hospital building maintenance is seen as critical. Studies by the National Health Service (NHS), in the United Kingdom, show that, in order to reduce incidents and long-term costs, regular preventive maintenance is carried out in critical areas such as ventilation and power supply systems (Dejaco, Gramigna, and Moretti, 2019). Investment in these processes has reduced the number of corrective work orders, increasing the safety and reliability of operations.

The sizing of maintenance teams is also a well-founded practice to meet the specific needs of hospitals, considering the complex demands of hospital systems. In medium and large hospitals in developed countries, maintenance teams are organized with specialized technicians, allocated to critical sectors, which facilitates incident response in an agile way and minimizes the risks of interruptions (Chen *et al*., 2020).

However, the Brazilian scientific literature still has important gaps in how to objectively and data-based design hospital building maintenance teams. While developed countries already apply models based on performance indicators, in Brazil, reactive practices and the lack of methodologies suitable for the reality of the Unified Health System (SUS) predominate.

This article proposes an analysis of the national and international scientific production on hospital building maintenance, with emphasis on the dimensioning of the workforce. For this, we use bibliographic review and bibliometric analysis techniques, to identify the main technical, operational

and normative variables that influence the composition of maintenance teams. Therefore, we hope to contribute to the development of safer, more efficient and sustainable practices in the management of hospital infrastructure.

A preliminary version of the bibliometric results presented in this study was published in the Annals of the X CBDEH (Gomes, 2024). However, the present article includes expanded analyses, a re-examined systematic review, and an in-depth discussion of critical variables.

2. Theoretical Foundation

2.1 Building Maintenance

From the moment a building comes to life, its aging process begins. It is at this point that maintenance activities take on a crucial role, transcending the mere correction of failures to become a strategic area for the lasting performance of the structure. Effective maintenance ensures that the building's occupancy achieves organizational goals and objectives, ensuring its functionality and appreciation over time (Cisne and Albuquerque Junior, 2021).

Negligence in building maintenance planning can generate a domino effect with negative consequences. Significant capital investments can be wasted when equipment and structures deteriorate prematurely, leading to lost warranties and the need for costly repairs. In addition, the lack of proper maintenance can compromise the safety of users, negatively impact productivity in the environment and, ultimately, discourage new investments in the system, creating a vicious cycle of decline (Lavy and Bilbo, 2009).

Building maintenance is organized into three pillars: safety, functionality and comfort, ensuring that the building offers adequate conditions to users and that investments are preserved in the long term (Guimarães, 2012). Hospital building maintenance is closely intertwined with the health service chain, assuming a strategic and multifaceted role. Its primary mission is to guarantee the safety and longevity of care buildings, ensuring an environment conducive to the recovery and well-being of patients. Hospital maintenance is an essential activity, requiring technical expertise, meticulous planning, impeccable organization, and efficient management (EBSERH, 2022).

Given this scenario, it is imperative to rethink the management of hospital maintenance, adopting effective measures to secure the full operational capacity of equipment and facilities. Investing in qualified professionals, optimizing procurement processes, and improving infrastructure are essential actions to avoid wasting resources and, above all, save lives.

Hospital building maintenance management, in addition to seeking the integrity and efficiency of systems, needs to make sure that the continuity of operations occurs without interference in clinical care. Karman and Fiorentini (1995) point out that, in hospitals, interventions need to be carefully planned and executed, preferably carried out at times and in areas that reduce the impact on patient care as much as possible. Performing scheduled maintenance at times of lower flow of people or closing sectors is a common practice, aiming to reduce the risk of service interruption and user discomfort (Dejaco, Gramigna, and Moretti, 2019).

In addition, hospital building maintenance involves specific challenges, such as managing potentially contaminating materials and guaranteeing that there will be no cross-contamination between clean and wasted areas. Studies show that, when well performed, hospital building maintenance contributes to the improvement of hospital safety and health indicators, in addition to generating savings by avoiding emergency repair costs and increasing the longevity of equipment (Wong, Olanrewaju, and Lim, 2021).

Therefore, hospital building maintenance is a complex and highly specialized process, which involves detailed planning, continuous training of the professionals involved, and constant monitoring of performance indicators. In this way, effective management of hospital building maintenance not only protects assets, but also promotes the safety and well-being of users, contributing to the sustainability and efficiency of health services.

2.2 Bibliometrics

Bibliometrics is an essential technique for organizing, cataloging and analyzing academic productions in a way that is systematic and statistic driven. This method makes it possible to map the evolution of a topic over time, identifying relevant changes, trends, and connections in the existing literature (Aria and Cuccurullo, 2017). It is widely used to structure information in areas that require in-depth understanding, such as hospital building maintenance, an essential field for the functioning of health institutions, but still lacking detailed research.

According to Aria and Cuccurullo (2017), scientific mapping not only contributes to research but also plays a strategic role in formulating effective policies and practices. To this end, bibliometrics is based on three classic laws: Bradford's Law, which investigates the productivity of journals; Lotka's Law, focused on the productivity of authors; and Zipf's Law, which examines the frequency of terms in scientific texts (Guedes and Borschiver, 2005).

3. Methodology

This study adopts a methodological approach composed of a quantitative bibliometric analysis and a descriptive literature review, with the objective of mapping the scientific production on hospital building maintenance and identifying the main variables that influence the sizing of the workforce in this context.

For the bibliometric analysis, the classic indicators available in the Bibliometrix package were used, including productivity of authors, journals and countries; analysis of co-authorship networks; bibliographic coupling; occurrence and co-occurrence of keywords; in addition to the temporal evolution of publications. The database was standardized with the removal of duplicates, harmonization of author names, and unification of keywords. Bradford, Lotka, and Zipf metrics were also applied to identify core journals, author productivity, and term frequency. The results were generated by Biblioshiny, Bibliometrix's graphical interface, which allowed the construction of scientific maps, trend graphs and thematic clusters.

Data collection was carried out in the Scopus database, widely recognized for the quality and scope of its scientific publications. The research combined two prompts, "building maintenance" and "health", along with the logical operator "AND" to identify documents that addressed both themes in a correlated way. The collected data was processed using the R software and the Bibliometrix package, providing a robust and visually understandable quantitative analysis (Aria and Cuccurullo, 2017).

Moreover, there was a qualitative synthesis of the most relevant publications, identifying the methods, indicators and recommended practices for the dimensioning of the workforce in hospital maintenance. Variables such as technical complexity of the systems, frequency of preventive and corrective maintenance, physical area of the hospitals, location of critical equipment, average response time to failures and performance indicators (KPIs) were extracted. The triangulation between quantitative and qualitative data allowed for a more comprehensive and grounded understanding of existing practices and gaps in the field.

4. Results

4.1 Bibliometrics Analysis

Data collection covered the period from 1989 to 2023, adding up to 185 publications distributed into 120 different sources (Illustration 1). This number of studies, over three decades, shows a significant lack of research in the area, especially in view of the rapid technological advancement and its direct implications for hospital management.



Illustration 1 . General Information. Source: author's production using the "R" and "Bibliometrix" software.

Annual scientific production showed moderate and irregular growth (Illustration 2), reaching its peak in 2012, with 17 articles published. However, the average increase of 5.41% per year remains insufficient given the complexity and importance of the issue. Fewer than 03 publications were recorded during 20 of the 34 years analyzed, evidencing the absence of a continuous and consistent evolution.

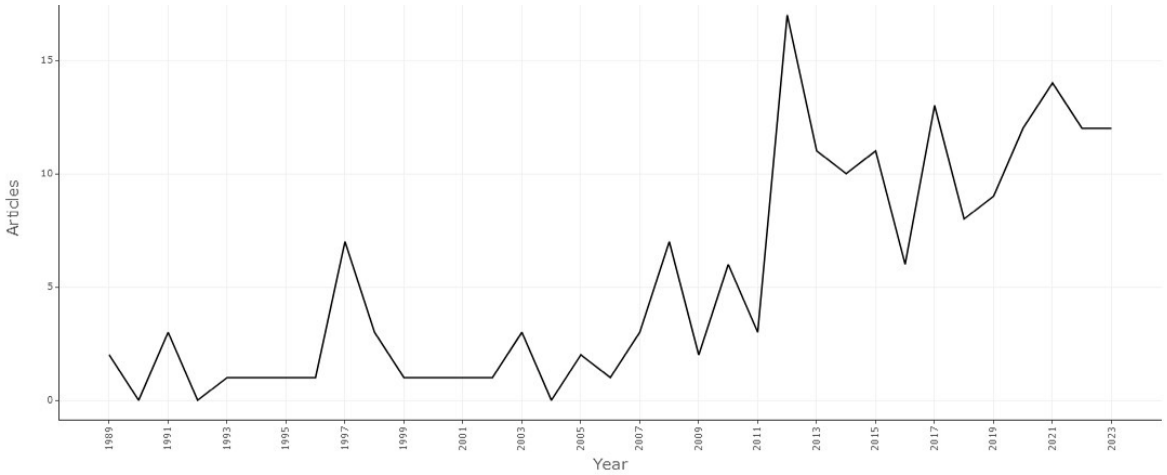


Illustration 2 . Annual scientific production. Source: author's production using the "R" and "Bibliometrix" software.

The most influential sources identified were, for the most part, health institutes, with a higher concentration of publications from 2010 onwards (Illustration 3). Authors such as Igal Shohet and Sarel Lavy, although recognized for high-quality and impactful work, have not actively published in the area since 2010, which may suggest a stagnation in recent and most relevant contributions (Illustration 4).

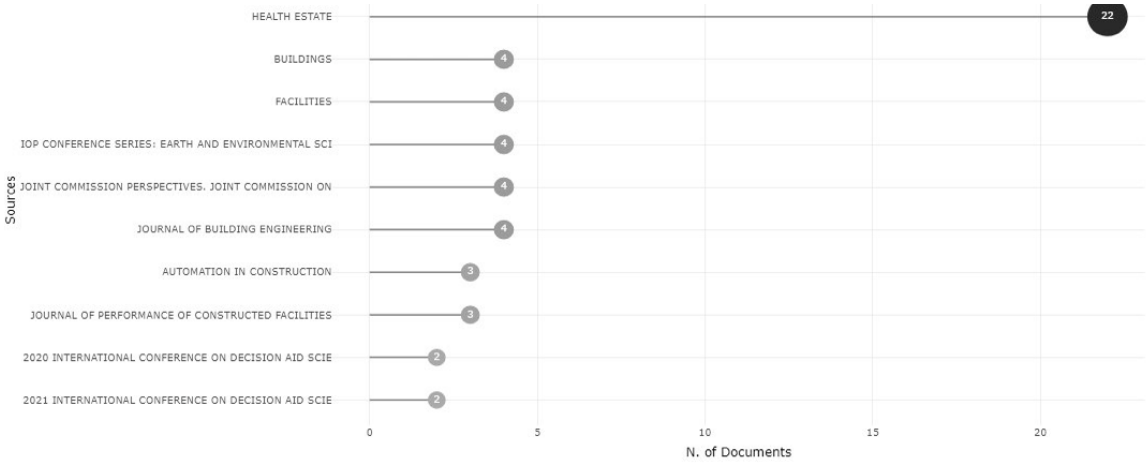


Figure 3 . Relevant sources. Source: author's production using the "R" and "Bibliometrix" software.

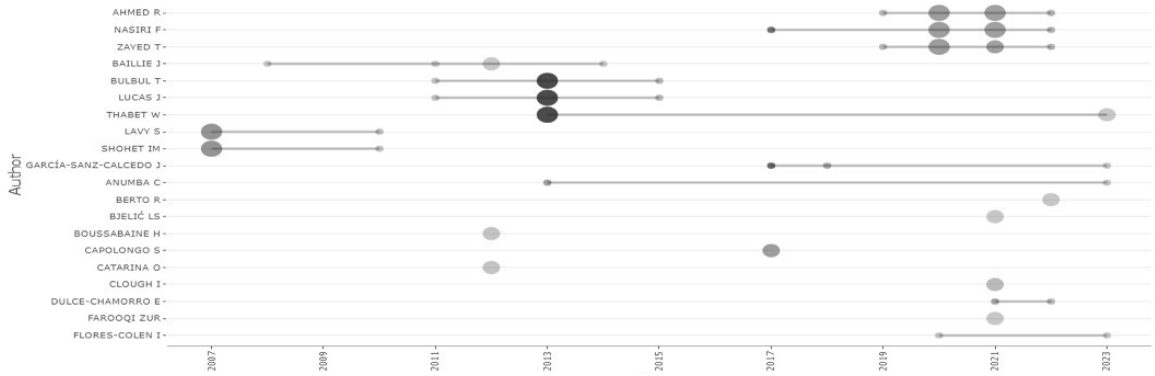


Illustration 4 . Scientific production over the years. Source: author's production using the "R" and "Bibliometrix" software.

The analysis revealed a significant geographic concentration of scientific production, with 156 of the 185 articles originating in the United States, which restricts the global applicability of the results. This inequality particularly affects countries such as Brazil, where technological, cultural, and socioeconomic differences directly influence practices and demands related to hospital building maintenance.



Illustration 5 . Scientific production by country. Source: author's production using the "R" and "Bibliometrix" software.

The study demonstrates the lack of up-to-date and in-depth research on hospital building maintenance, a key area for the safety and efficiency of operations. The concentration of publications in a few authors and regions reinforces the urgent need for new studies that contemplate the specificities of different realities and contexts.

4.2 Variables to Consider for a Sizing Methodology

According to the literature review regarding hospital building maintenance, the sizing of teams is a key element to ensure the operability, efficiency and safety of hospital facilities. This need becomes even more evident due to the importance of preventive maintenance and the urgency in meeting corrective demands, which, if not addressed in a timely manner, can directly impact patient safety and continuity of care (Chen *et al*., 2020; Guimarães, 2012). For the adequate dimensioning of these teams, some critical variables were identified in the literature that need to be considered.

Therefore, the first critical variable that influences the sizing of the building maintenance team is the complexity of the installed systems. In hospitals, in addition to conventional building infrastructure systems, such as lighting, electricity, and hydraulics, there is a set of specialized systems that require continuous and highly qualified attention, such as air conditioning systems, infection control systems, medical gas systems, pressurized ventilation systems in operating rooms, as well as redundant electrical networks and power generation systems for hydraulic emergency (Karman, Fiorentini and Karman, 1995; Lavy and Bilbo, 2009).

The presence of these systems requires professionals with specific training for each technical area, which means that the sizing of the team should not be based only on the number of professionals, but also on their level

of technical qualification. In a hospital environment, systems such as ventilation, medical gases, and electrical networks require specialized technicians in each area. Failures in these systems can have serious consequences, such as the interruption of critical procedures or health risks to patients and employees, which reinforces the need for a highly specialized and trained building maintenance team (Dejaco, Graigna, and Moretti, 2019; Jesumoroti, Olanrewaju and Khor, 2022).

On that ground, an additional relevant aspect in the sizing of the team is the necessary specialization of the professionals. Consequently, the sizing of the team must also prioritize the technical qualification and continuous training of the professionals involved, in accordance with national regulations, such as the NR-4, NR-10, NR-12 and NR-33 standards of the Brazilian Association of Technical Standards (ABNT, 2018; 2019; 2020; 2021).

Another fundamental factor highlighted by Xenos (1998) is the frequency of preventive and corrective maintenance. To keep a hospital operating efficiently and safely, it is crucial to take a proactive approach through regular preventative maintenance. With regard to hospital building maintenance teams, key factors must be considered, such as the workload associated with preventive and corrective maintenance, the average response time to failures, and the technical qualification required to deal with the various systems present in the hospital (Fotovatfard and Heravi, 2021). In addition, in hospitals, the response time to correct unforeseen failures is critical, especially when they involve systems that directly impact the lives of patients, such as life support systems or electricity supply. Therefore, the number of technicians available must be sufficient to handle not only preventive activities, but also to respond quickly to any emergency or operational failure that requires immediate intervention.

The size of the built area and the dispersion of critical equipment in the different sectors of the hospital are fundamental variables in the dimensioning of hospital maintenance teams, especially in large hospitals. The complexity and physical extent of the facilities, which include intensive care units, surgical centers, laboratories and support areas, require strategic planning to secure that the maintenance team is sized and positioned in order to serve all these areas efficiently (Guimarães, 2012; Dejaco, Gramigna and Moretti, 2019). According to Xenos (1998), the distribution of the maintenance team must consider both the criticality of the equipment and the physical location of the assets, which can significantly reduce the response time in cases of failure. This approach is corroborated by studies that indicate that the creation of specialized teams, allocated according to the importance of the systems and the proximity to critical hospital sectors, allows for greater speed and effectiveness in interventions (Fotovatfard and Heravi, 2021). In

addition, the dispersion of teams based on geographical zones within the hospital, as suggested by Wong, Olanrewaju, and Lim (2021), facilitates the execution of maintenance in an agile manner and minimizes the impact of interruptions in essential services, reinforcing the importance of structured maintenance management to optimize resources and improve the operational safety of hospital environments.

The use of performance indicators (KPIs) is widely recommended as a tool for the continuous evaluation of the effectiveness of maintenance teams. Indicators such as **average response time to corrective work orders, frequency of preventive maintenance**, and **failure recurrence rate** allow adjustments in the sizing and allocation of the team according to operational needs (Fotovatfard and Heravi, 2021). According to studies conducted by Xenos (1998), the analysis of these indicators is crucial to ensure that the maintenance team meets the demands of the hospital efficiently and that it is prepared for rapid interventions in critical systems. Additionally, recent studies have shown that hospitals that adopt automated monitoring systems are able to identify and resolve problems more quickly, increasing staff efficiency and reducing the number of corrective work orders (Ebiloma, Aigbavboa, and Anumba, 2023).

The study by Enshassi and El Shorafa (2015), carried out in the Gaza Strip, highlights that the dimensioning of manpower for hospital building maintenance should be based on performance indicators, such as the **Maintenance Efficiency Indicator (MEI)**, which measures the efficiency of the resources allocated in relation to the physical condition of the buildings. According to the authors, "MEI provides a quantitative indication of the efficiency with which maintenance activities are implemented, allowing adjustments in the allocation of resources and prioritization of preventive strategies" (Enshassi and El Shorafa, 2015, p. 222). This approach is essential to ensure a balance between corrective and preventive demands, avoiding overloads and optimizing the performance of maintenance teams. The approach considers the variability in the conditions of buildings and the complexity of hospital systems, demonstrating that inadequate planning can overload professionals with emergency demands, compromising the efficiency and functionality of the facilities. The use of KPIs allows you to optimize the performance of teams, adjusting human resources according to the specific needs of health institutions, enabling more effective and cost-effective maintenance.

A design methodology must comply with applicable national and international regulatory standards, such as NR-4, NR-12 and NR-33, which establish safety standards and specific procedures for building maintenance facilities and activities. Specific regulations for hospital environments, such as those of the National Health Surveillance Agency (Anvisa), also guide the planning and execution of maintenance (ABNT, 2018; ABNT, 2019; ABNT, 2020; ABNT, 2021).

The literature also suggests that the dimensioning of the hospital maintenance team should be a dynamic process, regularly reviewed to adapt to changes in the hospital environment, such as the introduction of new equipment and the expansion of care areas (Chen *et al*., 2020). In this sense, it is essential that the dimensioning includes a safety margin, given the unpredictable nature of many hospital interventions, in addition to the possibility of health and emergency crises, which may require quick and accurate responses (Xenos, 1998; Karman, 1994).

According to Picchiai (2009), a researcher at the Program for Advanced Studies in Hospital and Health Systems Administration (PROAHSA), Coelho (2006) emphasizes the strategic importance of dimensioning building maintenance to ensure the continuous operation of hospital infrastructures. In this context, outsourcing is pointed out as an efficient practice, and the presence of professionals, such as civil engineers, electricians and bricklayers, is recommended, in the proportion of one group for every 200 hospital beds, with the objective of meeting both routine and emergency demands (Picchiai, 2009, p. 142). Picchiai (2009) also reports that Coelho (2006) highlights the need to plan the maintenance sector considering the specificities of hospital infrastructures, such as the technological park installed and the qualification of the professionals involved. In addition, technical supervision, often performed by engineers, is considered essential to coordinate building and equipment maintenance activities, avoiding impacts on hospital services (Picchiai, 2009, p. 142).

Anvisa's RDC No. 2/2010 (BRASIL, 2010) establishes essential requirements for the physical infrastructure in health services, with the objective of ensuring safety, functionality and adequate hygienic-sanitary conditions. Although it deals with aspects related to building maintenance, the resolution does not offer specific guidelines aimed at the sizing of maintenance teams. This gap reinforces the need for specific methodologies that consider the particularities of the hospital environment.

In turn, ABNT NBR 5462:1994, which addresses reliability and maintenance, presents definitions of terms and concepts that are fundamental to the management and analysis of systems, equipment and facilities. Although this standard does not directly address team sizing, it does provide a valuable theoretical basis for decision-making in this field. However, its applicability is often more aligned with industrial contexts than with the hospital environment.

5. Final Considerations

Hospital building maintenance is an essential activity to guarantee patient safety, service continuity, and the efficiency of health infrastructure. This study showed a significant gap in the national scientific production on the sizing of the workforce in this sector, especially in large public institutions. The bibliometric analysis demonstrated the concentration of the literature in developed countries, which makes it difficult to apply its models directly to the Brazilian context, marked by specific technical, operational and regulatory challenges.

In view of this scenario, the proposal is to develop its own methodologies, based on historical data, performance indicators and applicable regulations, with a view to guiding the efficient planning of maintenance teams. In addition, it future research must deepen the empirical analysis in Brazilian hospitals, contributing to the formulation of guidelines that are more adapted to the local reality. Therefore, the effective management of hospital maintenance must be recognized as a structuring strategy for the quality of care and the sustainability of health services.

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Authors

Aline Neves Gomes Holds a degree in Architecture and Urbanism from the Federal University of Pará (UFPA), a degree in Mathematics from the State University of Pará (UEPA) and a Master's degree in Management Systems from the Fluminense Federal University (UFF). Six years work experience at the Beneficencia Portuguesa Hospital of Pará, also in the area of hospital architecture. Currently manages the Construction Work and Facilities Service of the National Cancer Institute (INCA), focusing on the integrated management of hospital building maintenance.

E-mail: ang@alprojetos.com

Marcelo J. Meiriño Architect and Urban Planner from the Federal University of Rio de Janeiro (UFRJ), with a Master's and Doctorate in Civil Engineering from the Fluminense Federal University (UFF). Occupational Safety Engineer and specialist in Energy Efficiency, working in the development of innovative and sustainable solutions. Marcelo is a professor at UFF in the master's and doctoral programs in Management Systems and coordinates the Center for Innovation and Technology for Sustainability (NITS/UFF). Coordinator of the Research Group on Innovations and Sustainability (CNPq/UFF) and of the National Congress of Excellence in Management. Marcelo was an exchange student at the IVLP, of the US Department of State. Marcelo works as a consultant in R&D projects (ANEEL) and in indexed scientific journals.

E-mail: marcelojm@id.uff.br

Fábio Aquino Business Administrator graduated from the Federal Rural University of Rio de Janeiro (UFRRJ), with a Master's and Doctorate in Management Systems from the Fluminense Federal University (UFF). Worked for 12 years in the private sector, in the financial and real estate sectors, as head of the Purchasing Department and Research Division at UFF, where he currently is a Chancellor. Served as a public contract manager in the Olympic legacy (2021–2023), taught at the Paraíso College, and is currently a professor at CEFET/RJ. Author of several articles published in congresses and scientific journals.

E-mail: faquin98@gmail.com

Article

The contribution of digital technologies to develop projects that ensure the necessary information to run and maintain hospital assets

Author

Adriana Tonani Mazzieiro Federal University of Minas Gerais – UFMG

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Abstract

Hospitals are complex buildings that require systematized and highly accurate operation and maintenance management. This research aims to discuss the specificities of these healthcare units and understand how digital technologies can contribute to the development of projects that aim to answer the information requirements necessary for this phase of their life cycle. The methodology is exploratory and begins with a literature review, followed by a study of two examples that consider different digital technologies for project development and the recording of information necessary for facility management. Although the cases apply diverse digital technologies, they are similar in their understanding that the information to be preserved and recorded for future use is present since the design at the initial phase of the asset's life cycle, throughout the construction phase, until it is handed over to the operation and maintenance phase.

Keywords:

digital technologies, hospitals, facilities management, operation and maintenance.

1. Introduction

Hospitals are complex functional facilities, that demand great attention from those involved in their administration regarding the both the infrastructure and medical equipment. With the development and ever-growing specialization of the various areas of medicine, hospital buildings increasingly need to meet diversified architectural spatial needs, to keep a high quality of care.

Due to the specific needs of healthcare settings, architects and urban planners must employ a systemic view, in order to respond to the physical-functional complexities of the buildings. At the same time, they must ensure that the qualities of humanization and environmental comfort necessary for the well-being of patients, take into account the shift in the contemporary paradigm of hospitals, now viewed as more than places of healing.

The amount of information to be stored, both in relation to physical infrastructures and hospital medical equipment, has grown exponentially, and the need to organize this information in an objective and systematized way is imperative for the effective operation and maintenance of a hospital.

The advancement of digital technologies used for designing, recording and storing information about built assets, already facilitated with the emergence of CAD – *Computer-Aided Design* – platforms has been significantly increased with the emergence of BIM – *Building Information Modeling platforms*, to the extent that not only the geometric data of the buildings are recorded, but also the pertinent information for future use, which can be made available in the three-dimensional model.

More assertiveness in the activities pertaining to maintenance of hospital buildings means that this crucial operation has become more effective, since the information necessary to remedy any complication that may occur is now available more directly to the user, increasing both the speed and the quality of response in the services provided to patients.

2. Rationale

The basis for this study was the realization of the importance of the management of the operation and maintenance activities of hospital assets. This fact was identified in the direct observation of the processes in several healthcare units where the author was able to work, and on a bibliographic review on the subject, where it was demonstrated how digital technologies could contribute to the improvement of such management.

This research also was based on the understanding that the life cycle of a hospital building begins with the feasibility study, and develops according to the following phases of architectural design and other engineering projects, such as construction, commissioning, operation and maintenance, until it must undergo renovations, be dismantled and/or demolished.

Given their high level of complexity, hospitals are buildings where the management of the built environment needs to be aligned with the most advanced operation and maintenance processes, in order not only to deliver a good operational result, but, mainly, to meet the demand of urgency presented in some of the maintenance situations. As quoted by Professor Jarbas Karman, in his book *Manutenção e Segurança Hospitalar Preditivas*:

> The hospital is considered one of the most complex projects from the point of view of architecture, engineering, facilities, equipment, security, as well as technology and administration. Their equipment, appliances, installations and supplies are of continuous and constant use (Karman, 2011, p.41).

From the earliest stages of hospital design, architects and urban planners should establish design principles that facilitate the future management of hospital assets by operation and maintenance teams. These principles should be consistently incorporated throughout the development of detailed design documents across all disciplines and carried forward into the construction phase. During construction, all modifications made to the original design should be accurately documented through as-built records, ensuring that the resulting information remains current and reliable. This updated documentation provides a trustworthy foundation for the efficient operation, maintenance, and long-term management of hospital facilities.

In recent years, several serious fires have occurred in Brazilian hospitals, highlighting the critical importance of effective facility management and fire safety systems. One of the most significant incidents took place in September 2019 at Badim Hospital in Rio de Janeiro, resulting in the deaths of 25 patients. Other major events followed, including a fire at Lourenço Jorge Municipal Hospital in October 2020, caused by a short circuit in the main electrical switchboard. Although the incident was successfully contained without fatalities, it underscored the vulnerability of critical infrastructure. In the same year, another fire broke out in Building 1 of the Federal Hospital of Bonsucesso, also in Rio de Janeiro, requiring the evacuation of approximately 200 patients and resulting in two fatalities. More recently, at Santa Casa de Misericórdia in Belo Horizonte, the state's largest hospital with approximately 1,200 beds, a fire in the intensive care unit on the tenth floor—reportedly triggered by an oxygen leak associated

with medical equipment—forced the emergency evacuation of patients on stretchers and in wheelchairs. The incident resulted in the deaths of three patients and the hospitalization of 25 staff members due to smoke inhalation[1].

Given the severity of these incidents and the recurring operational emergencies observed in Brazilian hospitals, it is imperative that healthcare facility projects incorporate the information requirements necessary for the operation and maintenance phase from the earliest stages of design. This includes establishing design principles and management strategies supported by methodologies that ensure the accuracy, integrity, and continuity of information throughout the building lifecycle. Such an approach enables maintenance teams to respond more effectively to routine operational demands as well as emergency situations, thereby reducing risks, improving decision-making, and minimizing potential human, operational, and financial losses.

3. Objectives

The primary objective of this article is to demonstrate how digital technologies can support the operation and maintenance of hospital facilities throughout their lifecycle, both in existing buildings undergoing renovation and physical modernization and in newly constructed healthcare facilities.

4. Methodologies

This study adopted an exploratory research approach (Gil, 2002, p. 41), based on a qualitative literature review addressing the importance of the operation and maintenance phase within the life cycle of hospital assets and the role of digital technologies in supporting the information requirements associated with this stage. Subsequently, case examples were analyzed to illustrate the importance of incorporating asset information requirements during the early stages of architectural design, thereby ensuring that the data necessary for effective operation, maintenance, and facility management are systematically considered throughout the project development process.

1 All the occurrences mentioned attest to the need to consider the importance of immediate access to information about the facilities of physical infrastructures and an integrated monitoring system for maintenance and operation, increasing the quality and efficiency of operations.

5. Literature Review

Hospital buildings require constant operation and maintenance processes, given their complexity and the intensity of use of their physical-functional structures. Many existing hospital buildings need constant actions to requalify their spaces, due to their physical negligence or their inadequacy

to the new functional demands, and do not have minimum records of sufficient information to provide adequate support to the operation and maintenance phase.

> More and more the hospital reveals itself to be a *permanent construction site and institution waiting for completion* - changes, innovations, technological advances, changes, renovations and new works follow one another; equipment and facilities are more frequently replaced; the useful life of products and the fight against physical and functional obsolescence become more present - generating the need for answers, planning, actions and investments that are always more agile (Karman, 2011, p.45).

Providing the information necessary for asset management should be a concern of the senior management[2] of hospital institutions, which should determine, within their organizational structure, the necessary information requirements for the operation and maintenance processes to occur effectively (ABNT NBR ISO 19650-1:2025).

When projects are developed using CAD-based[3] workflows, they must be fully coordinated across all design disciplines and comprehensively document the information required for the operation and maintenance phase. Even when documentation is limited to 2D drawings, schedules, or tabular records, it should accurately identify the location, characteristics, and specifications of the building's critical infrastructure systems and assets. Such documentation facilitates access to essential operational data by providing a complete and reliable record of the existing networks, equipment, and building systems, thereby supporting effective facility management throughout the asset's lifecycle.

The use of CAD (Computer-Aided Design) as the primary platform for project documentation remains the prevailing reality in most Brazilian hospitals. The transition to BIM (Building Information Modeling) requires substantial investments in hardware, software, and workforce training, as well as long-term strategic planning and dedicated financial resources for successful implementation. Consequently, many healthcare institutions continue to rely on conventional CAD-based documentation despite the recognized advantages of BIM.

Once BIM has been implemented, however, and provided that the information model has been properly structured to support facility management, it can serve as a comprehensive repository of asset information throughout the building's lifecycle. By integrating architectural, engineering, and asset data with operation and maintenance systems, BIM enables more efficient maintenance planning, improved decision-making, enhanced traceability of building components, and more effective management of healthcare facilities, representing a significant advancement over traditional documentation methods.

2 According to the ABNT NBR ISO19650 standard, senior management must determine the AIR – Asset Information Requirement, so that the asset information requirements in the AIM – Asset Information Model are met, in the operation and maintenance phase, when using the BIM methodology.

3 Although the construction industry is evolving towards the implementation of BIM in all sectors of the economy, the healthcare sector still faces several difficulties to adopt it. Nonetheless, that cannot compromise the registration of the information necessary for the operation and maintenance phase of hospitals, that is why CAD technologies are also necessary.

The operation and management phase constitutes the longest stage in the life cycle of a building and, consequently, accounts for the largest share of its total lifecycle costs. Therefore, improving the quality, accessibility, and reliability of asset information during this phase has a direct impact on operational efficiency, maintenance performance, and the long-term sustainability of healthcare facilities.

> Focusing on the use and operation phase of the life cycle of an enterprise, it is understood that it is the most expensive because it is the longest in relation to the others. Consequently, it is the stage that benefits the most from the history of information in a structured way, as it accumulates data on the evolution of the enterprise from the conception stage. In this phase, specific information is generated, which can be used to improve the performance of the projects, such as service requests, maintenance schedules, inspection reports, downtime and operations costs. (Mota; Moreira, 2025)

Due to the characteristic longevity of constructed buildings and, especially, the high costs of global investments in construction and equipment installations in hospital buildings, enhancing an efficient management of its physical assets and medical equipment becomes essential, not only to preserve its operational results, but, mainly, to respond to the safe and quality care of its users.

Asset management in Brazil is addressed by a series of technical standards translated from the international ISO 55000X series. Assets can include something that has real or potential value, tangible or intangible, financial or not[4]. The Brazilian standard ABNT NBR ISO 55000 defines terminology, overview and principles aimed at the expected results for an effective asset management process (ABNT NBR ISO 55000, 2024).

> Asset management can be understood as the management of inventories, plants, and equipment through records that list information. [...] These assets, which consist of the physical building, systems, surrounding environment, and equipment, must be maintained, upgraded, and operated with an efficiency that satisfies both the owner and the users in the most cost-effective way possible. (Mota; Moreira, 2025)

Facilities and clinical engineering are the assets whose management is strategically the most important for the operation and maintenance phase, since they directly affect safety, physical integrity of users and quality of healthcare performance. The processes for recording information about physical infrastructures and medical equipment may vary according to the digital technology applied, but the types of information to be stored can be systematized and standardized in any methodology adopted.

According to IFMA – *International Facility Management Association*, the management of facilities "is an area of knowledge whose organizational

4 In the case of this work, assets with real and tangible values stand out as the most important for recording projects, both in 2D and in BIM models, since the main focus of hospital operation and maintenance, in this research, is centered on the physical infrastructures of buildings and medical equipment necessary for quality care in health institutions.

function is to integrate people, places and processes within the built environment with the purpose of improving people's quality of life and the productivity of the main business" (IFMA, 2025).

In Brazilian Standard ABNT NBR ISO 41018:2023, the concept of facilities management is "one that integrates multiple disciplines to have an influence on the efficiency and productivity of the economies of organizations, societies, and communities, as well as the way in which individuals interact with the built environment".

At operational level, the management of facilities is responsible for handling all the physical infrastructures necessary for a building to function at its maximum efficiency and safety.

Clinical engineering management, according to Abeclin – Brazilian Association of Clinical Engineering is...

> "...the area of knowledge that must deal with engineering techniques in the management of health equipment in order to ensure the traceability, usability, quality, efficacy, effectiveness, safety and performance of this equipment, in order to promote patient safety". (ABECLIN, 2025)

At operational level, clinical engineering ensures the perfect functioning of medical equipment.

Regarding the information of the assets that must be managed in the operation and maintenance phase, the British Standard BS 8210:2012 establishes a list of the main records to be managed. According to the standard, asset data must include information such as the cataloguing of the identification number, location, useful life expectancy, discrimination, model and manufacturer, date of manufacture, supplier, date of acquisition and installation, cost, parts and cycle for replacement, energy consumption, depreciation and the final post-depreciation value, the maintenance cycle and the cost and type of training required for the maintenance operator (BS 8210:2012 *apud* Mota; Moreira, 2025, p.188).

This information can be recorded in hospital maintenance management systems, CAFM – Computer *Aided Facility Management/CMMS – Computerized Maintenance Management Systems*, which manage infrastructures and maintenance work orders in an ordinary way, or integrated into more advanced systems, which create the connection between FM – *Facility Management* systems and BIM modeling for asset management. The advantage of having an AIM model – *Asset Information Model* of the building, defined in the Brazilian Standard ABNT NBR ISO 19650-1:2025 as the information model related to the operation phase of an asset is that it associates geometric data with non-geometric data, in addition to being loaded with the information necessary for a more systematic management of the processes involved (ABNT NBR ISO 19650-1:2025).

FM – *Facility Management* systems, which enable integration with AIM – *Asset Information Model*, can enable this connection in different ways: directly, in which BIM models, in native or open formats ".ifc" – *Industry Foundation Classes*, can be inserted into the systems; through a connection through the development of an API – *Application Programming Interface*, an interface that facilitates the exchange of information and the integration of functionalities; or indirectly, using COBie – *Construction Operations Building Information Exchange*, an MVD – *Model View Definition*, a subset of the ".ifc" that selects from the model only the information necessary for the operation and maintenance phase, providing the non-geometric data interchangeable between the AIM model and the FM – *Facility Management systems*.

> COBie (Construction Operations Building Information Exchange) is a specification for the capture and delivery of design/ construction information to **Facility Managers**. COBie **Specifications** can be collated using a spreadsheet template or a COBie-enabled software solution. (BIM Dictionary, 2025)

In the following examples, it is be possible to understand the assumptions that can be adopted from the initial phase of the architectural project to meet the information requirements necessary for the operation and maintenance phase of assets and the different contributions of digital technologies that can help in this phase of the life cycle of hospital enterprises.

6. Project strategies to meet the information requirements for the operation and maintenance phase of hospital assets

6.1 Case A – Requalification of the building of the former Hilton Rocha Hospital – digital technology adopted: CAD – Computer-Aided Design

The Hilton Rocha Hospital, in Belo Horizonte, was designed by architect and professor Jarbas Karman in the 70s. The building functioned as the Hilton Rocha Institute, a hospital dedicated to ophthalmological treatments and ended its activities in 2002, years after the death of Dr. Hilton Rocha in 1993, for economic reasons. In 2009, it was purchased at a public auction by a group of doctors and, as of 2017, it went through a process of construction of the approved renovation and expansion project for its physical restructuring. Illustration 1 shows the existing hospital before its renovation and expansion.



Illustration 1 . Hilton Rocha Hospital before the renovation and expansion. Source: collection of the architects responsible for the renovation and expansion of the hospital, 2011.

Although, in the construction industry, the digital transformation with the use of BIM already occurred when the plans for the renovation and expansion of the hospital began, by decision of the owners, the projects were developed in CAD. Even using digital technology, without the use of geometric models, some design premises were adopted to meet the hospital's planning requirements, with the focus on the operation and maintenance phases of the building, distributed in the following steps:

a. Topographic and architectural survey of the existing hospital: aiming at registering the previous constructive potential to define the capacity of the old building to receive the necessary infrastructures to serve the different areas and equipment of the new hospital, as well as the structural feasibility for the construction of the required expansions. The analysis provided by these surveys aimed to investigate the pre-existing qualities of the building and its correspondence to the new operational configuration, making the most of its physical characteristics. The registration of the original structure, with information on dimensions and heights of the existing built elements, served as a basis for the establishment of locations of drilling for shafts of installations and horizontal distributions of infrastructures, in such a way that their positioning was governed by a structured organization, aiming at the as-built registration for future operation.

Therefore, the projects resulting from the surveys could be superimposed on plans and sections of the new proposal, to understand the technical feasibility of this strategy (Illustration 2).

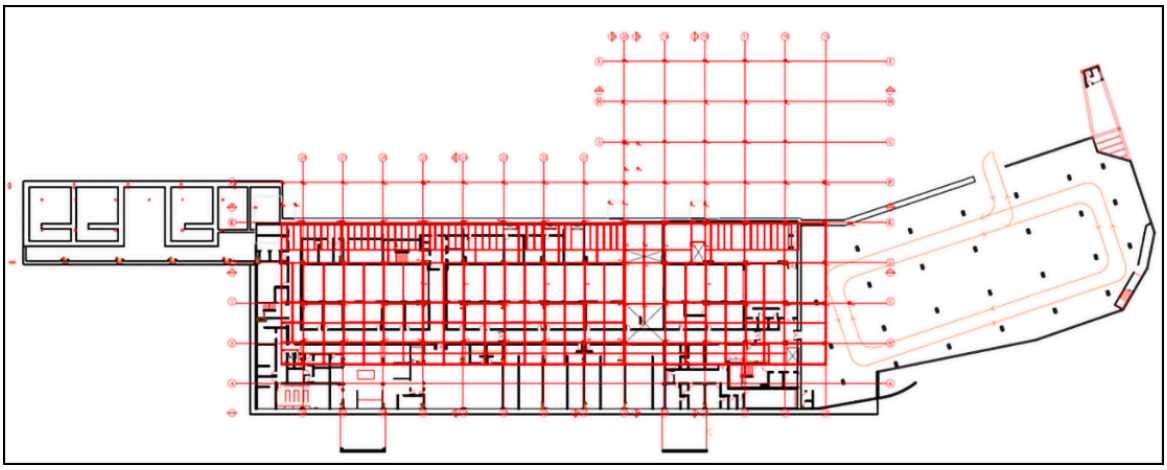


Illustration 2 . Superposition of the existing concrete structure and the expansion areas on the second floor. Source: technical collection of the architects responsible for the renovation and expansion of the hospital, 2017.

b. Master plan: from the survey and registration of the existing conditions, and the functional requirements established by the owners, the planning of the location of the hospital's care sectors was initiated, establishing a logic of spatial correspondences between the pre-existing built areas and the new areas programmed for the expansion of the services offered, considering the proximity between areas of related functions, and privacy for units to be more preserved from the public.

With the location of the new sectors of the hospital, it was possible to determine, from the initial phase of the project, the location of the strategic areas of building infrastructures and the main medical equipment, which require intense operation and maintenance processes. Consequently, the new sectors have already been designed to facilitate access to maintenance, positioning and dimensioning of technical areas, as well as proximity to the areas served and the choice of infrastructure systems appropriate to the new hospital configuration (Illustration 3).

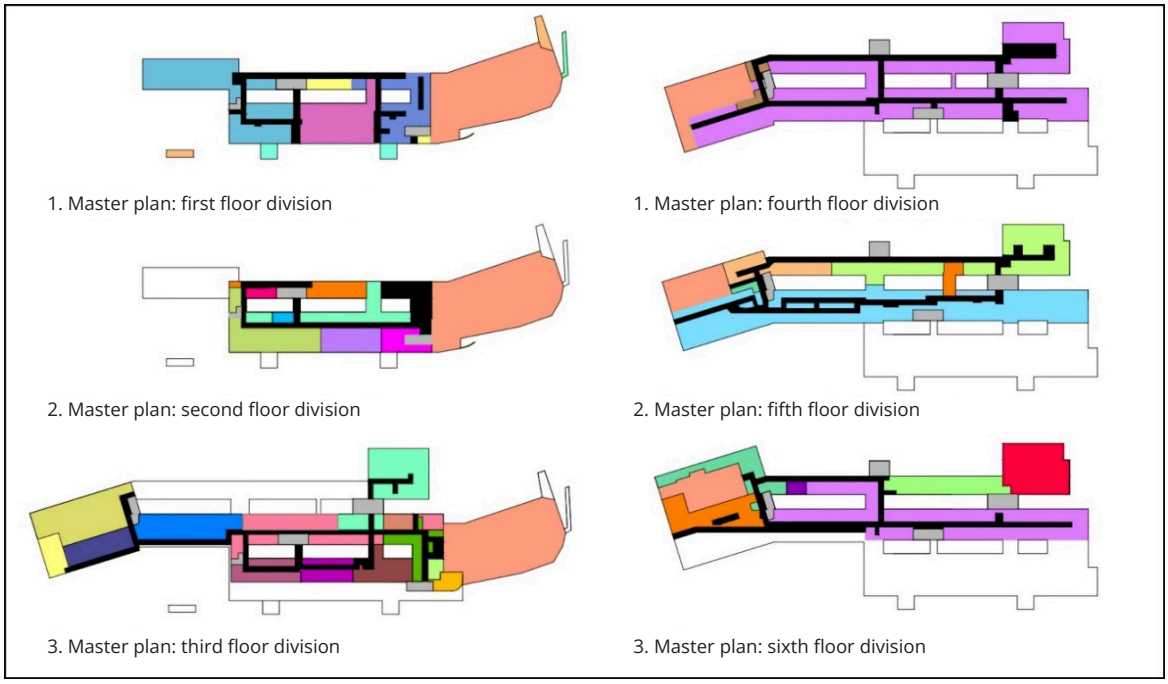


Illustration 3 . Master plan with the forecast of the location of all functional sectors and circulations. Source: technical collection of the architects responsible for the renovation and expansion of the hospital, 2017.

c. Development of the architectural preliminary project and simultaneous compatibility process with the other disciplines: although developed in CAD, the Autodoc project management platform was used for the information exchange processes, in order to manage all deliverables and communications between the architectural team, the project coordinator and the other designers, avoiding losing relevant data and allowing an agile and efficient exchange of information. The files made available in Autodoc followed a nomenclature standardization and had stages of development, even if prior to the standard, as recommended for a common data environment ABNT NBR ISO 19650:1-2025: work in progress, shared, published and archived.

The compatibility processes, duly managed by the architect responsible for the coordination, were recorded in overlapping files of plans and sections of various disciplines involved in the functional sectors, in addition to being documented in the shared repository of files in Autodoc, in such a way that all those responsible for the disciplines had the necessary information to solve the interferences between them and communicate the changes simultaneously through the system (Illustration 4).

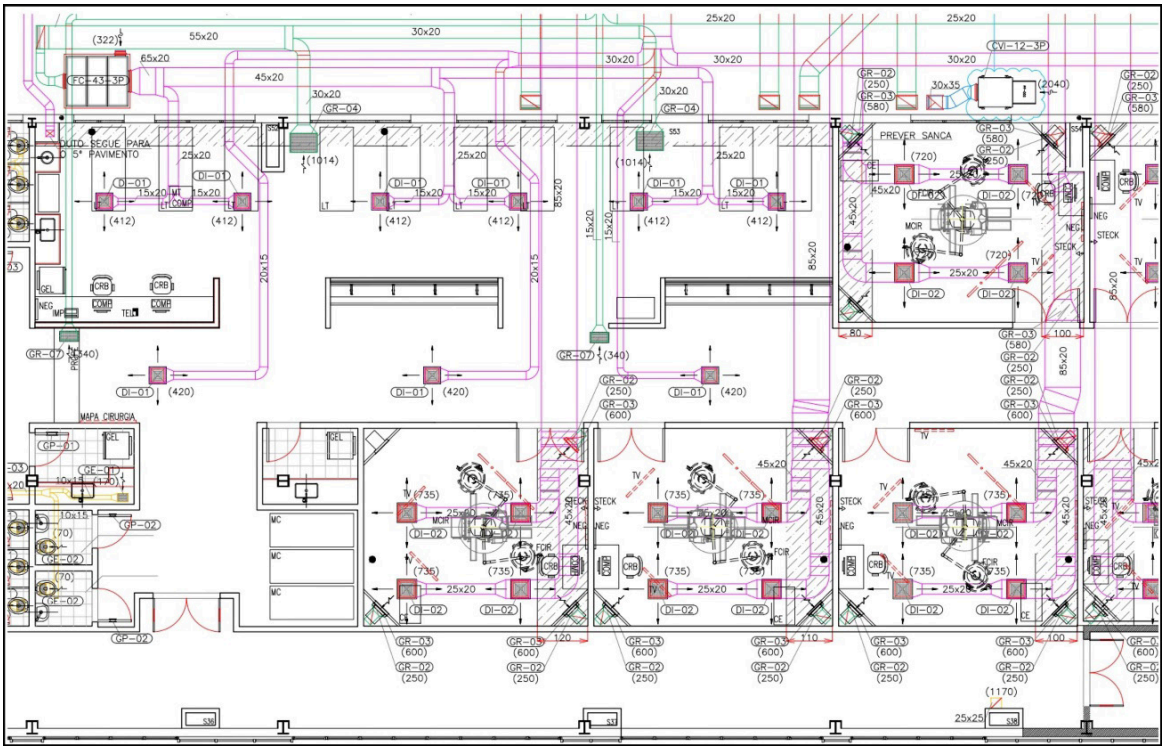


Illustration 4 . Example of the compatibility of part of the Outpatient Surgical Center sector: architecture x structure x air conditioning system. Source: technical collection of the architects responsible for the renovation and expansion of the hospital, 2018.

d. In the preliminary design phase, the interaction of the architectural team with the other designers ensured the determination of vertical routes for the distribution of the infrastructures, the shafts, throughout the building, providing for their future characterization with the registration of all pipes named by location in the built structure, in order to facilitate the identification of the assets to be managed in the operation and maintenance phase. Another premise given from the beginning by the architectural team to the other designers was the determination of horizontal plans for the distribution of infrastructure power supply networks, through the passage of relevant pipes through the ceilings of the main circulations and, when possible, not limited by the existing ceiling heights, at different heights, avoiding collisions between the various disciplines as much as possible (Illustration 5).

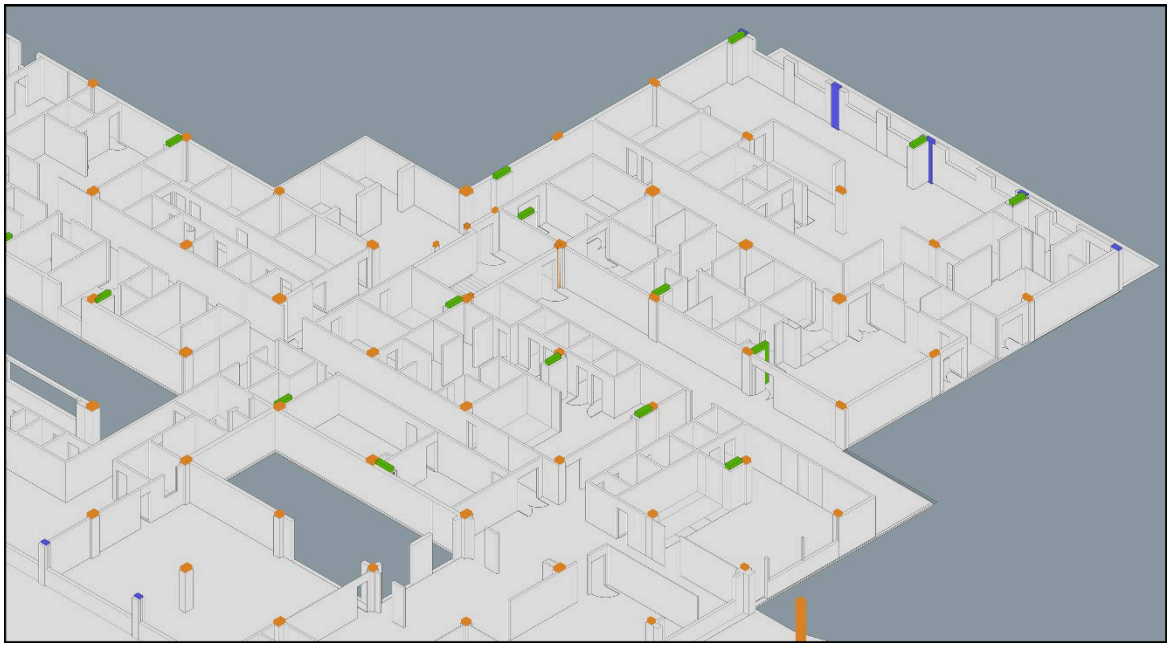


Illustration 5 . Illustration of the positioning of the shafts in green, and pillars in orange, determining the vertical passages of infrastructures. Source: technical collection of the architects responsible for the renovation and expansion of the hospital, 2017.

e. With the development of the executive projects, the architectural team created a file in Excel format with all the existing infrastructures in each of the shafts, already identified by their location in the building, in order to record the type of existing infrastructure, the dimensions of the corresponding pipes and the final sizes of the shafts (Table 1).

TAG SHAFT	PAVIMENTOS	ESTRUTURA	EIXO	MAPEAMENTO E TAG DOS SHAFTS - PRUMADAS HIDRÁULICAS / GASES													
				AF	AFV	AQ	RT	IRR	TQ	TV	TG	TS	END	AS	AP	APA	API
S1	3º	2	12-B	1XØ40	-	1XØ35	1XØ22	1XØ40	-	1XØ75	-	-	-	-	-	1XØ100	-
	2º	2		1XØ40	-	1XØ28	1XØ22	1XØ40	-	1XØ75	1XØ100	-	-	-	-	1XØ100	-
	1º	2						1XØ25	-		1XØ100	-	-	-	-	1XØ100	-
S2	3º	2	11-B	1XØ40	-	1XØ40	1XØ22	1XØ25	-	1XØ75	1XØ75	-	-	-	-	1XØ100	-
	2º	2		1XØ40	-	1XØ28	1XØ22	1XØ25	-	1XØ75	1XØ100	-	-	-	-	1XØ100	-
	1º	2						1XØ25	-		1XØ100	-	-	-	-	1XØ100	-
S3	3º	2	10-B	1XØ40	1XØ25	1XØ35	1XØ22	1XØ25	-	1XØ75	-	-	-	-	-	1XØ100	-
	2º	2		1XØ40	-	1XØ35	1XØ22	1XØ25	-	1XØ75	1XØ100	-	-	-	-	1XØ100	-
	1º	2		1XØ40	-	1XØ35	1XØ22	1XØ25	-	1XØ75	1XØ100	-	-	-	-	1XØ100	-
S4	3º	2	9-B	1XØ40	1XØ40			1XØ25	-	1XØ75	-	-	-	-	-	1x Ø100	-
	2º	2		1XØ40	1XØ40			1XØ25	-	1XØ75	-	-	-	-	-	1XØ100	-
	1º	2		1XØ32	1XØ25			1XØ25	-	1XØ75	-	-	-	-	-	1XØ100	-

Table 1 . Example of part of the identification spreadsheet of the 140 shafts created in the building, since the preliminary architectural design phase, and filled in with the locations and installations contained therein. Source: technical collection of the architects responsible for the renovation and expansion of the hospital, 2018.

Although the projects were developed in CAD, the premises of initial indication of the infrastructure passage routes in shafts and in predetermined horizontal planes and located with systematized naming

ensured that the data was not lost throughout the construction process and subsequent operation of the hospital.

The hospital has been operating since October 2020.

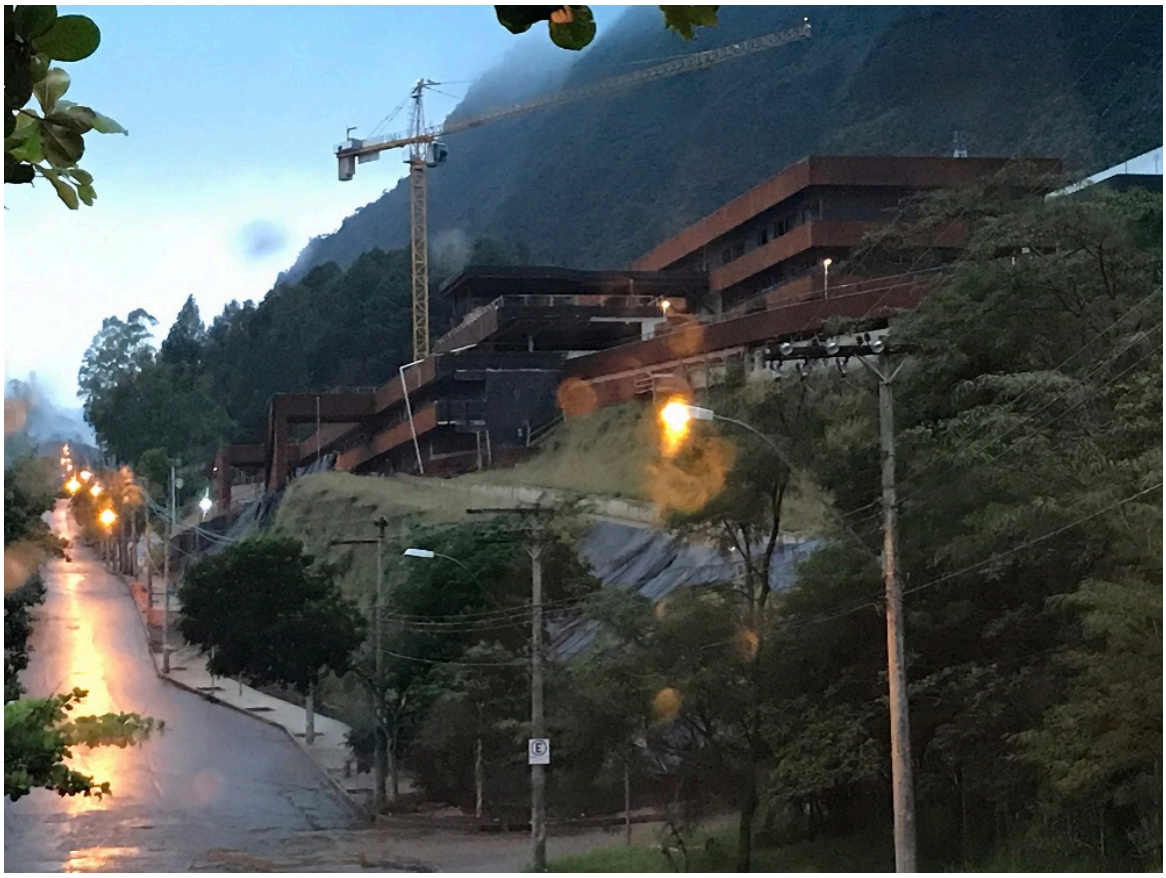


Illustration 6 . Photograph of the final phase of the work. Source: authorship, 2019.

6.2 Case B – Identification of information requirements for asset management in a hospital – digital technology adopted: BIM – Building Information Modeling

The use of BIM for FM – *Facility Management* has been incorporated into highly complex projects more frequently, based on the understanding that the AIM – *Asset Information Model* becomes a great ally for the efficient operational management of the building.

The case presented in this research is under development and is the joint construction of researchers, users, owners and engineers who are studying a way to make the data of physical infrastructures and medical equipment of a hospital can be identified and stored in the model for its future use in its operation and maintenance phase in an FM – *Facility Management* system to be implemented.

The methodology adopted so far is composed of the following steps:

1. Identification of the assets of the most relevant systems of the building to be considered in the models of physical infrastructures and clinical engineering: from the physical infrastructure projects of electrical, air conditioning and hydrosanitary systems and medical equipment, the corresponding assets were extracted in Excel tables, from the models of each discipline, to identify the criticality and importance of each of them for the operation and maintenance phase.

2. Selection of assets by the teams responsible for the operation and maintenance of the hospital: with the tables prepared for each system, they were submitted to those responsible for the operation and maintenance of the building so that, based on their understanding, the strategic assets were selected, with the objective of delimiting exactly the number of assets to be managed[5].

Besides submitting the asset tables, a list of information concerning each asset was sent, which was developed as described by Mota *et al*. (2023), based on the British Standard BS 8210:2012, together with another list, containing the information identified by the team responsible for managing the processes in the reality of operation and maintenance, and deemed important to be recorded in the models.

Initially, among the important information resulting from the team's analysis, the following were chosen asset identification, code, description, condition, location, criticality, acquisition date, model, manufacturer, initial cost, dimensions, photograph, serial number and SOP – Standard Operating Procedure. These requirements should be applied to the parameters of the assets in their geometric models of each discipline of origin, as exemplified in Illustration 7, in the discipline of clinical engineering.

5 One of the prerogatives of using the BIM methodology is the assertive choice of the information necessary for the models to be loaded only with that strategic and essential information, avoiding excess information and, on the other hand, the absence of it. Therefore, the need for collaborative work, with the presence, mainly, of senior management and FM managers – Facility Management in the choice of information to be inserted in the model.

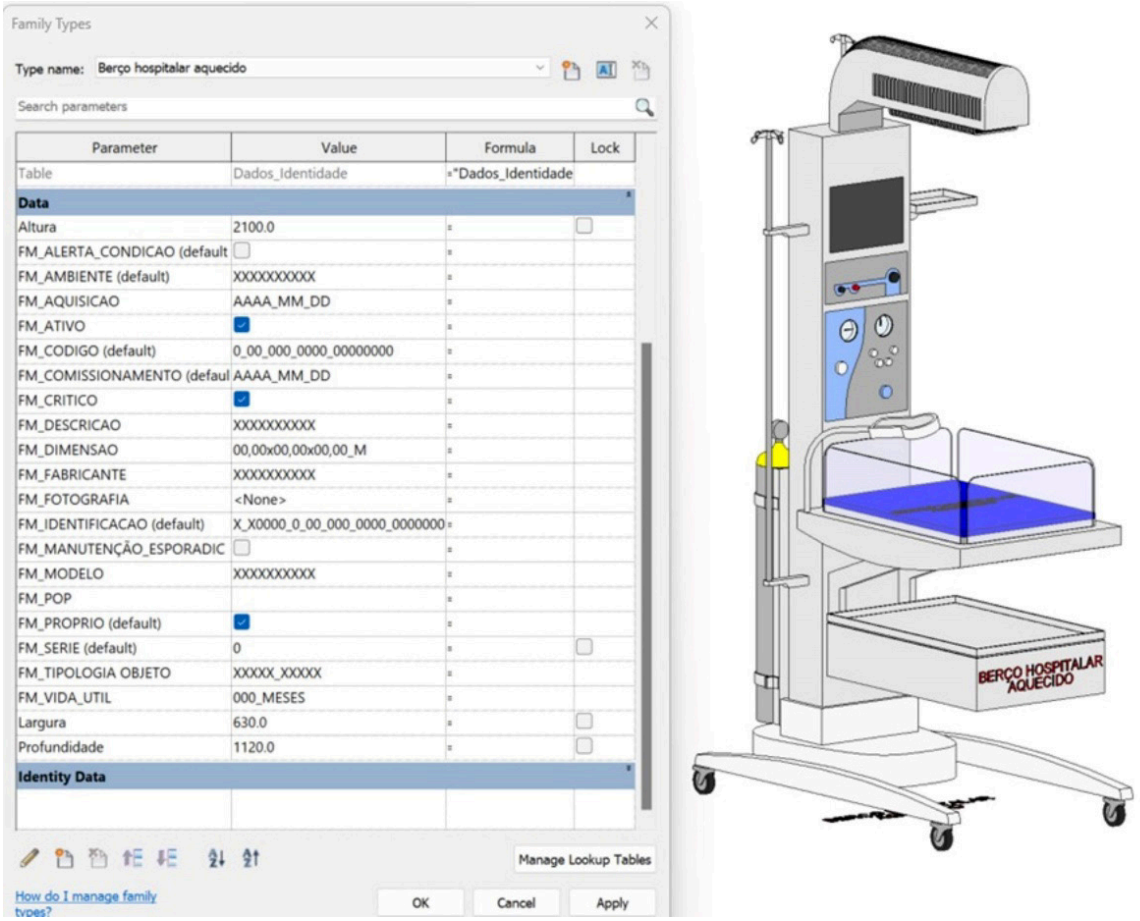


Illustration 7 . Example of the introduction of parameters in the clinical engineering model in a hospital equipment, based on the selection of the necessary information made together with the hospital team. Source: image courtesy of SIPPRO Engenharia, 2023.

3. Development of AIR – *Asset Information Requeriment.*

With the necessary information selected, a document was built with the standardization of the coding to identify each of the assets to be managed in a table to be completed from the beginning of the work, which should be updated as the assets are purchased, installed, commissioned and inserted in the model that accompanies the construction phase until the as-built model is completed and delivered to the operation phase, becoming the AIM – *Asset Information Model*. From this delivery, in the future, this model must always be updated, so that possible modifications in processes of renovations and asset replacements are recorded and the model continues to provide the necessary information for the continuous process of the building's life cycle.

4. In parallel with determining the information concerning assets, it was carried out research on FM – *Facility Management* systems capable of enabling integration with the BIM model, as described in the article by

Mota *et al* (2023). Of the existing FM systems selected and available in the Brazilian market, eight were exhaustively researched on the requirements to meet the demands of the hospital's operation and maintenance team in terms of implementation and use support, 2D and 3D visualization capacity, access to asset documentation, mobile and *offline* access to the system, platform and cloud storage limit, language, type of integration with the BIM model, type of collaboration and communication between users, data export possibilities, QR Code reader, connection to sensors, inventory control, registration of man-hours, generation of reports and *dashboards* and environment management. In addition to these general requirements, specific requirements for hospital buildings were added: clinical engineering management, cost center, integration with hospital care management systems, inventory of materials and medicines, and purchasing.

The systems are being tested by hospital users and, after choosing the system to be adopted, the next phase will be the integration of the asset model with the facilities management platform.

It is expected that, from the integration, the information loaded into the model will be shared with the hospital's operation and maintenance management system, consisting of a powerful tool for improving processes and the quality of services provided by the institution to all sectors and users of the hospital.

7. Conclusions

The lessons learned from the two approaches discussed above revealed both convergences and divergences in terms of methodology and outcomes.

In CAD-based workflows, it is possible to organize and structure information during the design phase so that essential asset data are preserved and made available for operation and maintenance activities. However, unlike BIM, this information is not intrinsically linked to the building geometry, preventing users from directly visualizing assets within a digital representation of the facility. Although the identification and organization of relevant information are feasible, the facility management (FM) system must be populated through the manual entry of data extracted from project documentation. This process duplicates data registration and increases the effort required for information management. Furthermore, throughout the operation and maintenance phase, the likelihood of inconsistencies and data loss increases substantially, since any modification to an asset must be updated both in the project documentation and separately within the FM system.

Conversely, when a BIM model is integrated with an FM platform from the design and construction stages onward, the model can be progressively populated with all the information required for the operation and maintenance phase, in accordance with the Asset Information Requirements (AIR). The subsequent step consists of selecting an FM platform capable of interoperating with the BIM model. This integration may occur through native software formats, the Industry Foundation Classes (IFC) open standard, application programming interfaces (APIs), or the exchange of structured asset information using the Construction Operations Building Information Exchange (COBie) format.

Among these alternatives, direct integration through native formats or fully interoperable platforms offers the greatest operational efficiency by minimizing data duplication and enabling bidirectional information exchange between the BIM model and the FM system. By contrast, integrations based on IFC, APIs, or COBie may be limited to unidirectional data transfer or require periodic re-export and re-import of updated datasets whenever assets are replaced or modified. Such procedures increase operational complexity and may compromise the consistency of information over time.

One of the principal advantages of BIM-enabled facility management is the integration of geometric and non-geometric information within a single digital environment. This integrated information repository facilitates rapid access to asset data, improves decision-making, enhances maintenance planning, and increases the responsiveness of operation and maintenance teams. As a result, healthcare organizations can achieve higher levels of operational efficiency, better asset performance, and improved quality of the services delivered.

Regardless of the technological platform adopted, recognizing the importance of preserving reliable asset information throughout the lifecycle of complex facilities such as hospitals is essential. The identification of Asset Information Requirements (AIR) from the earliest design stages through construction and handover should be understood as a shared responsibility among designers, contractors, facility managers, healthcare professionals, and project owners.

The adoption of BIM for facility management represents a significant advancement in the management of healthcare facilities and is gradually expanding in Brazil. As investments in digital transformation continue and BIM implementation becomes more widespread, it is expected that Brazilian hospitals will increasingly adopt integrated information management practices, leading to substantial improvements in operational efficiency, maintenance performance, and the overall quality and resilience of healthcare infrastructure.

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Autora

Adriana Tonani Mazzieiro holds a bachelor's degree in Architecture and Urbanism, and a master's degree in Architecture and Urbanism, with research on Methodology for restructuring existing general hospitals (1998). Currently, she is a PhD student at the Federal University of Minas Gerais (UFMG), in the NPGAU Program of Architecture and Urbanism, with research in digital technologies, mainly focused on BIM. Adriana is a member of the UFMG BIM cell in the ANTAC Network – National Association of Built Environment Technology; worked as adjunct professor I of the Architecture and Urbanism course at Fumec University, from 2002 to 2022 and as substitute professor of the Architecture and Urbanism course at UFMG, from 2024 to 2025. Since 2025, Adriana has been a professor of the master program in BIM Management at the Zigurat Institute of Technology, in the discipline of BIM for Facility Management. Additionally, Adriana was the architect and urban planner responsible for the: (i) Santa Casa de Misericórdia de Belo Horizonte, from 1991 to 1995; (ii) the renovations and expansions of the Military Police Hospital of Minas Gerais, from 2000 to 2010; and (iii) for the renovation and expansion project of the former Hilton Rocha Hospital, from 2011 to 2019, where she assumed, from 2017 to 2019, the coordination and compatibility of executive projects concerning areas of 38,000 m2. Finally, Adriana has been founding partner of Quattromani Associated Architects since 2000, and BIM coordinator at SIPPRO Engineering since 2022.

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Institution: Universidade Federal de Minas Gerais (Federal University of Minas Gerais)

Contact details: adtonani@gmail.com

Article

Circular economy in healthcare facilities

Authors
Antonio Pedro Alves de Carvalho Federal University of Bahia
Jair de Jesus Lima Federal University of Bahia

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Abstract

The traditional linear economy—driven by an "extract-produce-discard" paradigm—has fostered technological growth at a severe environmental and social cost, including resource depletion, pollution, and waste accumulation. The healthcare sector significantly exacerbates these issues due to its intensive energy and water consumption, alongside a heavy reliance on single-use materials. To counter this, the Circular Economy (CE) offers a sustainable framework for healthcare by minimizing resource extraction and maximizing reuse and recycling. This study conducts a literature review on the application of CE principles in Healthcare Facilities (HFs). It explores sustainable design, energy and water efficiency, and waste management, highlighting successful case studies from Brazil and around the globe. Findings indicate that integrating CE into healthcare not only lowers operational costs and waste but also reduces greenhouse gas (GHG) emissions and supports the Sustainable Development Goals (SDGs). Ultimately, adopting circular strategies is crucial for harmonizing essential healthcare delivery with environmental stewardship.

Keywords:

circular economy, healthcare facilities, environment.

Introduction

Since the Industrial Revolution, society has adopted the linear economy model, heavily dependent on the extraction of natural resources, production of goods, distribution, consumption, and disposal of waste (Fernandes, 2024). Although this model has driven technological advances and economic growth, it has also significantly contributed to the generation of negative environmental impacts, such as excessive extraction of natural resources, increased pollution, and accumulation of waste, which have now become challenges that humanity must face (Barcelos, 2024) (Illustration 1).

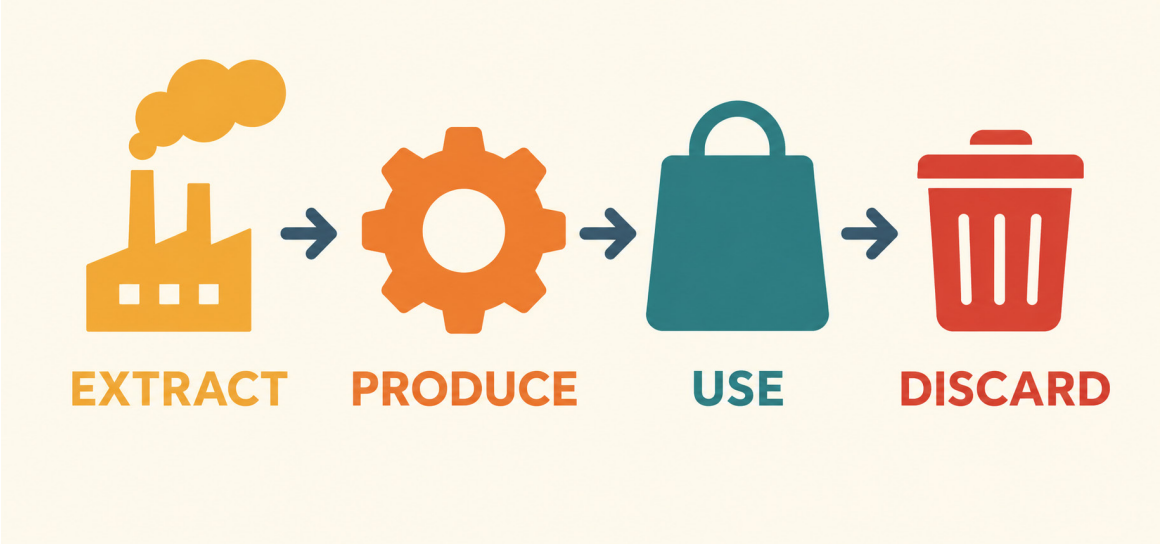


Illustration 1 . Linear economy structure. Source: AI-generated.

Among the main consequences of this system are depletion of natural resources, excessive generation of waste, emission of greenhouse gases (GHG) and other products that are harmful to the environment, putting human health at risk due to air pollution and soil and water contamination, in addition to causing phenomena such as ozone layer depletion, biodiversity loss and catastrophic climate change (MacNeill *et al*., 2020).

Such effects are linked to the various stages of the process of "extract, produce, use and discard". The unbridled exploitation of raw materials, such as minerals, water, and fossil fuels, with the consequent generation of waste, contributes to the depletion of natural resources and pollution of the environment. Pollution is linked to the production process because, to ensure the manufacture of goods in a consumerist society, the emission of by-products is increased, contaminating air, water, and soil. Early and inadequate disposal of products intensifies waste generation, aggravating environmental pollution (Barcelos, 2024).

When operating under the linear economy model, the health sector becomes responsible for a significant part of GHG emissions. Healthcare facilities (HFs) and the medical devices used are based on this model, being dependent on single-use disposable equipment (MacNeill *et al*., 2020). According to the Health Care Without Harm report, made in collaboration with Arup Consultoria (2019), in 2019, the health sector was responsible for about 4.4% of the total GHG generated in the world, which corresponds to two gigatons of carbon dioxide. This contribution is similar to the annual GHG emissions of 514 medium-sized coal-fired power plants. In addition, if it were considered a country, the health system would be the fifth largest emitter on the planet (Karliner *et al*., 2019).

GHG emissions resulting from healthcare occur by various means, especially energy consumption, transportation, manufacture, use, and disposal of products in general. Emissions occurring directly from health facilities and vehicles belonging to the sector correspond to about 17% of the area's global footprint. Approximately 12% are related to indirect emissions associated with purchased energy, such as electricity, steam, cooling, and heating. Most emissions – about 71% – are related to the supply chain, encompassing production, transportation, and disposal of inputs, such as medicines, chemicals, food, medical devices, and hospital equipment (Karliner *et al*., 2019).

The concept of circular economy (CE) emerges as an innovative solution, which seeks to implement a new production system, establishing significant structural changes and assuming a greater role by going against the traditional model of linear economy, known for its practices defined by the "open cycle" paradigm: extract-produce-discard (Abdalla; Sampaio, 2018).

CE aims to reduce the use of raw materials and their associated environmental impacts, with strategies that extend the useful life of resources. According to Viet (2012), this is made possible by the 3R principle, which consists of practices to be adopted with the objective of increasing the useful life of materials already processed, reducing the extraction of natural resources for use as raw materials:

- **Reduce** – apply management techniques to minimize the number of materials consumed for a given purpose, such as water, energy, and minerals.

- **Reuse** – to use again a material, either for the same purpose for which it was developed, or for a similar one, extending its useful life, before being discarded or sent to recycling.

- **Recycling** – set of techniques aimed at reusing waste, reinserting it back into the production cycle. This process includes a series of

activities, such as collecting, sorting and processing materials, to transform them into raw material for manufacturing new products (see Illustration 2).



Illustration 2 . Circular economy structure. Source: SMAS-Sintra (2025).

The adoption of a circular model in the health sector has the potential to promote significant reductions in operating costs, reduce the amount of waste generated and environmental impacts, in addition to contributing to the improvement of the quality of services and public health (Fernandes, 2024). At the same time, the adoption of circular practices contributes directly or indirectly to the advancement of the Sustainable Development Goals (SDGs) established by the United Nations (UN) to be met by 2030, such as SDG 3 (Good Health and Well-Being); SDG 6 (Clean Water and Sanitation); SDG 7 (Affordable and Clean Energy); SDG 8 (Decent Work and Economic Growth); SDG 11 (Sustainable Cities and Communities); SDG 12 (Responsible Consumption and Production); SDG 13 (Climate Action); and SDG 15 (Life on Land) (Azizuddin; Shamsuzzoha; Piya, 2021; Schroeder; Anggraeni; Weber, 2019).

The SDGs, along with sustainable finance, play an important role for the health sector. For government and healthcare facility administrations, it is critical that their financing prioritizes the inclusion of environmental, social, and governance (ESG) factors in investment decisions (Zaza; Sepetis; Bagos, 2022).

HF infrastructure can play a key role in making the health sector less polluting and reducing its impact on climate change. However, due to high demand, achieving sustainability goals from carbon neutrality by 2030 will require a significant shift from healthcare providers. The GHG emissions generated by this sector are strongly related to its performance, the type of services and the place where they are provided, as well as policies aimed at strengthening best practices that contain the demand for services (Or; Seppänen, 2024).

According to the World Health Organization (WHO, 2009), by reducing the carbon footprint and moving towards neutrality, the health sector can become an example in the response to climate change, playing a leading role in advocating for a healthy and sustainable future. In this sense, it is essential to adopt a comprehensive approach based on the CE principle. This includes initiatives such as sustainable *design* strategies, energy efficiency procedures, water saving, sewage treatment, and waste management, reducing the environmental footprint of the sector, which has increasing importance in modern society.

Methodology

This article consists of a literature review aiming at gathering, analyzing, and synthesizing the existing knowledge regarding circular economy in healthcare establishments. The purpose is to present a review on how the transition to a circular model can be applied to HFs, addressing issues such as sustainable *design*, energy efficiency, water use and waste management.

To this end, we searched open-access databases of Google Scholar, CAPES Journals, Scielo, Scopus and SciSpace, using keywords related to the theme, such as *Circular Economy; Circular Economy and Healthcare Establishment; Circular Economy Strategies in Hospitals; Energy Efficiency in Hospitals; Sustainable architecture in hospitals; Water Saving Strategies in Hospitals; Hospital Wastewater; Circular Economy in Hospital Sewage Treatment; Hospital Waste Management* and its counterparts in Portuguese.

Also included in the review, there are materials that directly addressed the application of the circular economy in healthcare facilities published in the last five years, with full text available in Portuguese or English. In some cases, studies of greater relevance were considered, even if they did not meet the criterion of publication period. On the other hand, works that were not directly linked to the central theme, as well as documents from closed domains, were excluded.

Initially, 91 studies relevant to the theme were identified. For the selection of references, the inclusion and exclusion criteria were applied, and 76 were selected to compose the review.

Design strategies

The architecture of HFs is characterized by high complexity and functional requirements linked to medical procedures and practices, which undergo constant changes and updates (Lopes, 2014). According to Biro (2024), the construction sector, as well as the design, is responsible for more than 30% of the extraction of the planet's natural resources, making it essential that all constructions seek greater sustainability.

More than being a trend or competitive edge, sustainability in health-oriented buildings has become a must-have since the planning stage. The introduction of environmental sustainability in healthcare units can occur through the inclusion of sustainable construction principles in new projects, as well as in the modernization of existing hospitals (WHO, 2009).

For sustainable HF projects, it is essential to consider the following aspects:

- **Environmental** – e.g.: adapting to the environment using existing natural resources.
- **Economic** – e.g.: use of rational, standardized, flexible, modular construction systems with reuse of materials, to avoid waste and waste generation; qualification of labor and the adoption of technologies that contribute to the reduction of water and energy consumption.
- **Social** – e.g.: commitment to the well-being of all users involved in all stages of the construction, without neglecting aesthetic issues (Lopes, 2014).

There are several strategies related to healthcare buildings that cause it to have minimal environmental impact. It is essential to apply these strategies in all stages of the building's life cycle, such as planning, design, execution, occupation, maintenance, rehabilitation, and eventual disassembly (Vilas-Boas, 2011). In this sense, the application of sustainable design strategies can be considered as an effective approach, as it contributes to increasing the useful life cycle and reducing the maintenance costs of the building (Alsawaf; Albadry, 2022). These methods reduce environmental impact while improving social equity, patient comfort, and healthcare worker productivity (Biro, 2024).

An example of a sustainability strategy is the Design for Adaptability and Disassembly (DfAD). DfAD, when applied in the planning of the useful life of health buildings, can positively favor sustainable development (ISO, 2020). Disassembly, following the 3R principle – reduce, reuse, and recycling – is important for the recovery of construction materials, especially during maintenance, renovation, relocation, and reassembly

stages, enabling non-destructive recovery of these materials and their reintroduction into the production chain, either to perform the same function or to originate new products (Davis, 2024). The introduction of adaptability principles, on the other hand, can reduce demolitions and construction of new buildings by enabling the reuse or modification of existing structures, extending their useful life and allowing them to accommodate a greater variety of uses, ensuring the effective use of resources and the implementation of CE principles in buildings (ISO, 2020).

As a basic principle for the DfAD approach, modular building construction plays a key role in promoting sustainability by reducing building-related environmental impacts (Paliwal, 2019). This principle is particularly useful for healthcare buildings, which traditionally requires frequent changes of use. This construction model offers a potentially sustainable alternative to the building process, based on the use of prefabricated parts that are installed and connected on site for the assembling of buildings with high functional flexibility (Lawson; Ogden; Goodier, 2014). The use of modules in construction allows for the development of buildings with structures that reduce waste, optimize the use of materials, and take an efficient approach to address the challenges of industrialization and maintenance (Morales, 2023).

According to Morales (2023), the implementation of modular construction allows for more efficiency of the materials used and a reduction in waste generation – approximately 90%, when compared to the traditional construction model – since approximately 70% of the construction process can take place in a controlled environment. Using eco-labeled materials, as well as recycling and reusing modular components at the end of their life cycle, intensifies the reduction of losses.

Modular construction provides greater flexibility in the design of projects, facilitating adaptability and disassembly processes. Therefore, projects might meet different purposes during the use or recovery of products, parts, and materials, if a building must undergo renovation. After the deactivation of modular buildings, their components can be recycled or reused in new units more easily, contributing to decreased disposal of construction materials (Sajid *et al*., 2024).

A successful example of the applicability of the modular construction system in buildings aimed at the health sector are the SARAH hospitals, planned by architect João Filgueiras Lima, known as Lelé. Prefabricated systems in reinforced mortar and metal structure are widely used in all stages of the buildings (Illustration 3), from the superstructure to hospital objects, which provides more flexibility and facilitates the stages of construction, assembly and, especially, the maintenance and future expansions of hospitals (Lukiantchuki *et al*., 2011).



Illustration 3 . Outside view of SARAH Technology Center (CTRS). Source: Lukiantchuki *et al.* (2011).

The integration of biophilic design into HF architecture represents another efficient measure to promote sustainability in the health sector (Zhao; Zhan; Xu, 2022). This approach seeks to integrate natural elements into the configuration of built environments, with the potential both to favor users' well-being and promote greater sustainability in the building, by reducing energy consumption and encouraging environmentally responsible construction practices (Santos; Torres, 2024).

In the Brazilian context, Albert Einstein Hospital, located in São Paulo, is an example of the applicability of biophilic design. The green roof system (Illustration 4) helps to reduce the heating of the building, in addition to enabling the collection of rainwater, which is reused to water the gardens. Among the main results obtained with green roofs, the following stand out: reduction of urban heat islands, which increase the temperature in highly built places; electricity savings, due to reduced use of air conditioning systems; and control of rainwater flow, consequently reducing flooding in urban areas (Vilas-Boas, 2011)



Illustration 4 . Green roof at Albert Einstein Hospital, SP. Source: Vilas-Boas (2011).

The use of bioclimatic principles, such as ventilation, natural lighting, vegetation, and landscaping, can contribute significantly to reducing the urban heat island effect, improving biodiversity, mitigating air pollution, optimizing air quality, improving thermal comfort, and encouraging the use of certified materials, promoting indoor environments that favor the recovery of health. This practice directly supports the advancement of SDG 3 (Good Health and Well-being) and SDG 13 (Climate Action), the most enhanced by biophilic design (Zhong; Schröder; Bekkering, 2022).

The capture of natural ventilation and light in HFs can occur indirectly through different methods. Elements such as conveniently placed frames, *brises*, and windows that direct wind and sun can be adopted. As for lighting, methods such as openings on the roof, sheds, windows with *brises* and lounges with wider shaded openings stand out. Resources such as skylights or reflective pipes can be used in more complex situations, when it is not possible to incorporate large frames or open the environment to external areas, (Vilas-Boas, 2011).

Energy efficiency

HFs require energy consumption in a variety of forms, such as thermal, used for heating, hot water and steam generation, and cooling, for air conditioning systems, besides electricity cost to operate medical equipment, lighting, exhaust fan, and ventilation systems (Suszanowicz; Ratuszny, 2019). This demand is intensified due to the continuous growth in energy consumption in these facilities, since, unlike other types of buildings, the HFs often operate continuously during the 24 hours, receiving people with health problems, who are extremely vulnerable to small variations in environmental conditions. In treatment sites, it is

necessary to maintain specific parameters of temperature and indoor air quality, especially in highly specialized spaces, such as operating rooms, ICUs, and laboratories (Zaza; Sepetis; Bagos, 2022).

Due to such a high energy demand, approximately 40% of the health sector's climate footprint comes from the use of electricity and thermal energy. This consumption includes energy purchased by health units and by manufacturers and suppliers of health goods and services (Karliner *et al*., 2019). Heating, ventilation, and air conditioning systems are the most important part of electricity consumption in hospitals, as they are considered essential for the health of patients, for increasing employee productivity, and for the proper functioning of medical equipment, which consume, on average, 50% of the total electricity in these buildings (Oliveira, 2021).

According to a study carried out by the *Kigali Cooling Efficiency Program* (UNEP, 2019), linked to the United Nations, which in 2018 analyzed global emissions related to air conditioning from HFs, approximately 365 million tons of CO_2 are released annually into the atmosphere due to the cooling and ventilation of buildings, equivalent to the emissions generated by more than 75 million cars or 110 coal-fired power plants during a year. The introduction of climatization systems managed by Artificial Intelligence (AI) in HF can lead to significant savings in energy consumption.

In addition to being manufactured using fossil fuels, air conditioning and cooling systems use hydrofluorocarbons (HFCs) and other cooling gases that, when released into the atmosphere, intensify the greenhouse effect (Oliveira, 2021). Besides the demands for air conditioning, HFs develop many activities that require high energy consumption, such as the use of medical equipment and specialized laboratories, sterilization, laundry, and food services (Zaza; Sepetis; Bagos, 2022). Due to these characteristics, AEs face two contradictory challenges: meeting the growing energy demand while reducing the carbon footprint in the sector (Tomanek, 2024).

Much of the environmental impacts on public health produced by energy consumption result from the burning of fossil fuels, such as oil, coal, and gas, generating GHG emissions and air pollution, influencing both climate change and health problems. In this sense, with the improvement of energy efficiency and the transition to clean and renewable energy sources, the health sector can play a vital role in mitigating GHG emissions and reducing the damage to public health caused by climate change and atmospheric pollution (Corvalan *et al*., 2020).

Various renewable energy sources can be introduced into hospital buildings for the generation of electricity, heat, and cooling, such as solar, wind, biomass, and geothermal energy. Low-carbon technologies, such

as cogeneration systems and heat pumps, can also be used for the same purpose (Vourdoubas, 2022). These alternative energy sources can be used in lighting, pumping and water heating systems, uses that correspond to a considerable part of the energy consumption of health buildings, both in developed and developing countries (WHO, 2009), contributing to the reduction of the climate footprint and to the increase of energy resilience, in addition to complying with current regulations and global goals related to the mitigation of environmental disasters (Vourdoubas, 2022)

Solar energy is considered one of the best options to ensure long-term energy sustainability, as it offers several advantages, such as being an abundant source, having reduced transmission and distribution losses, low operating costs, and being a clean source, reducing the intensity of fuel emissions in general (Duraivelu; Elumalai, 2021). This system can be used to produce solar energy through either photovoltaic or thermal technology, being used in small, medium, and large energy generation systems (Vourdoubas, 2022).

A study carried out by Al-Rawi, Bicer, and Al-Ghamdi (2023), in a hospital situated in the Gulf Cooperation Council (GCC) region, which employs a solar-powered water heating system, highlighted the potential of the combined integration of solar thermal and photovoltaic technologies into HFs in the region, enhancing benefits such as reduced energy costs, increasing energy security and promoting sustainability. The results showed that the solar thermal system used in the hospital contributes with about 12% of the energy costs of the hot water systems, with an efficiency of around 46%; the photovoltaic system collaborated with approximately 29.6% of the total HVAC load, evidencing the potential of both systems to promote energy efficiency and reduce the dependence on traditional energy sources in HFs.

In a study conducted in two hospitals located in Romania, Prada *et al*. (2020) show that the implementation of photovoltaic solar energy can meet 62.68% to 75.51% of the energy consumption needed for heating, air conditioning, and hot water production. In addition, the example demonstrated the reduction of 77% to 67% of CO_2 emissions, directly impacting global warming, pollution, and the reduction of GHG emissions.

In the global context, Vourdoubas (2021), in a review of several successful applications of renewable energy in hospitals around the world, highlighted that the use of solar energy can be energy efficient by 40% to 80%, when contributing to the cooling system, and 30% to 40% concerning hospital heating. Regarding geothermal energy, he showed that its application can obtain an efficiency of 70% to 90%, especially in the use of geothermal fluids for heating buildings.

Solar energy can also be applied together with other technologies with low or no carbon emissions, such as in cogeneration systems. In this case, at the same time that solar energy is converted into electrical energy in a central power plant, to be used to operate vapor compression coolers for the production of cooling, the waste heat rejected by the heat engine can be used to drive an absorption cooler, playing an important role in both energy savings and the reduction of environmental pollution (Çakir; Çomakli; Yüksel, 2012).

Cogeneration systems represent a promising solution to reduce GHG emissions and their operating costs. Cogeneration plants operate based on a single source of energy or fuel, the main one being natural gas (Franco *et al*., 2017). They may also utilize biomass, such as agricultural and forestry waste, by-products and waste, bioethanol, biodiesel, or biogas produced from organic waste (Vourdoubas, 2022). Its implementation aims at the simultaneous and integrated production of electrical and thermal energy, mitigating energy losses. Cogeneration can be classified into two types: combined heat and power (CHP) systems, which produce electricity and heat; and trigeneration, known as combined cooling, heating, and power (CCHP), which generates electrical and thermal energy in the form of heat and cold (Chen-Xu *et al*., 2024).

CHP and CCHP systems have higher efficiency compared to traditional generation methods. While conventional media have an efficiency of approximately 60%, CHP systems can have rates between 87% and 92%; CCHP systems, on the other hand, reach between 85% and 90%. These percentages may vary depending on the size of the project (Teke; Timur, 2014).

In the context of the use of cogeneration in HFs, Alexis and Liakos (2013) argue, through a study carried out in a hospital located in Greece, that the implementation of a cogeneration system can lead to a reduction in annual operating costs by 32%, in addition to a reduction in annual primary energy consumption by 28%. In addition, they attest to a significant annual reduction in pollutant emissions, with estimated decreases of between 46.5% and 48.6% for CO_2, between 75.9% and 82.8% for SO_2, between 2.3% and 7.5% for NOx, and between 75.9% and 82.9% for suspended particles.

The use of AI-managed lighting systems is another technological innovation that plays an important role in promoting energy efficiency in HFs (Tomanek, 2024). These systems use advanced mechanisms for lighting, such as sensors to detect occupancy, automation, and connectivity to control lighting more efficiently. Unlike traditional models, which work manually, these systems make it possible to significantly reduce energy consumption by automatically reducing or turning off lights

in unoccupied or sparsely occupied areas, adjusting brightness, color temperature, and even the direction of light depending on various factors, such as the presence of natural lighting, the time, the presence of people and the activities performed on site, in addition to the use of high energy efficiency lamps (Wipro Lighting, 2024).

According to Teke and Timur (2013), in a review of practical studies on energy efficiency and energy saving potentials in lighting systems in hospitals, the implementation of intelligent systems in HFs can contribute to savings of approximately 60% to 80% of the energy consumed, especially if used in indoor lighting and air conditioning, with an estimated payback time of between 1.5 and 5 years, varying according to the control systems and size of the establishment.

Water saving

The health sector has high water consumption, as it needs to keep environments and materials disinfected, operate medical equipment and ensure patient hygiene. Their unique characteristics mean that HFs consume significantly more water per square meter than other types of buildings, making it difficult to adopt circular economy principles in this sector (Teslim, 2024). The amount of water used depends on different factors, such as the profile of the establishment, number of beds, type of hospitalization, length of hospital existence, sources of access, general services present within the structure, including kitchen, laundry and air conditioning, institutional management policies and awareness in the management of the infrastructure in relation to the preservation of the environment, climate and cultural and geographical factors (Verlicchi *et al*., 2010).

A study conducted by the Victorian Government Department of Health (2009) related to water consumption in HFs, located in Victoria, Australia, highlighted that, within hospitals, the highest water consumption is related to: hygiene (cleaning and washing); sanitation (discharge of waste into the sewer); ingestion (drinking and food preparation); general processes (cleaning, sanitizing, sterilization, washing, heating, cooling, filtering and water treatment) and irrigation (ornamental gardens and lawns). The survey also points out that sanitary facilities (basins, showers, and sinks) represent between 20% and 40% of total consumption, while toilets (toilets and pan sanitizers) vary from 15% to 30%. Sterilization, laboratory, and cooling processes contribute about 15% to 40%, and food preparation, with 5% to 25% of total water consumption.

Water consumption in HFs also varies considerably both throughout the day and throughout the year. Regarding the average daily demand,

there may be an increase of up to 20% between the hours of 8 am and 4 pm and a decrease of 30% between 1 am and 8 am; in addition, higher average values may occur during warmer months (*Verlicchi et al*., 2010). The explanation for the high consumption of water during such morning and afternoon hours is associated with the fact that, it is throughout these periods that patient treatments and laboratory analyses are carried out (Altın; Altın, 2017).

Due to the variety of functions that require water consumption in HFs, the effective and efficient use of the resource is essential in these institutions. The implementation of water-saving routines in a hospital environment faces great restriction, since hygiene procedures and maintenance of water quality comply with strict and demanding standards (Priyalal, 2019). According to Oliveira *et al*. (2021), the water used in hospitals must be free of pathogenic microorganisms, as they represent a significant risk of severe infectious outbreaks, making it important to constantly wash hands with quality water, in addition to cleaning the environment, food production and consumption. Maintaining water quality, therefore, is fundamental, as its contamination may be related to the transmission of diseases, mainly affecting patients, who have different degrees, but always existing, of low resistance to infections (Ferreira; Caran, 2023).

Efficiency in water management in hospital buildings is achieved through the rigorous adoption of good practices and appropriate technologies, such as regular water audits, which aim to identify areas of high consumption and possible leaks. In line with this, the use of leak detection systems is essential to locate and correct as soon as possible problems that could cause significant water waste. Replacing old sanitary instruments, such as toilets, faucets, and showers, with more economical models can significantly reduce water consumption. Likewise, the use of newer dishwashers and washing machines, with low water consumption, helps to reduce waste in the kitchen and laundry areas (Teslim, 2024).

According to Silva *et al*. (2024), the introduction of greywater reuse systems and the use of rainwater are efficient solutions to promote water resource savings and environmental sustainability in HFs. These measures occur from the collection, treatment, and reuse of water from showers, washbasins, tanks and washing machines, in addition to the capture of rainwater through gutters installed on roofs, terraces and open areas. The collected water must undergo specific treatment processes, which include varying degrees of filtration, and disinfection. These waters, depending on the type of treatment, can even be used for potable purposes, making the process more expensive. The most common is the use of simple treatments, using this type of water for irrigation, cleaning, flushing toilets and washing surfaces.

Due to the complexity of the processes that use water in health, adequate technical planning is necessary for the reuse of greywater and rainwater use, such as the installation of separate pipes, efficient collection systems, as well as reservoirs protected against contamination and redistribution systems with specific pumps and pipes for these procedures. Water quality must also be inspected, and the efficiency of the systems must be ensured (Silva *et al*., 2024).

The implementation of water management and conservation strategies in HFs offers a few economic and environmental benefits. The reduction in water consumption contributes directly to the reduction of expenses in services, resulting in significant savings over time. The adoption of efficient technologies tends to reduce maintenance-related expenses and extend the lifespan of equipment. At the same time, these initiatives contribute significantly to the achievement of goals related to environmental sustainability, relieving pressure on local water resources and reducing the environmental footprint of this type of building (Teslim, 2024).

Sewage treatment

Access to sewage treatment is important for fighting water-related diseases in HFs (PAHO, 2021). As pointed out by Lima (2023), advances in the treatment of patients and the development of new drugs have contributed to the increase of liquid hospital waste generation, which ends up making it difficult to treat raw water from springs.

The amount and characteristics of wastewater generated by hospitals can vary considerably according to the services offered, such as the number of beds, the number of patients, and the availability of laboratories (Hocaoglu *et al*., 2021). In developed countries, each bed, on average, can generate more than 1,000 liters of wastewater per day, while for developing countries the estimated volume is 200 liters to 400 liters per bed per day (Kumari; Maurya; Tiwari, 2020).

Residual water from administrative areas, room bathrooms or normal wards are considered domestic. On the other hand, wastewater resulting from direct patient care, analysis and research activities, containing toxic substances, such as disinfectants, detergents, drug residues, infectious excrement, radioelements and other chemical products, such as acids, alkalis, solvents, benzene, hydrocarbons and coloring agents, are classified as specific residuals and must have their destination monitored (Chartier *et al*., 2014). Such effluents, when handled and disposed of improperly, represent a serious risk to human health and the environment, due to their ability to contaminate watersheds, pollute surface and groundwater (Majumder *et al*., 2021).

According to Lima (2023), contaminated hospital sewage, as a rule, must be treated in specialized Effluent Treatment Plants (ETR). These operations are divided into three types: physical, such as sorting, mixing, flocculation, sedimentation, flotation and filtration; chemical, which removes or converts contaminants through the addition of chemical products or reactions, such as precipitation, adsorption, and disinfection; and biological, which use microorganisms to remove organic and inorganic materials and carry out processes such as carbonaceous, nitrification and denitrification.

The purification process of HFs' effluents generally consists of five successive steps, including pre-treatment (physical and mechanical), primary treatment (physical and chemical), secondary treatment (chemical and biological), tertiary treatment (physical and chemical) and treatment of the formed sludge (supervised dumping, recycling or incineration) (Crini; Lichtfouse, 2019). Throughout these stages, suspended solid parts, sedimentable mineral matter, inorganic solids, suspended organic matter, pathogenic organisms are eliminated (Lima, 2023).

Common sewage treatment methods have disadvantages, such as excessive energy consumption, generation of large amounts of sludge and GHG emissions. These treatment processes follow a linear economy system, that is, their main objective is only to generate a treated effluent, but without providing the recovery of energy and resources (Oliveira *et al*., 2022).

According to Oliveira *et al*. (2022), the implementation of sewage treatment strategies focused on the principles of CE proposes a change in the way sewage is understood. Instead of being considered only an environmental liability, as occurs in the linear model, it becomes a resource capable of promoting revenues from its treatment, with a focus on the recovery and use of by-products. The components of the system are interpreted with a new look at sustainability, aligning with the principles of CE.

Efficient sewage treatment is a way to achieve the goals set by the UN for 2030, especially SDG 6 (Clean Water and Sanitation), which seeks to ensure the availability and sustainable management of water and sanitation for all. Within this objective, goals 6.2 and 6.3 stand out, which aim to ensure equitable access to sanitation and hygiene for all, as well as to promote improvement in water quality by reducing pollution, eliminating dumping, and minimizing the release of chemicals and hazardous materials. It also proposes to significantly decrease untreated wastewater, increasing recycling and safe reuse on a global scale (UN, 2025).

Besides SDG 6, other goals can be achieved directly or indirectly by promoting the circular economy and the sustainable development of sewage treatment systems. The generation of renewable energy from

gases from anaerobic ETR systems, the contribution to the development of sustainable cities, the control of GHG and waste from these treatments are some of the points that are associated with the goals aimed at Affordable and Clean Energy (SDG 7), Sustainable Cities and Communities (SDG 11), and Climate Action (SDG 13) (Oliveira *et al*., 2022).

Waste management

Worldwide, health is one of the fastest growing sectors, causing a significant generation of waste, due to the provision of a multitude of services for disease control and patient treatment (Kenny; Priyadarshini, 2021). Using the United States as an example, Voudrias (2018) highlighted that this country produces about 5.9 million tons of health service waste (HSW) per year. The COVID-19 pandemic was another determining factor for the increase in the generation of HSW, due to the use of significant amounts of masks and PPEs, with developing countries being the most affected by this hazardous and toxic waste, due to poor management systems (Dihan *et al*., 2023).

According to RDC no. 222, of March 28, 2018 (Anvisa, 2018), HSW are classified into five groups: A, B, C, D, and E. Group A corresponds to materials with possible presence of biological agents that, due to their characteristics, may present a risk of infection, such as laboratory materials, carcasses, anatomical specimens, tissues, transfusion bags containing blood, etc. Group B includes chemical substances that may present risks to public health or the environment, depending on its characteristics of flammability, corrosivity, reactivity and toxicity, such as medicines, disinfectants, waste containing heavy metals and laboratory reagents. Group C encompasses any materials containing radionuclides above the limits allowed by the National Nuclear Energy Commission (CNEN), including radioactive waste from research and teaching laboratories in the health area, clinical analysis laboratories, nuclear medicine and radiotherapy services. Group D covers waste that does not present a biological, chemical or radioactive risk to health or the environment, and can be compared with household waste, such as food leftovers, waste from administrative areas and materials used for hygiene, among others. Group E includes sharp or scarifying materials, such as razor blades, needles, glass ampoules, drills, diamond tips, scalpel blades, lancets, spatulas and other similar materials.

Such waste is mainly generated in hospitals, laboratories, research centers, blood banks, and nursing homes (WHO, 2024). Of the total waste generated by HFs, about 85% is general, non-hazardous, similar to domestic. The remaining 15% are considered hazardous due to biological, chemical, or radioactive contamination (WHO, 2024). For an economical

management of the treatment, however, a strict segregation at the time of production of this waste is necessary.

Inadequate management of HSW can aggravate climate change, due to open burning of garbage, which releases dangerous pollutants, including dioxins, furans and toxic metals such as lead, cadmium, and mercury, as well as considerable amounts of carbon dioxide. In addition, the disposal of biodegradable waste causes significant GHG emissions, such as methane, whose influence on the climate is even stronger than that of other gases (Deviyanti; Shahriar, 2022).

The traditional extract-produce-discard model has been predominant in waste management, resulting in increasingly visible environmental and economic impacts, especially in sectors such as health, where a significant portion of the waste generated is considered dangerous, making the process unsustainable in such environments (Sepetis; Georgantas; Nikolaou, 2025).

In this sense, the adoption of CE principles for HSW management is considered a measure that contributes to urban sustainability, as it contributes to the reduction of environmental impacts, increases resource efficiency, and strengthens circular material flows (D'Alessandro *et al*., 2024). Effective HSW management contributes significantly to the achievement of certain SDGs, especially: SDG 3 (Good Health and Well-being); SDG 6 (Clean Water and Sanitation); SDG 8 (Decent Work and Economic Growth); SDG 12 (Responsible Consumption and Production); and SDG 13 (Climate Action) (Sharma *et al*., 2021).

The implementation of CE in the HSW management system is more complex than in other sectors, due to the type of waste, especially due to the presence of hazardous substances, representing a challenge, since many materials employed in HFs are used just once, with very low possibility of recycling or reuse, even in other less demanding sectors (Dihan *et al*., 2023).

To implement a sustainable management scenario for the HSW management system, it is necessary to adopt CE strategies that involve minimizing waste generation, because the lower the waste production, the lower the costs for its management and the greater the efficiency in the use of materials. To this end, it is necessary for HFs to form teams that develop strategic procedures for waste management, such as making smart purchases based on the life cycle of products, predicting their environmental effects, such as toxicity, the cost of disposal, as well as the possibility of reusing and recycling materials (Dihan *et al*., 2023).

For CE, sustainable acquisition means, initially, a strategy that aims to reduce the consumption of natural resources and materials, as well as to minimize the environmental impacts of the inputs used, prioritizing

products composed of renewable materials or raw materials with recycled content (Sanofi, 2024). It is worth highlighting the purchase of recyclable plastic products, such as polyethylene or polypropylene, instead of tools composed of Polyvinyl Chloride (PVC), as well as the replacement of single-use face masks with others made of durable materials, which allow sterilization and reuse (Dihan *et al*., 2023).

To apply HSW treatment strategies, segregation in production becomes essential to ensure the safe handling, disposal, and minimization of environmental and health risks (Aquilina, 2025). Segregation consists of separating and selecting waste at the place of generation according to the classification adopted. Its main objectives are: to avoid contamination of waste considered common; to enable the implementation of management procedures for each separate group; to allow specific treatment for each category of waste; to minimize the risks of contamination of the responsible persons; to reduce expenses related to waste management; to enable the adoption of reuse and recycling of non-hazardous waste (Brasil, [n.d]).

Another strategy that seeks to mitigate the general effects of HSW on the environment is to extend the useful life of certain materials, either through reuse or other means, such as repair, refurbishment, or reuse. To adopt this practice, however, it is necessary to implement strict segregation techniques, accompanied by separate collections to distinguish hazardous, non-hazardous, reusable, and recyclable substances (Dihan *et al*., 2023). For the contaminated materials used in HFs to be considered reusable, it is essential that they undergo rigorous sterilization processes (Voudrias, 2018). Among the items that can be considered reusable, surgical gowns, curtains, table covers, surgical instruments, sharps containers, laparoscopic instruments, suction receptacles, and anesthetic trays stand out (Voudrias, 2018).

The reuse of materials contributes both to the reduction of cost and to the amount of waste generation. According to a survey conducted by Kwakye, Brat and Makary (2011), a reduction of approximately 15,422 kg/year of waste and savings of US$ 175,000/year was estimated in a hospital with 1,000 beds, only using reusable containers for sharps instead of disposable materials.

According to Voudrias (2018), recycling is another technique that can be undertaken at HFs before waste disposal. Due to the concerns and regulations associated with handling hazardous HSW, however, the use of recycling can be difficult, or even impossible, when it involves some types of waste. There is, however, a substantial number of non-hazardous materials in HFs that can be easily and safely recycled, contributing to environmental and financial savings. Among these materials there are blue

wrapping – a polypropylene-based material used to wrap sterile materials, and which represents approximately 20% of the waste generated in operating rooms –, cardboard, glass, paper, beverage cans, newspapers, magazines, PET plastics, batteries, and electrical and electronic equipment (Voudrias, 2018).

The implementation of recycling practices can significantly reduce the total waste generated in HFs, directly contributing to the reduction of GHG emissions associated with improper disposal and the mitigation of climate change. This initiative can promote substantial cost savings related to the disposal of this waste (Tabibi, 2024). According to Ultreras-Rodríguez *et al*. (2024), in an analysis of cases in hospitals and clinics, the adoption of recycling and reuse programs contributes to a reduction of up to 40% in the amount of waste sent to landfills or incineration. These authors also state that an 18% decrease in operating costs related to waste disposal in selected HFs was recorded.

According to MacNeill *et al*. (2020), the transition to CE in the health sector requires the collaboration of diverse groups of stakeholders, such as hospital administrators, medical providers, and equipment manufacturers, who must act with a shared goal of systemic transformation.

Conclusion

The introduction of CE in HFs is not only a viable alternative, but a necessary one in the face of the range of environmental, social, and economic challenges faced by the world population and the planet. By shifting from the linear model based on "extract, produce, use, and discard" to a practice that prioritizes reduction, reuse, and recycling, HFs can significantly minimize their environmental impacts, natural resource extraction, and generate operational and financial benefits. These practices are directly aligned with the fulfillment of the UN Sustainable Development Goals, demonstrating the importance of the health sector in this role.

The adoption of solutions such as sustainable design, energy efficiency, adequate water management, effluent treatment and responsible waste management, demonstrates that HFs can provide quality care services with environmental responsibility. The examples presented during this review reinforce the efficiency of these strategies, proving their environmental, economic, and social benefits.

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Authors

Antonio Pedro Alves de Carvalho Architect and Civil Engineer, with a Ph.D from the Universitat Politècnica de Catalunya. Full Professor at the Faculty of Architecture of the Federal University of Bahia, coordinator of the Editorial Board of the Brazilian Association for the Development of Hospital Buildings (ABDEH), acting as a researcher in the areas of hospital architecture, architectural design methodology, environment and health.

Jair de Jesus Lima With an interdisciplinary bachelor's degree in Science and Technology, Jair is currently studying for an undergraduate degree in Sanitary and Environmental Engineering at the Federal University of Bahia.

Article

Natural lighting and design process employed by Siegbert Zanettini: Ermelino Matarazzo Hospital

Authors
Danielly Marcianny Silva Eulário University of São Paulo
Paulo Sergio Scarazzato University of São Paulo
Ludmila Cardoso Fagundes Mendes Federal University of Minas Gerais

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Abstract

This article analyzes the approach to natural lighting in the design process of architect Siegbert Zanettini, focusing on the Ermelino Matarazzo Municipal Hospital in São Paulo. The research is grounded in contemporary discussions on the benefits of natural light in health care settings, particularly in relation to well-being, patient recovery, and circadian rhythm regulation. The study was conducted through a literature review, analysis of the architectural project, and an interview with the architect. The results show that architectural solutions such as atriums with skylights, shading devices, and appropriate façade orientation contribute to the distribution of natural light in indoor environments. It is concluded that the design process plays a fundamental role in the incorporation of passive natural lighting strategies, capable of promoting more humanized and efficient hospital environments aligned with local climatic conditions.

Keywords:

hospital architecture, natural lighting, design process, eco-efficiency, post-occupancy evaluation.

Introduction

The hospital environment has adapted to the changes that have occurred according to its function, complexity, and activities of the occupants. The challenge for such environments is to contribute to alleviating suffering (Lisbon, 2021). However, the beginning of the organization of hospitals does not arise from the search for "a positive action of the hospital on the patient or disease", according to Lisboa, 2021:

> The first factor of the transformation was not the search for a positive action of the hospital on the patient or the disease, but simply the annulment of the negative effects of the hospital. It was not first sought to medicalize the hospital, but to purify it from the harmful effects of the disorder it entailed. And disorder here means diseases that he could arouse in the hospitalized people and spread in the city in which he was situated, as well as the economic and social disorder of which he was the perpetual focus [...]. (Lisbon, 2021, p.78)

Hospital buildings differ from other typologies, as observed by Jarbas Karman (Bitencourt; Saccomori, 2021), founder of the Institute of Hospital Research.

> "I believe that few know how to 'see' a hospital, because the hospital, unfortunately, is very little known among us; Many do not even go into the merits of the solutions presented, not caring that they are summary and superficial, as long as the appearance of the plan is 'clean' and the exterior monumental. This way of evaluating the architectural work may lend itself to commercial buildings, but never to a hospital. The hospital is quite different because, while each department and integral part must observe exact dimensions, it is necessary that these departments and parts are arranged in accordance with the ideal interconnections. Any concession will be reflected in the increase in the cost of maintaining the hospital." (Jarbas Karman, Folha da Manhã, August 24, 1958. IPH, 2016)

Zanettini's approach concerning hospital projects is fully in line with that of Jarbas Karman because, by consciously working with the potential of natural lighting in such buildings, he contributes to their energy efficiency. In addition, the correct use of natural lighting that goes through the control of insolation and glare potentially present in it contributes to greater well-being, comfort, and health promotion of patients and employees.

The literature on hospital buildings indicates that conventional forms can cause unnecessary stress to patients and healthcare teams. An alternative to reduce this problem is employing evidence-based design methodology, which can result in projects with physical configurations capable of reducing fatigue, to make enhance care, in addition to enabling safety and quality environments for occupants (Ulrich *et al*., 2004).

The contact of hospital patients with nature, through visual outside access from the bed, can result in faster recovery, due to reduced stress and pain. Positive distractions, such as access to views of nature, in addition to access to daylight, help patients to feel the ambiance, overcoming their pain or anguish (Ulrich, 1991). In this context, good contemporary hospital architecture seeks, through the methodology of Evidence-Based Design (EBD), to meet the needs of distinct groups of occupants of hospital environments, which can sometimes be conflicting. It takes sensitivity and creativity. Ulrich proposes to evaluate gains and losses for the proportion of a "psychologically supportive" architectural project.

Aspects such as room geometry, building orientation, glass transmittance, and internal surfaces light reflection are relevant. External factors, such as the latitude and longitude of the location, climate data, and the types of skies, also impact the quantity and quality of natural light in environments. These factors must be considered in the architectural design to optimize the capture and distribution of natural lighting, to promote visual comfort and the well-being of users (Garcia *et al*., 2020).

Goals

The main goal of this article is to analyze the approach to natural lighting in the design process of architect Siegbert Zanettini, adopted at Ermelino Matarazzo Municipal Hospital, at a time before the use of principles discussed today in the field of Evidence-Based Design. Ahead of his time, Zanettini understood the importance of visual connection with the outside and the use of atriums in his hospital projects, as resources for stress reduction and psychological support advocated by Ulrich.

Literature review

The contribution of natural lighting in healthcare environments

Light gives rhythm to life through visual or non-visual effects (Brandston, 2010). The essential contribution of daylight is linked to the general well-being of human beings, related to human physiology, by contributing to the regulation of the circadian cycle, in addition to reducing energy use and making the environment more humane, welcoming (Heschong, 2021).

From a physiological point of view, daylight has a significant impact on the human circadian system, which is responsible for regulating several biological processes, such as the sleep-wake cycle, mood, and levels of alertness. The light that reaches the retina acts as the main synchronizer of these biological rhythms in relation to the natural 24-hour cycle of day and night. When people spend prolonged periods in environments with

little exposure to natural light, circadian dysregulation can occur, which can result in several health problems, such as sleep disorders, metabolic alterations, and negative impacts on psychological well-being (Acosta, Leslie, and Figueiró, 2017).

Natural lighting is widely recognized as a key environmental attribute in healthcare settings, due to the benefits that encompass human health, well-being, and performance in everyday activities. Historically, the conception of the "therapeutic hospital" in the 18th century already associated cure rates with spatial quality, highlighting ventilation and sunlight as crucial factors for recovery. With the advancement of contemporary research, it has been understood that light is not just a visual need, but an element that influences the biological clock, helping to regulate endocrine and mitigate stress and fatigue (Ribeiro *et al*, 2020).

Both direct sunlight and daylight contribute to the recovery of patients, especially when they have direct outside view or, at least, perceive the passage of time through the day. Good health care practices employed in the late 19th and early 20th centuries, such as the use of balconies, brises, and contact with fresh air in tuberculosis treatment hospitals, can be seen as recovery (Cooper-Marcus and Barnes, 1995).

Another relevant aspect refers to the impact of natural lighting on the performance and productivity of health professionals. Studies indicate that work environments adequately provided with natural lighting can improve concentration, reduce visual fatigue, and even contribute to the reduction of errors by health professionals. The presence of daylight at workstations and care areas, therefore, not only benefits patients, but also improves the working conditions of medical and technical staff (Capolongo *et al*, 2016).

In addition to the physiological effects, natural lighting contributes to the psychological and emotional aspects of users. The presence of windows and the possibility of viewing the outside environment promote a sense of connection with the outside world, reducing the sense of isolation often experienced by hospitalized patients. This visual contact with the outside can contribute to the reduction of stress and the creation of more humanized environments, favoring the therapeutic process (Acosta, Leslie and Figueiró, 2017).

In hospital environments, the presence of natural lighting is considered a determining factor of health, as it promotes the synchronization of human physiology. Studies indicate that the existence of windows and access to sunlight significantly reduce the occurrence of postoperative pain, fever, and depression in patients. In addition, natural lighting contributes to the improvement of the sleep cycle and accelerates recovery in prolonged treatments, such as oncology, and in intensive care units (ICU). The

deprivation of this visual contact with the outside can lead the individual to situations of discomfort, since contact with the external environment meets a biological need for visual information (Ribeiro *et al*, 2020).

In addition to the benefits for health and user experience, the use of natural lighting is also beneficial from an energy and environmental point of view. Reducing the dependence on artificial lighting during the day can reduce the energy consumption of hospital buildings, contributing to sustainability and energy efficiency strategies. By carefully considering aspects such as orientation, sizing of openings, materials, and spatial organization, it is possible to create environments that maximize the benefits of daylight, promoting healthier and more efficient spaces (Acosta, Leslie, and Figueiró, 2017).

Influence of architectural design on the perception of daylight in the built space

The guidelines present in regulations determine conditions and attributes of healthcare spaces, the connection between windows, outdoor and indoor environments, and occupants. Although there is still no common ground concerning the quality of viewing of a window applied to distinct types of occupations and buildings. The design process of hospital buildings must therefore be committed to the quality of life of those who will work or be treated, as environments such as inpatient rooms may require different openings than those in workspaces, given the specificity of the occupation (Ko *et al*., 2021).

The study of implantation, the volumetry of the buildings and the configuration of the facades are aspects of the utmost importance in the design process, as they are related to the quality of natural lighting, including the control of insolation. When the architect is aware of this, in addition to being on the right track to obtaining appropriate results, it facilitates the work of specialized consultancy, responsible for ensuring adequate natural lighting inside the building, with the correct control of glare and heat gain (Ko *et al*., 2021).

From the point of view of environmental comfort, natural lighting also influences the aesthetic perception and spatial quality of hospital environments. The variation of light throughout the day creates more dynamic and pleasant environments, contributing to the positive perception of the built space. In this sense, the effective planning of natural lighting must consider aspects such as solar orientation, sizing of openings, internal materials, and light control strategies, ensuring adequate levels of lighting without causing glare or visual discomfort (Acosta, Leslie and Figueiró, 2017).

The orientation of the facades also alters the spatial perception of light. Facades facing north or south, in tropical latitudes, present distinct behaviors of uniformity and direct light entry, requiring specific design solutions for each case. The absence of sun protection elements, such as fixed or mobile *brises*, for example, is a common design flaw that results in visual discomfort due to excess direct light and heat. Thus, the design process must balance the need for high illuminances with the quality of the view and the control of glare, understanding that shading solutions and the correct sizing of openings are essential to ensure healthy and attractive indoor spaces (Ribeiro *et al*, 2020).

Among the most important architectural elements for the entry and distribution of daylight are the size and position of the windows, the ratio between the glazed area and the façade, the orientation of the building, as well as the characteristics of the internal surfaces. The correct sizing of openings is considered an essential factor to allow natural lighting to reach different areas of the environment, to offer both visual lighting and the stimuli necessary for the circadian system (Acosta, Leslie and Figueiró, 2017).

The presence of windows enables daylight view, so as to result in a more pleasant environment, with views and distractions (Lam, 1977). An architecture based on natural light is an architecture conditioned by environmental conditions. During the design process, there are characteristics that need to be considered to achieve the appropriate result. Thus, the integration of natural lighting in the architectural design of hospital buildings is an essential strategy to promote healthier, more humanized, and efficient environments. By considering the physiological, psychological, and functional effects of daylight, architects and other design professionals can contribute significantly to improving the quality of healthcare environments and the overall well-being of their users (Acosta, Leslie, and Figueiró, 2017).

The height of the windowsill is a representative design element for luminous comfort and the view of the surroundings. Windows with high windowsills tend to provide a greater range in the distribution and uniformity of light, which reduces the possibility of direct glare in the work area. However, because they are above the visual field, these openings often restrict the patient's view of the sky, preventing contact with the horizon line. On the other hand, windows with low windowsills optimize visual contact with the landscape but might lead to uneven lighting and increase the risk of glare, especially for bedridden users (Ribeiro *et al*, 2020).

Simulation studies in hospital settings demonstrate that the connection between the window area and the façade may significantly influence the levels of circadian stimulation received by occupants. In certain contexts, a

higher proportion of glazed area allows adequate levels of natural lighting to reach deeper areas of the environment, increasing the probability that users receive sufficient light stimuli for the synchronization of biological rhythms (Acosta, Leslie and Figueiró, 2017).

The challenges of 20th century hospitals, by João Filgueiras Lima, Lelé

Zanettini is an admirer of the work of architect João Filgueiras Lima (Lelé) and his contribution to healthcare architecture in Brazil. This topic addresses some of Zanetti's ideas from his book **Arquitetura, uma experiência na área da saúde (Architecture, an experience in the health area)**. In an interview with the authors, Zanettini highlighted the influence of Lelé's work on his professional career, especially regarding the relationship between architecture, technology, and environmental conditions.

> (...) I had an extraordinarily strong relationship with him (Lelé), because I was also thinking about industrializing. And he was good. He was the best architect of the time. Somehow, I walked kind of parallel to the whole process of Brazilian construction, together with Lelé. Always in a critical sense. (Excerpt from an interview given by the architect, professor and Dr. Siegbert Zanettini to the authors on 4/7/2024.)

The model of a technological hospital was consolidated in the 20th century, characterized by the integration of different medical specialties in the same unit and by the intensive use of technologies. After World War II, scientific advances, and the participation of large companies in the medical-hospital sector significantly expanded the supply of specialized equipment and systems. This process contributed to the automation of several hospital services and to transformations in the organization of spaces and building facilities (Lima, 2012). The development of bacteriology and infection control techniques has also directly influenced the design of hospital buildings. In this context, natural lighting and ventilation, common in pavilion hospitals, were gradually replaced by artificial air conditioning and lighting systems. Consequently, hospital environments have become more hermetic and technically controlled.

> The technological exhibitionism of the time made the hospital environment artificial and inhumane, to the point of influencing the patient's depressive stage, causing such a psychological state, so that it began to hinder the healing processes themselves. In 1960, efforts were being made to change this way of thinking about the hospital at the Hospital Foundation of Brasília, in an attempt to establish an extensible and flexible hospital model, which would facilitate innovations, but which would promote less hermetic hospitals, with integration into landscaped outdoor spaces, so that patients could have outdoor therapies and sunbathing (Lima, 2012, p.41).

Method

Based on the literature review presented, the present research was divided into two main stages: (1) analysis of the architectural design of Ermelino Matarazzo Municipal Hospital, with emphasis on the strategies adopted for the availability and control of daylight; and (2) interview with Architect Zanettini.

The starting point for the research was the search and reading of references about hospital projects, with special attention to aspects of visual perception and natural lighting. The bibliography is discussed with other authors who highlight the importance of natural lighting in healthcare facilities, such as Ko *et al*., Ulrich, Cooper-Marcus, Barnes and Lima, among other authors relevant to the context addressed.

The research is characterized as a qualitative case study, with an exploratory approach, analyzing the azimuthal and visual morphological orientation. The architectural project of Ermelino Matarazzo Municipal Hospital was analyzed, with emphasis on design strategies related to the use of natural lighting. The analysis was conducted based on criteria identified in the literature, such as orientation of the facades, presence of shading devices, configuration of atriums and relationship between openings and internal spaces. In addition, a semi-structured interview was conducted with the architect Ziegbert Zanettini, author of the project, who confirmed that the proposed solutions for natural lighting and the control of insolation were conscious, due to the benefits they provide.

Results

Project analysis

The building studied by this article is in the eastern region of the city of São Paulo, Brazil, and was inaugurated in 1991. It stands out for the engagement it provided, since it was developed, planned and executed with representatives of the local community, technicians from the City Hall and members of the health commission, "listening to suggestions and accepting changes". For everyone to understand what was being built, it was necessary to explain to the members of the commission what an architectural project was, the need to prepare a project and how the design process of the hospital space would take place (Zanettini, 2002).



Illustration 1 . Ermelino Matarazzo Municipal Hospital. Source: Zanettini, 2000.

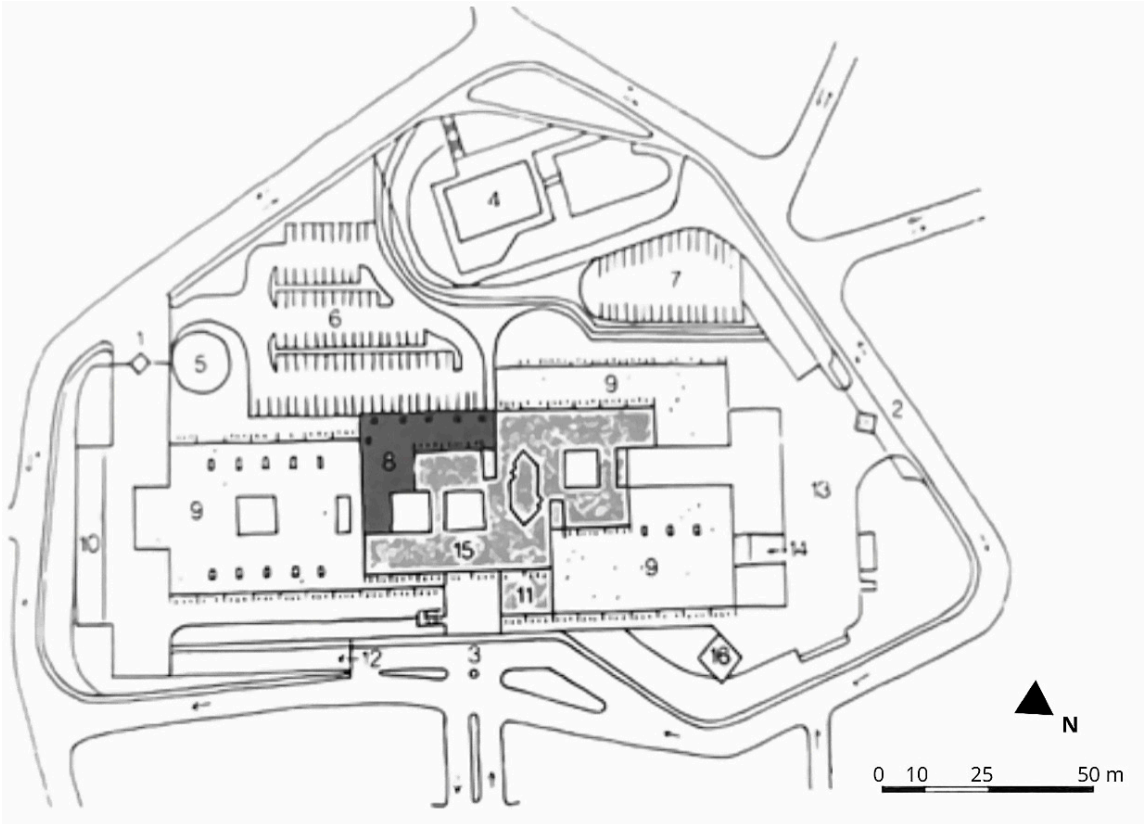
Ermelino Matarazzo Municipal Hospital differs in its conception because it is the result of a collaborative dynamic. From monitoring the work to its inauguration, there the health commission was engaged in the entire process, in which the architect sought to meet the needs of the local population, according to the reality of those who live and use the space.

> "Our hospital is different because in it the details of operation and architecture were conceived based on suggestions and demands from users. We went up to the floors to follow the development of the work, so that it would not be delayed, we gave our opinion on the finishing, and we understood the floor, subfloor and ceiling height". (Text of the health commission for the population. Zanettini, 2000, p.214.)

The humanization of the hospital began in the participatory process and materialized in the quality of the architectural object, valued by the adequate capture and distribution of natural lighting, associated with careful control of insolation.

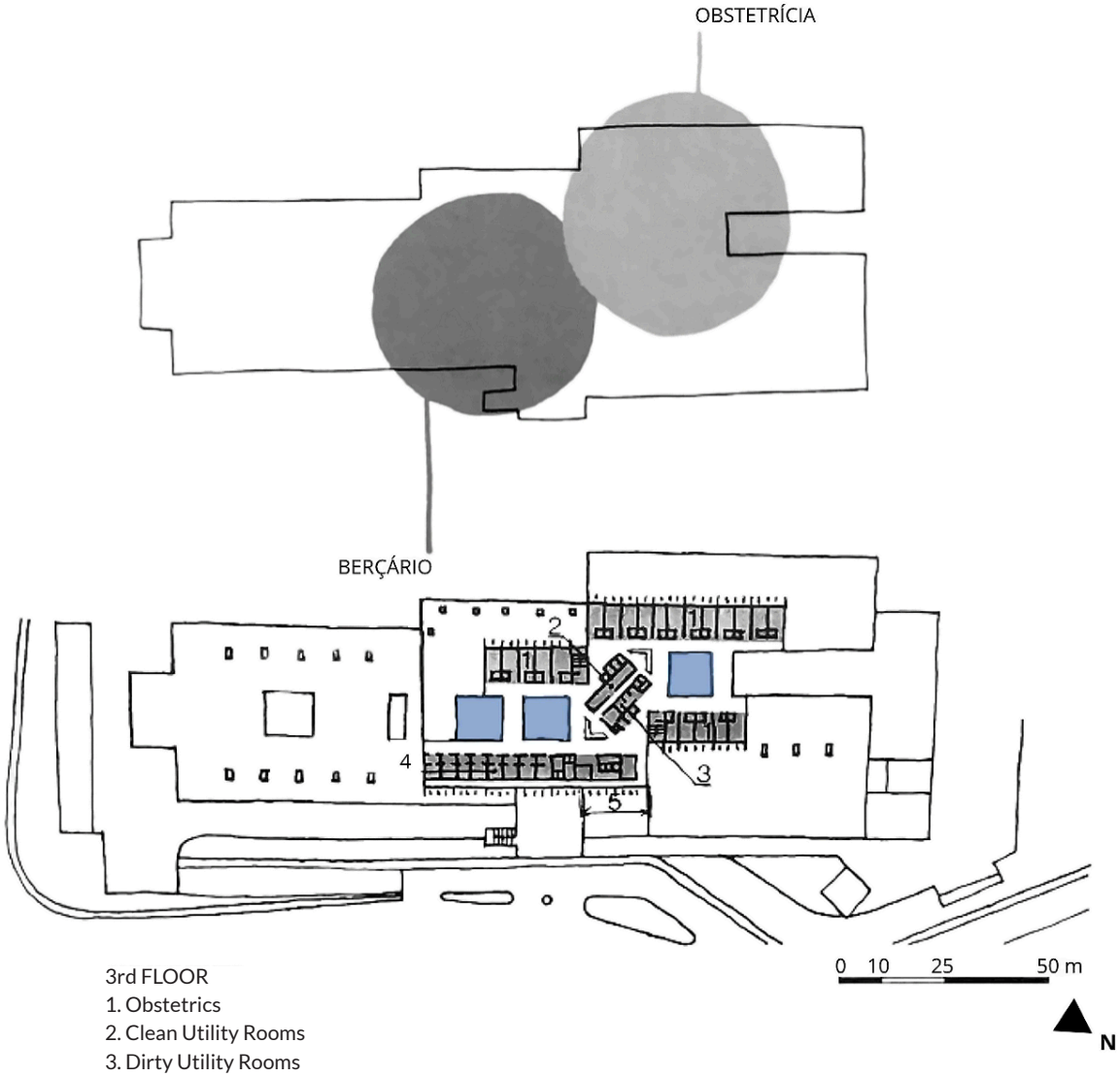
Architectural analysis based on bibliography

Ermelino Matarazzo Municipal Hospital presents solutions regarding natural lighting, such as the use of skylights, located in atriums, and *brises* on the northeast and southwest facades. For the preparation of this article, the third floor, intended for Obstetrics and Nursery, and the fourth floor, where Obstetrics and Pediatrics are located, were considered, as shown in the plans below (Illustrations 2 to 4):



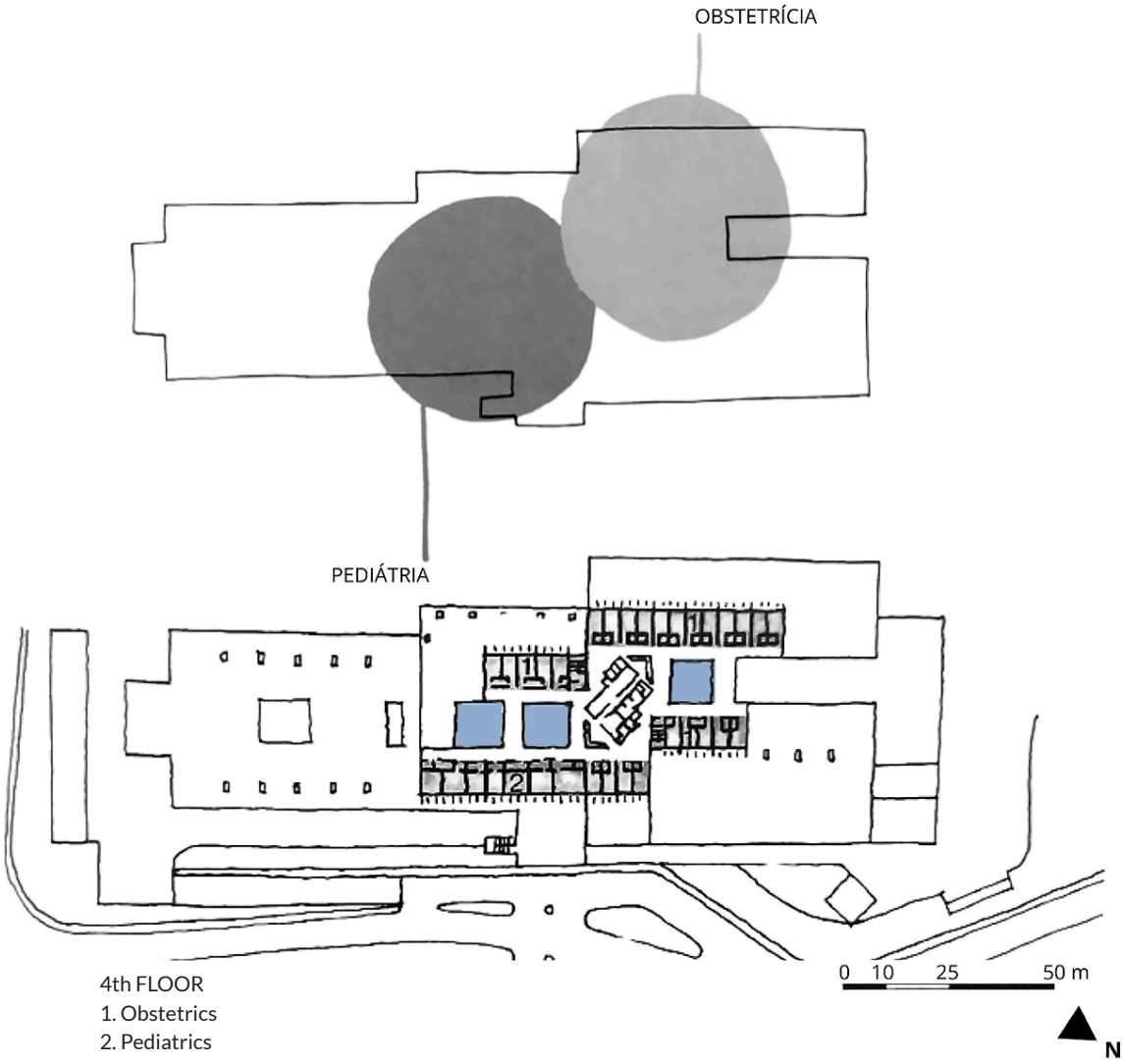
IMPLEMENTATION
1. Outpatient access
2. Service entrance
3. Main entrance
4. Daycare
5. Helipad
6. General public parking lot
7. Staff parking lot
8. Surgery and Obstetrics Center
9. Green roof
10. Ambulance station
11. Assembly hall
12. Ambulance entrance
13. Service court
14. Docking stations
15. Vertical block for inpatients
16. Vehicle loading, cleaning and maintenance

Illustration 2 . Implementation of Ermelino Matarazzo Municipal Hospital. Source: Zanettini, 2000.



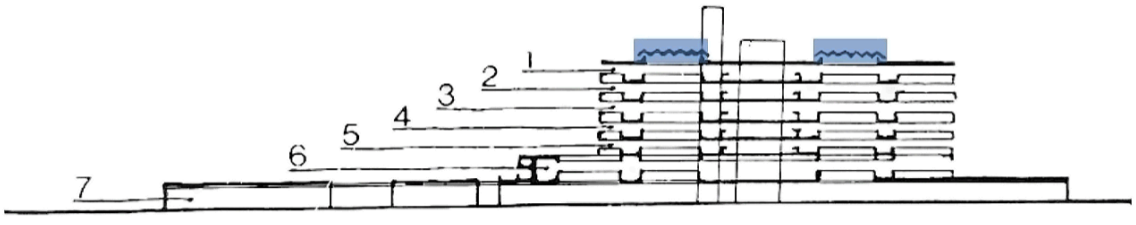
3rd FLOOR
1. Obstetrics
2. Clean Utility Rooms
3. Dirty Utility Rooms
4. Nursery
5. Common area/Service shaft

Illustration 3 . Diagram and plan of care units on the third floor, with the location of Obstetrics and Nursery. Source: Zanettini, 2000.



4th FLOOR
1. Obstetrics
2. Pediatrics

Illustration 4 . Diagram and plan of care units on the fourth floor, with the location of Obstetrics and Pediatrics. Source: Zanettini, 2000.



Atriums
1. Surgical ward
2. Medical ward
3. Obstetrics/Pediatrics
4. Obstetrics/Nursery
5. Administration office
6. Surgery and Obstetrics Center/ICU
7. Emergency Room/Services

Illustration 5 . Schematic view indicating the division of units by floor, with the location of Obstetrics and Pediatrics; and Obstetrics and Nursery. Source: Zanettini, 2000.

In the blueprints, it is possible to observe three atriums covered by translucent skylights, which are present on all floors. The adopted solution allows the perception of the variation of natural lighting throughout the day and the seasons, which favors the balance of the circadian cycle of all users, since patients, companions, medical and healthcare staff have visual access to the covered and illuminated atriums. In addition, this solution can contribute to the saving of electric lighting since all floors have indirect access to daylight.

The atria have fins, which control direct sunlight, resulting in greater visual comfort. The presence of atriums with skylights allows the distribution of natural lighting in deep areas of the hospital plant, a strategy that contributes to more homogeneous levels of illuminance and reduces the dependence on artificial lighting during the day.

Another solution adopted by Zanettini is the use of shading elements for the openings on the facades, with fixed *brises*, which provide more control of glare and distribution of diffuse light, increasing the comfort of patients. The *brises* are located along the entire length of the northwest and southwest facades, where there is the Nursery, on the third floor, and the Pediatrics, on the fourth floor.



Illustration 6 . Shading solution on the northwest and southwest facades of Ermelino Matarazzo Municipal Hospital. Source: Zanettini, 2000.



Illustration 7 . Atrium with a translucent roof that allows the perception of daylight. Source: Zanettini, 2000.

Interview

In an interview with the authors in 2024, Zanettini emphasized the importance of technology in architectural design and, consequently, in the perception of light in interior spaces.

> You can't do architecture without technology. (...) The world of arts and the world of sciences; architecture is where those two meet. I explain why architecture seeks to meet all possible technical, visual and environmental conditions. (...) This is my struggle: understanding our climate, clearly understanding our biomes, and each one with its characteristics. To understand the wind regimes, the density, the opening of light, the whole way to understand it in the place, with its determined soil, with its subsoil as well. (Excerpt from the interview given by the architect, professor Dr. Siegbert Zanettini on 4/7/2024.)

The architect's criticism of the "closed and heavy" hospitals of the 60s is reflected in his design process, with emphasis on the use of "eco-efficiency" applied in Ermelino Matarazzo Hospital.

> In the 1960s I began to question this architecture. I started to address some concepts of eco-efficiency; the issue of sustainability began to arise. The eco-efficiency that I launched in the 1960s was originally concerned with understanding our reality, our environment, contributing to our architecture. And how, in a way, it was decisive in this architecture. So, this concept of mine comes from many years. It comes from 60 years ago. At the time, I called it eco-efficiency, but I was already beginning to discuss why works were so closed, so heavy, so striking in the sense of worrying about their beauty but did not respond to the Brazilian environmental conditions. (Excerpt from the interview given by the architect, professor Dr. Siegbert Zanettini on 4/7/2024.)

During the interview, the architect also spoke about the importance of considering local climatic conditions during the design of architectural projects.

> I am Brazilian. And I understood my climate; the project also needs to understand this climate. In my opinion, it is fundamental. If you don't have that, in my opinion, the project is flawed from the beginning. I don't think architecture is independent from the place. The place defines architecture; that is how strong it is. The initial cost of production, of thinking, that no longer exists. Now it's time to produce. (Excerpt from the interview given by the architect, professor Dr. Siegbert Zanettini on 4/7/2024.)

Discussion

As it is a project with social participation, Ermelino Matarazzo Municipal Hospital has specificities that make it a unique building in the field of healthcare architecture. As presented by the architect Zanettini in his book **Arquitetura, Razão, Sensibilidade (Architecture, Reason, Sensitivity)**, there were some weekly meetings to discuss the project, besides "an agenda previously discussed in assemblies with the residents". The analysis of Ermelino Matarazzo Municipal Hospital shows that the design strategies adopted by Siegbert Zanettini anticipate contemporary discussions about "therapeutic hospital", where light is not only a visual need, but an element of biological synchronization. The following technical constraints are integration of natural light into the built environment, understanding the climate and the biome.

The presence of central atriums covered by skylights is a fundamental element for the distribution of natural light on the internal floors of the building. This solution allows daytime lighting to penetrate deeper areas of the building, reducing the dependence on electric lighting during the day,

contributing to the perception of light variation over time. As discussed by Acosta, Leslie and Figueiró (2017), exposure to natural lighting plays a relevant role in the regulation of the circadian system and directly influences the well-being and circadian rhythm of patients and healthcare professionals.

In addition, the atriums function as elements of spatial orientation and visual connection between the different floors of the building. This strategy contributes to the creation of more open and less institutionalized environments, which endorses the discussions proposed by Ulrich (1991) about hospital environments capable of reducing the psychological stress of users. Another relevant aspect refers to the adoption of shading devices on the facades, by means of *brise-soleil*. These elements make it possible to control the incidence of direct solar radiation, avoiding glare and excessive thermal gain, while maintaining the entry of diffused light into indoor environments. According to Ribeiro *et al*. (2020), solar control strategies are essential to ensure visual comfort and environmental quality in hospital spaces.

The solutions adopted in the project also demonstrate a strong relationship with the local climatic conditions, an aspect emphasized by the architect himself in an interview. This approach evidences a design approach based on the understanding of the climate and the Brazilian environmental context, emphasizing the reflections proposed by João Filgueiras Lima (2012) on the importance of integrating architecture, technology and environmental conditions in the design of hospital buildings. Thus, it is observed that the project of Ermelino Matarazzo Municipal Hospital incorporates positive natural lighting strategies that not only respond to technical and environmental issues but also contribute to the spatial quality and humanization of health care environments.

Conclusion

This research demonstrated that architectural design solutions focused on the use of natural lighting are fundamental for the creation of humanized and efficient hospital environments. The use of shading elements and the appropriate orientation of façades can effectively reduce glare and improve thermal comfort, fostering a positive interaction between users and their surroundings. It is concluded that the design process, when grounded in a careful reading of place and in the science of light, can promote spaces that go beyond mere technical functionality, acting as active agents in humanization and hospitality.

Acknowledgments

The researchers thank the architect Siegbert Zanettini and his daughters Adriana and Luciana Zanettini for their support and collaboration with the research, the interview granted and the sharing of the project files. We would also like to thank professor and researcher Erick Vicente, professor of the Postgraduate Course in Hospital Architecture at Einstein Education Center – Abram Szajman Health Education Center, for providing contact with *Zanettini Arquitetura* office.

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Authors

Danielly Marcianny Silva Eulário is a master's student in the Graduate Program in Architecture and Urbanism from University of São Paulo's Architecture and Urbanism and Design Undergraduate Course (FAU-USP). Danielly holds a postgraduate degree in Hospital Architecture from Ensino Einstein Abram Szajman Health Education Center. She owns a bachelor's degree in Architecture and Urbanism from the Federal University of Minas Gerais (UFMG) and Polytechnic Institute of Bragança (IPB). Danielly is also affiliated to ABDEH, Brazilian Association for the Development of Hospital Buildings.

E-mail: danielly.eulario@usp.br

Paulo Sergio Scarazzato is an associate Professor at University of São Paulo's Architecture and Urbanism and Design Undergraduate Program (FAU-USP), where he completed his degree in architecture and urbanism in 1979, began his academic career in 1981, and obtained the titles of master (1988), Ph.D (1995), and associate professor (2018). He has a special interest in topics associated with lighting (natural and electrical) applied to the design process of architectural space and its teaching in the training of the architect. As a representative of FAU-USP, he participates in technical committees of the Brazilian Association of Technical Standards (ABNT), the Commission Internationale de Léclairage (CIE), and the Illuminating Engineering Society (IES), an entity of which he has been a member since 2010. He has also been a member of the Society of Light and Lighting (SLL) since 2015. In his non-academic curriculum, he has authorial architectural and lighting projects for different types of buildings, at different scales (small, medium and large).

E-mail: pasezato@usp.br

Ludmila Cardoso Fagundes Mendes holds a master's degree and is a Ph.D. student in Built Environment and Sustainable Heritage at the Federal University of Minas Gerais (UFMG). CAPES scholarship holder with Sandwich Doctorate in progress at the Polytechnic University of Gdansk (Poland); specialist in Technological Systems and Sustainability Applied to the Built Environment at UFMG. Ludmila holds a bachelor's degree from the Architect and Urban Planner Course from the Federal University of Viçosa (UFV). She is also a researcher at the Laboratory of Environmental Comfort and Energy Efficiency in the Built Environment (LABCON-UFMG). Ludmila is affiliated to ABDEH, Brazilian Association for the Development of Hospital Buildings.

E-mail: ludmilamendes@ufmg.br

Article

Hospital managers' perceptions of the incorporation of emerging technologies and their impact on the physical infrastructure of hospitals in Santa Catarina

Authors
João Paulo Lucchetta Pompermaier Federal University of Santa Catarina – UFSC
Lizandra Garcia Lupi Vergara Federal University of Santa Catarina – UFSC
Patrícia Biasi Cavalcanti Federal University of Santa Catarina – UFSC

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Abstract

The advancement of technological innovations has transformed hospitals, yet many institutions still face difficulties in adapting their physical, regulatory, and organizational infrastructure. This study examines the perceptions of hospital managers in Santa Catarina regarding the incorporation of emerging technologies and their relationship with physical infrastructure. A literature review and semi-structured interviews were conducted with managers from public and private hospitals, and the data were subjected to content analysis according to Bardin (2016). The results highlighted challenges such as aging buildings, insufficient preventive maintenance, space limitations, regulatory constraints, inadequate IT infrastructure, excessive costs, and a shortage of professionals with a systemic perspective. The most affected areas were the surgical center, imaging and diagnostics, ICU, pharmacy, emergency department, and administration. In conclusion, the adoption of emerging technologies requires strategic planning, physical renovations, continuous training, and public policies aimed at hospital modernization.

Keywords:

healthcare 4.0; emerging technologies; healthcare architecture; hospital infrastructure; hospital management.

Introduction

The growing advance of technological innovations has driven significant transformations in hospitals worldwide, impacting the management, infrastructure, and provision of healthcare (Marques; Ferreira, 2020; Raimo *et al*., 2023). The adoption of digital technologies has evolved at an unprecedented pace across healthcare ecosystems (Dal Mas *et al*., 2023) and, often, the speed of technological innovation exceeds the responsiveness of hospital institutions. Furthermore, according to recent data, 65% of healthcare organizations have increased the adoption of digital technologies after the COVID-19 pandemic (Deloitte, 2020).

This process is also driven by Health 4.0, an emerging concept derived from Industry 4.0, which has evolved considerably in the last decade (Ahsan; Siddique, 2022). The main objective is to apply the principles of Industry 4.0 to health systems, integrating emerging technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), big data, robotics, cloud computing, telehealth, among others (Gupta; Singh, 2022; Pompermaier *et al*., 2024; Tortorella *et al*., 2019). However, for health services to incorporate these principles, they need guidelines and adequate infrastructure (Chanchaichujit *et al*., 2019).

Recent studies have sought to understand the impacts of such emerging technologies on the physical infrastructure of hospitals. Machry (2010) found that the renovations of existing hospital buildings are mainly caused by the incorporation of technological innovations that alter the physical-spatial configuration in a variety of ways. Bause *et al*. (2019) point to the importance of redesigning hospital processes, while Al-Jaroodi *et al*. (2022) highlight the importance of the Hospital Master Plan to transform and adapt current infrastructure solutions. Pompermaier (2024) analyzed the impacts of emerging technologies on hospital buildings in Brazil, concluding that these impacts transcend the physical space and are manifested in changes in the organizational structure.

Incorporating emerging technologies can bring numerous health benefits, such as agility, high-quality services, more precise and personalized care, greater reliability, cost reduction, among others (Al-Jaroodi *et al*., 2020; Bause *et al*., 2019; Gupta; Singh, 2022). However, there are also challenges associated with the technological modernization of hospitals that involve technical and infrastructure barriers, psychological and personal issues, concerns about increased working hours or workload (Nascimento *et al*., 2023), interoperability, organizational resistance (Dal Mas *et al*., 2023), among others.

Despite the growing literature on Health 4.0, there is a gap in empirical research on how Brazilian hospital managers perceive and face the

challenges of technological incorporation in contexts of old infrastructure and limited resources. In view of this context of transformation, this study aims to investigate the perception of hospital managers in the state of Santa Catarina about the incorporation of emerging technologies, focusing on the relationship between these innovations and the hospital's physical infrastructure.

Santa Catarina has a hospital network recognized on the national scene for excellence in innovation and management in the health area, driven in recent years by government initiatives that seek to modernize the technology park and promote the digital transformation of the public system through significant investments in technology and innovation (FAPESC, 2025; SES-SC, 2025). This context offers a favorable environment for the empirical investigation of the challenges of technological incorporation in hospitals, with the possibility of an in-depth analysis of a state health system in an active process of modernization. In addition, the regional delimitation favors an in-depth and contextualized approach, enabling a more accurate understanding of the challenges and opportunities of Health 4.0 in a specific and transferable regional context.

The state also stands out for its socioeconomic characteristics and hospital infrastructure, which enables a more realistic assessment of the implementation of these innovations. By focusing on this geographic cut, the research seeks to provide information that can be applied both to the local context and to other regions with similar profiles, contributing to the formulation of more effective strategies in the adoption of emerging technologies in the health area.

Method

This work results from applied research with focus on the generation of practical solutions to specific problems from the collection of data in the field. It adopts a qualitative approach and exploratory design, aiming to deepen the understanding of the investigated phenomenon (Gil, 2023). The methodological approach was structured in three sequential stages: (1) literature review; (2) semi-structured interviews; and (3) analysis of the data collected.

The literature review (Phase 1) was carried out through a comprehensive search in scientific articles, theses, dissertations and books, both national and international. The objective of this phase was to deepen the understanding of Health 4.0 and its relationship with the hospital physical infrastructure, serving as a basis for the construction of the interview script.

Semi-structured interviews (Phase 2) were conducted with hospital managers from public and private institutions in the state of Santa Catarina. This type of interview is conducted based on a previously prepared script, maintaining, however, flexibility for the researcher to deepen, reformulate or explore the themes as the conversation develops. This characteristic gives greater freedom in conducting the interview and allows for a broader and more detailed investigation of the questions of interest to the research (Marconi; Lakatos, 2017).

Participants were chosen through intentional non-probabilistic sampling, in which individuals were deliberately chosen based on criteria previously defined for the research (Creswell, 2009; Marconi; Lakatos, 2017). The inclusion criteria adopted were: (i) being a hospital manager working in a public or private institution in Santa Catarina; (ii) exercising a function of direction, coordination, management, superintendence, or equivalent position; (iii) agreeing to participate voluntarily and signing the Informed Consent Form (ICF). To operationalize this strategy, a mapping of hospitals was carried out from the National Registry of Health Establishments (CNES), with specific consultations for the state of Santa Catarina. Based on this survey, the hospitals were contacted directly, and their managers were invited to participate voluntarily in the study.

The interviews were conducted with 12 managers between September and October 2024, previously scheduled with the participants and conducted remotely, by videoconference (Google Meet platform), with an average duration of 45 minutes, following the pre-defined script (Chart 1). Before the beginning of each interview, the participants signed the Informed Consent Form, containing information on the ethical and legal procedures adopted, as well as their agreement to participate in the research. The interviews were recorded and later transcribed in full, ensuring the reliability of the information collected.

Part I: Demographic data	
01	Training
02	Professional experience
03	Institution (public or private)
04	Job position
05	Experience in the position
Part II: Specific data	
01	What are the main barriers your hospital faces in incorporating emerging technologies in terms of physical infrastructure?
02	How have emerging technologies impacted your hospital's physical environment?
03	Which sectors of the hospital do you consider will be most impacted by the adoption of emerging technologies, and how does this influence architectural planning?
04	How do you believe emerging technologies will impact hospitals' architectural planning on the short, medium, and long term, and how has your hospital been prepared?

Chart 1 . Script of the semi-structured interviews. Source: Authors, 2024.

According to data from the Hospital Policy and Management Observatory (OPGH) of the Oswaldo Cruz Foundation (FIOCRUZ), extracted in December 2024 from CNES, Santa Catarina has 306 hospitals. These establishments are distributed among various categories (isolated day hospital, specialized hospital, general hospital, polyclinic/specialty center, birth centers, and emergency room/emergency care) and different legal regimes (profitable and non-profitable private institutions, public and teaching hospitals). The survey sample, composed of twelve hospital managers, each representing a different institution, represents 3.92% of the total hospitals in the state. Although this percentage is small, the qualitative and exploratory nature of the study does not aim at statistical representativeness, but rather analytical depth (Creswell, 2009). In qualitative research, a sample of twelve participants is often considered sufficient to reach "saturation", a point at which new interviews do not provide substantively different information from that already obtained (Boddy, 2016; Guest; Bunce; Johnson, 2006).

Finally, for the analysis of the data obtained (Phase 3), the content analysis technique was used, as recommended by Bardin (2016). This method allows you to organize and interpret the information collected, transforming the raw data into categories and patterns that highlight the main characteristics of the analyzed content.

Content analysis was conducted in three main phases (i) pre-analysis; (ii) exploitation of the material; and (iii) treatment of results, inference, and interpretation. In the pre-analysis, the data were organized, transcribed and submitted to an initial reading, allowing familiarization with the material and the identification of relevant aspects. In this phase, there was also the definition of preliminary criteria and categories to guide the subsequent analysis. In the material exploration stage, the answers were coded and classified into units of analysis, based on the identification of patterns, recurrences, and emerging themes. This process allowed the structuring of information in a systematic way, facilitating the interpretation of the findings. Finally, in the stage of treatment of the results, inference and interpretation, the organized data were critically analyzed in the light of the theoretical framework adopted.

Results and discussions

This section presents and discusses the results obtained through semi-structured interviews conducted with 12 hospital managers in Santa Catarina, organized into four thematic axes: (1) barriers to technological incorporation; (2) impacts of emerging technologies on the hospital physical environment; (3) hospital sectors most impacted; and (4) future perspectives. The participants were from nine cities (Araranguá, Blumenau, Chapecó, Florianópolis, Ibirama, Joaçaba, Joinville, Rio do Sul and São José), which expanded the diversity of the empirical set and allowed us to capture different institutional and territorial realities of the state. This geographic scope contributed to enriching the analysis, by incorporating perceptions from different contexts and, thus, offering a more plural and representative panorama of the investigated scenario.

As to the participant profile, it was observed that 58.3% work in public institutions, and 41.7% in private institutions, which allowed the analysis of different models of hospital management. The professional training of managers was diversified, with a predominance of nurses, reflecting the strong insertion of this category in the management of health services. The length of professional experience varied among the participants, contributing to the incorporation of diverse levels of experience and maturity in the analysis of the questions investigated. Illustration 1 presents an infographic with the geographic distribution and demographic data of the sample, highlighting its main characteristics.

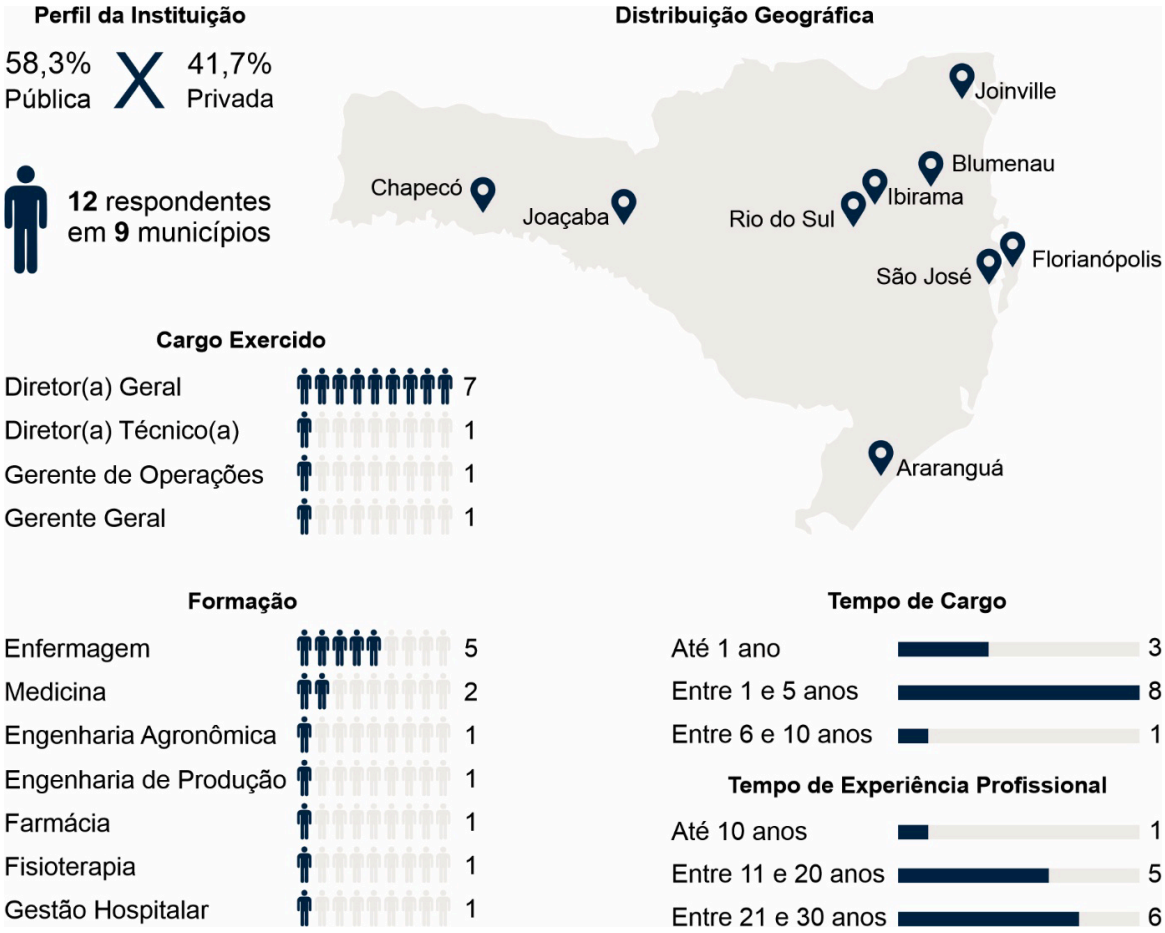


Illustration 1 . Demographic profile of participants. Source: Authors, 2025.

Barriers to technological incorporation

First, the participants were asked about the main barriers that the hospital faces for the incorporation of emerging technologies in terms of physical infrastructure. A convergence in the answers was evidenced, but also important nuances, summarized in Chart 2.

Barrier	Description	Interviewee
Old infrastructure and lack of preventive maintenance	Old hospital buildings, many without significant renovations for decades, make it difficult to adapt to modern technologies. The absence of preventive maintenance aggravates structural problems, resulting in mainly corrective and costly interventions.	E1, E2, E4, E7, E9, E10, E11
Limited physical space	The growth in hospital demand exceeded the physical capacity of the buildings, limiting the installation of new equipment and technologies.	E4, E7
Difficulty with regulatory standards	The growth of hospitals has resulted in structures that do not meet current regulations, requiring renovations to adapt.	E8
IT infrastructure issues	Hospitals were not designed to support modern networks, compromising the implementation of technologies.	E6, E10, E11
High cost of incorporation	The investments required for incorporation are high, and many hospitals do not have enough budget for such improvements.	E5, E6, E8, E9, E12
Lack of professionals with a systemic view of hospital processes	The absence of qualified professionals to plan and manage the implementation of new technologies hinders hospital modernization. It is aggravated by the turnover of temporary contracts, which interrupts the learning curve.	E3, E4

Chart 2 . Barriers to the incorporation of emerging technologies in hospitals. Source: Authors, 2025.

As evidenced, the adoption of emerging technologies in the hospitals studied faces structural, regulatory, and financial challenges. The old infrastructure represents one of the biggest obstacles, as buildings designed decades ago did not encompass the current needs for technological modernization, which was evidenced in 7 of the 12 hospitals. The range of ages of the buildings in the sample is, in itself, revealing: the reports range from 30-year-old structures, such as E7, to 45 years, mentioned by E4, through a 115-year-old centennial building, mentioned by E6, to the case of E9, which describes a 164-year-old hospital, cases that point to very different contexts of architectural challenges, which cannot be treated in a homogeneous way by health planning. In addition, the limitation of physical space aggravates the situation. E4, for example, mentions that, due to the lack of areas available for expansion, the ideal solution would be the construction of new units.

However, it is observed that, in practice, the most recurrent strategy of public health management has been to conduct renovations and expansions in existing units to accommodate the growing demand for care, instead of the construction of new hospitals. This option, although necessary in certain contexts, often compromises the original architectural quality, generates overload, and does not structurally solve the demands of modernization of the physical infrastructure. This movement also contrasts with the global trend of decentralization of health, in which the planning of smaller establishments closer to the community to be served is prioritized (Mahmood *et al*., 2024; Nunes; Ferreira, 2022).

Another limiting factor is the need for regulatory compliance. Standards of the National Health Surveillance Agency (Anvisa) and state and municipal health surveillance require specific adaptations in hospital structures to ensure the safety and quality of the services provided. E8 reports that, in the case of their hospital, which was inaugurated in 1979, the growth over the decades occurred in an unplanned manner, without adequately considering the regulatory requirements. Currently, however, the institution has an architect hired to plan new expansions and services already in compliance with health surveillance standards, which highlights both the complexity of the modernization process and the need for more rigorous technical planning.

Information Technology (IT) infrastructure is another significant barrier. Many hospitals do not have adequate cabling or capacity to support high-performance networks, which makes it impossible to implement remote monitoring systems, electronic medical records, and process automation. However, there are also positive examples, as mentioned in E6, which recently overcame this limitation and implemented bedside checking of medication administration, demonstrating that modernization is feasible with targeted investments. The most serious case identified in the survey, however, is that of E11, which reports the complete loss of electronic medical records from 2018 to 2021, due to a blackout that occurred in 2021. The collapse was attributed to the continued use of a data center installed in 2008, which was supposed to be replaced every five years. At the time of the research, the equipment had not yet been replaced, illustrating how the fragility of the IT infrastructure can have irreversible consequences for the continuity of care and patient safety.

The high cost to acquire and incorporate new technologies is a transversal barrier to all previous challenges. Hospitals that want to incorporate state-of-the-art equipment, such as surgical robots or intelligent hospital management systems, often run into a lack of financial resources, which is even more evident in public hospitals (E5, E8, E12). E8 explicitly highlights that, in their institution, the primary barrier is financial, and not

physical: “the greatest difficulty is financial... The implementation of these technologies ends up being limited much more to the issue of financial transfer than a limitation of the physical infrastructure”. This position is relevant because it reveals that, even where the physical infrastructure is favorable (E8 describes a horizontal hospital with good installed capacity), the absence of a budget forecast for investment is the main obstacle. This scenario reinforces the need for public policies and incentives to facilitate technological modernization in the health area.

Finally, the lack of professionals with a systemic view of hospital processes compromises the effectiveness of the implementation of innovative technologies. Modern hospital management requires an integrated approach, combining technical knowledge with strategic planning to optimize investments in innovation. E3 highlights this gap, emphasizing the need to train professionals to lead digital transformation processes in health. Likewise, E4 reported the difficulty of keeping trained professionals due to the turnover of contracts, compromising the learning curve necessary for the efficient use of technologies. These findings are in line with Dal Mas *et al*. (2023), who identify organizational resistance and the lack of digital skills as central barriers to digital transformation in healthcare, as well as with Fogaça (2025), who highlights the high turnover and absences of health professionals, in addition to the importance of talent retention. In this sense, retention is a fundamental strategy to ensure the continuity of processes, consolidate institutional learning and favor the sustainable incorporation of technologies in health services.

Impacts of emerging technologies on the hospital’s physical environment

Next, interviewees were asked how emerging technologies have impacted the hospital’s physical environment. From the answers collected, it was possible to identify common patterns among hospitals.

Several hospitals mentioned the need for structural adaptations to accommodate new technologies. E6, for example, highlighted that the current master plan already provides for adjustments to receive state-of-the-art technologies, while E7 stressed the need for physical resizing for equipment such as magnetic resonance imaging and radiotherapy bunkers.

In terms of technological integration, hospitals face challenges in upgrading their facilities. E9 mentioned difficulties in implementing Wi-Fi networks due to the old structure, which would require extremely high investments. E10 also highlighted that, due to the lack of preparation of the building to receive structured cabling, it was necessary to install

external and simplified systems, with apparent wires in several sectors. This solution, although functional, compromises cleanliness and can impact patient safety, increasing the risk of hospital infections, in addition to highlighting the limitations of buildings not designed for current technology demands. On the other hand, E8 highlighted that the horizontal architecture of their hospital favors the incorporation of new technologies, facilitating adjustments in the electrical and network infrastructure.

The acquisition of modern equipment has directly impacted hospital processes. E2 mentioned the implantation of a surgical arch for USD 100 thousand and the introduction of portable ultrasounds that allow bedside exams. The evolution of imaging technologies was highlighted as one of the areas of greatest growth, corroborating the findings of Topol (2019) on the centrality of imaging in the hospital digitization process.

Modernization has also led to a redesign of hospital processes, as mentioned by E3. The use of digital systems to check medication was a differential, according to E9, as it involves resources such as electronic prescription, electronic patient records, and bedside checking. E6 describes an equivalent implementation in which the professional scans the barcode of the patient's wristband before administering any medication, automating both the process of following-up and of stocking. These tools make it possible to automate prescriptions, reduce administration errors, optimize drug inventories, and increase care safety.

Some limitations in access to emerging technologies were reported by interviewees, as in the case of E5, who mentioned not having these resources in their institution. In addition, E10 highlighted that the slowness in the bidding processes represents an obstacle to the implementation of innovations, highlighting administrative challenges that can impact modernization, regardless of the size or management model of the hospital.

Most impacted hospital sectors

To further understand the impacts of the incorporation of emerging technologies, participants were asked which hospital sectors they consider the most impacted, as well as the influence of this process on hospital architectural planning. Chart 3 presents a summary of the most recurrent sectors and their main considerations.

Sector	Influence on architectural planning	Interviewee
Surgical Center	Need to adapt the rooms to new high-tech equipment (robotics, Artificial Intelligence, among others). The heterogeneity of sizes and layouts of existing operating rooms is a concrete obstacle.	E2, E6, E7, E10
Sterile Processing Department (SPD)	Need to adapt the rooms to new high-tech equipment and more efficient flows in sterilization.	E1
Imaging and Diagnostics	Need large rooms and infrastructure to support advanced equipment, such as MRI machines, CT scans, continuous monitoring systems, and digital connectivity for electronic medical records, telehealth, and smart device integration.	E2, E7, E9
Pharmacy	Need automated systems for inventory control and spaces adaptable to tracking technologies, such as RFID tags, barcodes, and sensors for the location of hospital equipment and materials.	E4, E12
Intensive Care Unit (ICU)	Require modern infrastructure to support digital patient care and monitoring technologies.	E4, E10
Emergency and Emergency Room	Adaptation of service flows and integration with digital screening systems.	E8
Administration	Need spaces for monitoring centers and modernization of infrastructure to support the digitalization of processes.	E5, E11
Hospitalization	Need smarter and more automated rooms to improve patient experience.	E6
Oncology & Specialty Treatments	Sectors dedicated to cancer treatment require specialized infrastructure, including radiotherapy rooms with radiation protection, PET-CT equipment for cancer staging and, in perspective, units for performing CAR-T therapy, an innovative immunotherapy modality that consists of the genetic modification of T lymphocytes for the treatment of specific tumors, still incipient in Brazil.	E7, E9, E12

Chart 3 . Hospital sectors most impacted by emerging technologies and the influence on architectural planning. Source: Authors, 2025.

The results of the analysis reveal that the adoption of emerging technologies has a significant impact on several hospital sectors, especially the operating room, imaging and diagnosis, ICU, pharmacy, and emergency. The modernization of these spaces requires adequate infrastructure to support advanced equipment, such as surgical robotics, artificial intelligence monitoring, and digital tracking systems for supplies. In addition, the digitalization of hospital management and the implementation of telehealth require the creation of specific spaces for monitoring centers and optimization of operational flows. Two findings deserve special mention: (a) the emergence of the oncology sector as an area of growing technological and infrastructural pressure – E7 describes a "frightening oncological demand" resulting from changes in the regional epidemiological profile, which drives the urgent need for radiotherapy bunkers and highly complex equipment; and (b) the emergence of cutting-edge technologies that are still incipient in Brazil, such as CAR-T therapy, mentioned by E12 as a future project of the institution, indicating that the frontier of technological incorporation in the hospitals studied goes beyond the conventional Health 4.0 technologies discussed in the literature.

In architectural planning, these advancements require a more flexible and adaptable approach, ensuring that hospital spaces can evolve with new technological demands. The need to expand rooms, reconfigure internal flows, and integrate intelligent systems are fundamental aspects for efficiency and quality in service. Thus, technological transformations not only impact clinical efficiency, but also reshape the spatial organization of hospitals. This finding reinforces the argument of Al-Jaroodi *et al*. (2022), that the Hospital Master Plan should incorporate a long-term vision of future technological demands.

Future perspectives

Finally, interviewees were also asked about future perspectives. Participants evaluated how emerging technologies should impact hospital architectural planning in the short, medium, and long term. The responses converged on a set of interrelated trends and constraints but also revealed a remarkable contrast between institutions with structured strategic planning and those that operate in a predominantly reactive mode, a difference that is not merely in financial capacity, but also in organizational governance.

In general terms, emerging technologies are perceived as transforming hospital operations, with the potential to accelerate diagnoses, optimize care flows, and increase care safety. E3, for example, highlighted that the main changes should occur in the imaging and diagnostic sectors,

pointing to more accurate equipment and the possibility of connectivity via mobile devices that make reports and feedback more agile. However, E4 highlighted a concrete limitation to the effectiveness of this digital transformation: the lack of integration between municipal and state health systems, so that, despite the monitoring of internal data, many institutions still do not have access to information on patients treated in Emergency Care Units (UPAs) or Basic Health Units (UBS), which would reduce the continuity of care and the value added by digitalization. E4 adds that the current systems are often fragmented and complex to navigate, showing that hospital digital transformation is not limited to the existence of digital systems, but also requires that these systems be integrated, intuitive and interoperable with other health networks.

At the same time, the interviewees identified that modernization implies not only the incorporation of technology, but also physical changes in the hospital building. Several institutions reported the need for renovations or expansions to accommodate new technologies, from the readjustment of imaging areas to the creation of specialized units. E2 mentioned that their master plan foresees expansions, such as the modernization of the emergency room and the creation of a new neonatal ICU, exemplifying documented plans that, however, come up against the limitations of the existing physical structure. E7 stressed the need for maintenance and modernization of the building and plans the construction of a new building over the next decade, showing that, for some hospitals, the medium-term solution involves new constructions, while others still depend on internal renovations. The most ambitious case identified in the research is that of E9, which describes the construction of a 10-story tower, designed with a focus on cutting-edge technologies (robotics, pneumatic conveying, and real-time monitoring). The initiative represents a long-term strategy that stands out for the volume of planning and the degree of technological ambition, contrasting with the reality of most of the institutions in the sample.

It is important to emphasize that the standardization of environments emerges as a facilitating condition for the incorporation of cutting-edge technologies. As pointed out by E6, who observed that the existence of nine operating rooms with different sizes and layouts hinders the adoption of equipment, such as robotic surgery, and prevents the optimization of flows and operating costs. E6 projects that the standardization of surgical environments, in addition to enabling robotic surgery in multiple rooms, will bring “absurd cost reduction” due to the gain in scale in the processes, an argument that directly articulates architecture, operational efficiency, and economic sustainability of technological incorporation.

Digitalization, although ongoing, manifests itself with different degrees of maturity among the hospitals studied. Some already have advanced monitoring systems and organized initiatives for innovation governance.

Others, however, face difficulties in integrating heterogeneous platforms and ensuring interoperability. E11 drew attention to the fact that the speed of technological evolution was much higher than the capacity of some hospitals to keep up with such changes, resulting in reactive rather than initiative-taking processes, which reinforces the need for clear institutional policies to guide the adoption of new technologies. E10 endorses this diagnosis by stating that "technologies came very quickly and we did not keep up with the same speed", adding that the absence of a clear institutional policy for technological incorporation means that acquisitions occur on demand, and not by planning.

The contrast between the styles of innovation management is one of the most relevant findings of the study. While E8 describes the creation of a structured Innovation Commission to evaluate and plan the incorporation of new technologies, and E12 reports the hiring of an external company to conduct strategic planning in three time horizons (short, medium and long term), E11 describes the opposite reality: "we work putting out fires on a daily basis", without being able to prepare medium or long-term planning, because the financial resources are insufficient even to cover basic operational demands. This asymmetry between institutions reveals that maturity in innovation governance is not determined only by the size or legal profile of the hospital but above all by the stability and sufficiency of the funding received.

A recurring aspect in the speeches was the centrality of financing and governance in the feasibility of the prospective transformations. Most hospitals pointed to financial difficulties that limit both infrastructure modernization and the implementation of integrated digital systems. Public hospitals reported dependence on transfers and management contracts whose values do not always cover operational and investment demands; E10 exemplified this condition by stating that the unit is "constantly in money deficit". On the other hand, E5 declared lack of preparation to implement emerging technologies, reinforcing that the absence of financial and strategic planning is a concrete obstacle to advancement. These testimonies indicate that, in addition to design decisions, the incorporation of innovations requires more robust public policies, diversified financing mechanisms, and public-private partnerships that can enable structural interventions and ensure the continuity of investments in technology.

The strategies adopted by some institutions point to ways to mitigate the identified obstacles: in addition to the aforementioned Innovation Committee, pointed out by E8, practices such as the standardization of surgical environments (E6), the master plan that contemplates strategic expansions (E2) and the adaptation of services to the expectations of new

generations of patients (E9) demonstrate that organizational and design measures can favor more orderly transitions. E9 points out, in this sense, a trend that has not yet been explored in the national literature: the need to adapt the hospital product to the technological profile of the younger generations of patients, who arrive at the health system with expectations of a digital experience that hospitals today are not prepared to meet, both in terms of interface and care processes mediated by technology.

Finally, Illustration 2 wraps up, in concentric layers, the relationship of interdependence between emerging technologies (inner layer), the physical and procedural requirements necessary for their incorporation (intermediate layer) and the external constraints that enable or limit this process (outer layer).

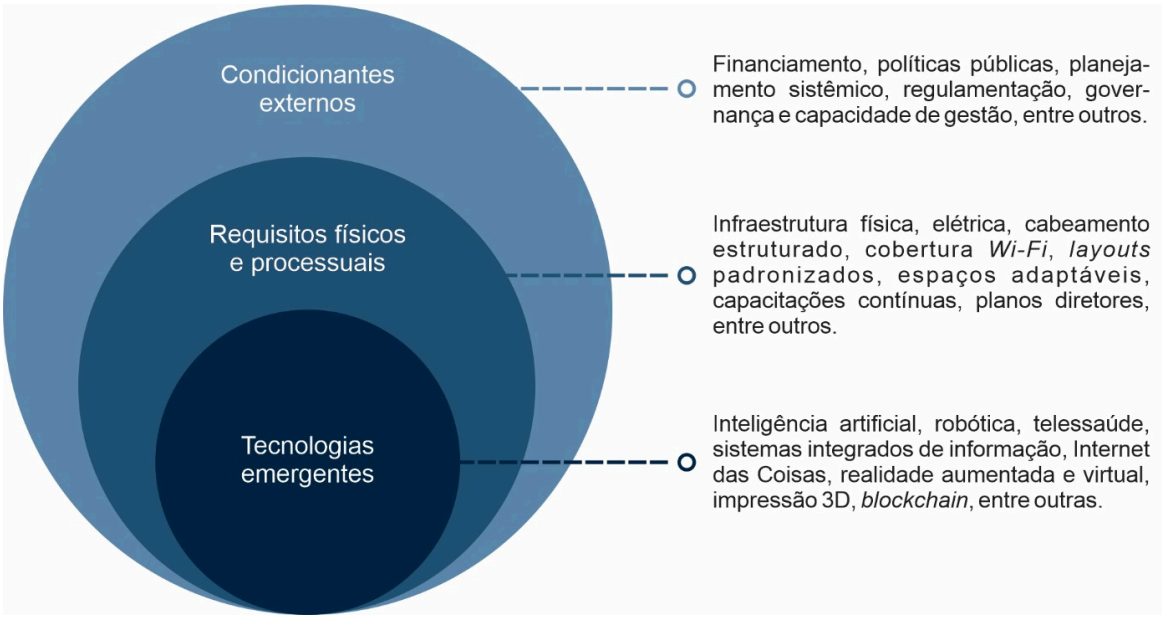


Illustration 2 . Conceptual diagram. Source: Authors (2025).

The diagram translates the central evidence of the study: advances in emerging technologies only materialize when supported by adequate infrastructure (standardized rooms, cabling, networks, imaging areas), institutional processes (master plans, innovation commissions, standardization) and macro constraints linked to the management and planning of the health network (financing, public policies and governance).

The findings also allow us to affirm that the incorporation of hospital technology, when seen from the perspective of managers, is a multilayered phenomenon: it is not limited to the availability of equipment or system, but involves the physical adequacy of the space (dimensions, construction materials, electrical and network installations),

the readjustment of operational processes, the training and retention of professionals, the financial sustainability of the management model and, ultimately, the existence of a public policy that guides and finances this set of transformations in a coordinated and continuous manner.

The diagram intends not only to summarize the findings, but also to highlight that the transition to a more technological hospital model requires coordinated actions at multiple levels and depends simultaneously on investments, conscious architectural planning, institutional governance, and articulated public policies.

Final considerations

This study investigated the incorporation of emerging technologies in the context of Health 4.0 in hospitals in the state of Santa Catarina, focusing on the relationship between these innovations and hospital physical infrastructure. Based on the analysis of the collected data, it is concluded that the incorporation of emerging technologies in hospitals faces multifaceted challenges, including inadequate infrastructure, financial constraints, and the need for more comprehensive public policies that ensure quality of care and guide strategic planning across the hospital network. Overcoming these barriers requires structural reforms, training and continuous development of managers, as well as policies that promote modernization and technological incorporation in the hospital sector.

The findings of this study show that the incorporation of technology in the state hospital network is heterogeneous. A small portion of institutions have already implemented advanced technologies and plan more ambitious incorporations. However, most institutions face significant structural and financial constraints, which restrict the widespread adoption of cutting-edge technologies. In addition, the managers' statements reveal a noticeable distinction between sectors: public hospitals tend to report greater dependence on transfers, obstacles in purchasing processes and budget restrictions; private institutions, although also facing challenges, often have greater investment capacity and agility to incorporate innovations. This differentiation, however, is not absolute. There is internal variation in both sectors.

Hospitals, both public and private, that have already invested in the modernization of their IT infrastructure demonstrate that it is possible to overcome these difficulties, as long as there is adequate allocation of resources and efforts. Thus, the adoption of emerging technologies can contribute significantly to the efficiency and quality of health services in Brazil.

Considering this scenario, it is evident that hospital transformation is not only a matter of technological modernization, but of deep restructuring of hospital processes, fiscal management, and organizational culture. As evidenced by the managers' reports, the absence of adequate funding does not only generate restrictions on the acquisition of equipment: it produces systemic effects on planning capacity, the motivation of management teams and patient safety. This chain of consequences reinforces that hospital technological modernization cannot be treated as an isolated sectoral policy, but must integrate broader agendas of financing, regulation, and governance of the health system. The construction of a more technological hospital environment requires a joint effort among managers, health professionals, and public policy makers, ensuring that innovations indeed benefit the quality of care and the patient experience.

Although the study is limited to the state of Santa Catarina, the challenges identified, old infrastructure, financial constraints, regulatory gaps, and shortage of qualified professionals, are shared by other Brazilian regions with a similar socioeconomic profile, giving broader relevance to the findings. Future research could broaden the geographic scope, include cross-state comparative analyses, and adopt a mixed approach, combining qualitative and quantitative methods. This strategy would allow, on the one hand, deepening the contextual understanding of the experiences and perceptions of the actors involved and, on the other hand, to measure more accurately indicators of digital maturity, enabling greater analytical robustness and expanding the potential for generalization of the results.

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Ethical considerations

The research was submitted to the Ethics Committee for Research with Human Beings (CEPSH) of the Federal University of Santa Catarina (UFSC) (CAAE 81424924.0.0000.0121); approval notice: 7.157.381. The participants signed the Informed Consent Form (ICF), agreeing to participate voluntarily, anonymously and confidentially.

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Authors

João Paulo Lucchetta Pompermaier PhD student in the Graduate Program in Architecture and Urbanism (PósARQ) at the Federal University of Santa Catarina (UFSC). Master's degree in Architecture and Urbanism from the Federal University of Santa Catarina (UFSC). Postgraduate student in Innovation, Emerging and Immersive Technologies for Digital Health (UFG). Specialist in Neuroarchitecture (UNISUL), in Teaching in Higher Education (UNICSUL) and in Interior Design. Graduated in Architecture and Urbanism from the Business Faculty of Chapecó (FAEM/UCEFF). Member of the research group GMETTA – Multidisciplinary Group of Ergonomics of Work and Applied Technologies (UFSC/CNPq) and of the Study Group in Architecture and Hospital Engineering (GEA-hosp/UFBA).

Email: joaopaulopompermaier@gmail.com

Lizandra Garcia Lupi Vergara Architect and Urban Planner and Occupational Safety Engineer. PhD and master's degree in Ergonomics from the Graduate Program in Production Engineering (PPGEP) at the Federal University of Santa Catarina (UFSC) and Post-Doctorate from the University of Illinois at Urbana-Champaign, USA. Full professor of Production Engineering at UFSC, working in the Undergraduate (DEPS) and Graduate Programs in Production Engineering (PPGEP) and Architecture and Urbanism (PósARQ). Supervisor at the Ergonomics Laboratory (LABERGO) and the Assistive Technology and Ergonomics Laboratory (LABTAE). Leader of the research group GMETTA - Multidisciplinary Group of Ergonomics of Work and Applied Technologies (UFSC/CNPq).

Email: l.vergara@ufsc.br

Patrícia Biasi Cavalcanti PhD in Architecture from the Graduate Program in Architecture (PROARQ/FAU) at the Federal University of Rio de Janeiro (UFRJ), with a doctoral internship (sandwich doctorate) at California Polythecnic State University/CA/USA. Graduated in Architecture and Urbanism from the Federal University of Santa Catarina (UFSC) and master's degree in Architecture, more specifically in the sub-area of Technology and Habitability, from the Federal University of Rio Grande do Sul (UFRGS). Associate professor at the Department of Design and Graphic Expression at the Federal University of Santa Catarina (UFSC).

E-mail: patibiasi@yahoo.com

Article

Emergency Hospital of São Bernardo do Campo: context and project

Autores
Sérgio Luiz Salles Souza
Ângelo Bucci

Curator of images and diagrams: **Gabriela Pedini**

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Abstract

This article presents a case study on the intersection between highly complex architecture, participatory dialogue, and urban resilience in the design of the Emergency Hospital of São Bernardo do Campo (EHSBC). In this project, a 20,600 m² health facility functions as critical infrastructure on a site with severe hydrological constraints and high urban density. The methodology is based on an analysis of the participatory co-design process and the technical validation of passive bioclimatic strategies. The adoption of a "dike hospital" structure and the elevation of vital systems ensure operational continuity under conditions of environmental stress. Technical and structural rigor, combined with Evidence-Based Design (EBD), positions EHSBC not only as a clinical building, but as an instrument of urban recalibration and social dignity.

Keywords:

hospital architecture; urban resilience; Evidence-Based Design; critical infrastructure; public health.

1. Introduction – High complexity challenges in vulnerable territories

One of the great challenges of architecture for contemporary public health in Brazil is to reconcile programs of high technological density with urban contexts, often marked by lack of infrastructure and environmental vulnerability. The Emergency Hospital of São Bernardo do Campo (EHSBC) is at the epicenter of this discussion. Designing an emergency hospital — that, by definition, does not admit interruptions — on a narrow site (185 m x 40 m), with a history of recurrent flooding and a shallow water table, requires the project to transcend the medical function to become an "infrastructure of resistance".

This article aims to demonstrate how the choice of architectural design was essential to solve the conflicts between programmatic demand and site restrictions. According to the *SBC Manual of Sustainable Projects and Works*, urban resilience should be the pillar of public interventions in risk areas. At EHSBC, this guideline materialized in an architectural concept that can be called a "dike hospital", in which the building itself acts as a technical and logistical barrier.

According to Roger Ulrich's (1984) definition, taken from his seminal studies on the impact of the built environment on patient recovery, architecture can mitigate patient stress and accelerate clinical recovery processes. Unlike a traditional descriptive memorial, this analysis is based on **Evidence-Based Design (EBD)**. In the context of EHSBC, EBD is therefore a management strategy.

> The integration of natural light and visual connection with the outdoors are not only elements of comfort, but active components in regulating the circadian cycle and reducing delirium in critical environments. (Adapted from the Architecture Memorial – ARQ-PE-0020.)

The author proposes a technical immersion on four fundamental axes: participatory project methodology; flow solutions guided by risk assessment protocols, such as the Manchester Protocol; bioclimatic performance validated by simulations (Mitsidi Report); and tectonics of prestressed concrete as a ten-meter intercolumn and beam-free slabs, ensuring future flexibility. This analysis shows how much the public architecture of excellence is aligned with the operational resilience and humanization of care in the Brazilian Unified Health System (SUS).

2. Methodology – The praxis of co-design and evidence-based decision-making

The programmatic complexity of emergency facilities requires a methodology that transcends the isolated drawing board and establishes itself as a process of dialogue. In the development of EHSBC, co-design (participatory design) was adopted, not only as a listening tool, but as a rigorous technical validation mechanism. As documented in the *Executive Project Memorial* (PE-0010), the process was built on weekly cycles of multidisciplinary collaboration.

The approach was echoed in the theory of Sanders and Stappers (2008), who define co-creation as a paradigm shift in which the user, in this case, the clinical and technical staff, becomes the expert in their own experience, while the architect acts as the facilitator of this spatial synergy. The practice of "design as research" allows design to anticipate operational failures by optimizing workflow. In his reflections on methods of participation, Henry Sanoff (2000) points out that the inclusion of stakeholders in the initial phases of the project reduces institutional resistance and increases the functional effectiveness of the public building.

At EHSBC, this dynamic was fundamental to define the technical backbone and supply logistics. Each specialty (intensivists, traumatology, neurology, pediatrics) contributed with their flowchart of care, which were translated into spatial layouts, ensuring that the design was not just a formal response but a "healthcare algorithm". The methodological process followed four rigorous steps:

1. Immersion and diagnosis – analysis of the demands from the local healthcare network.

2. Synthesis and prototyping of flows – creation of spatial simulations based on the Manchester Protocol.

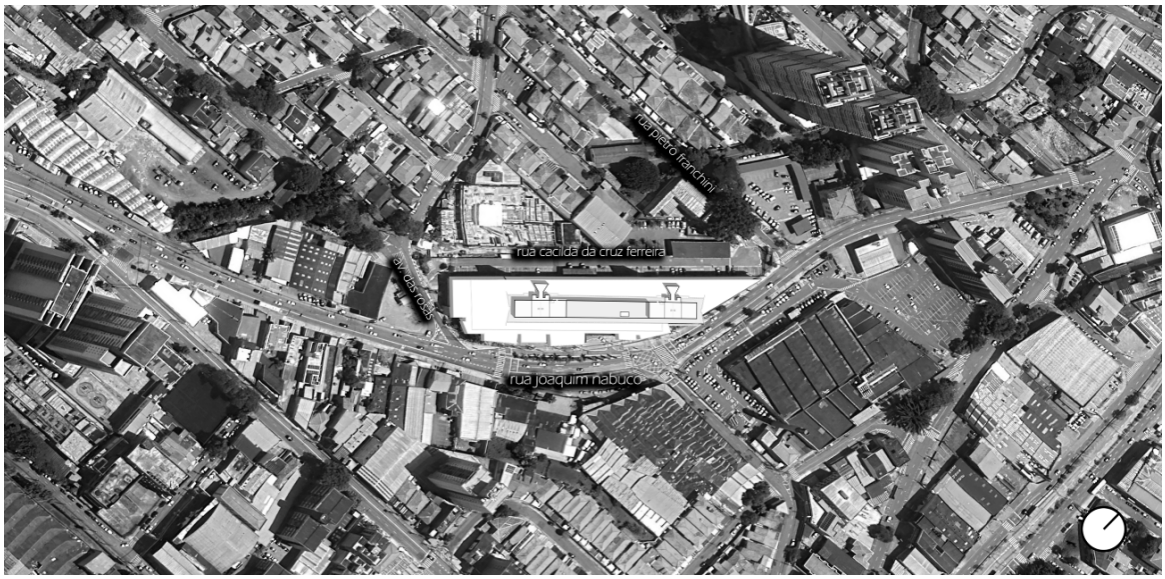
3. Technical iteration – systematic meetings of multidisciplinary compatibility (building structure and systems).

4. Final validation – approval of scale models by the Health Department.



3. The site – The "dike hospital" as a manifestation of infrastructural urbanism

The biggest challenge of the project was the implementation of the EHSBC in a lot measuring 185 meters by 40 meters, containing hydromorphic soil and low slope. The architectural answer — the " dike hospital" concept — is not merely an engineering solution, but a theoretical statement about architecture as urban infrastructure.



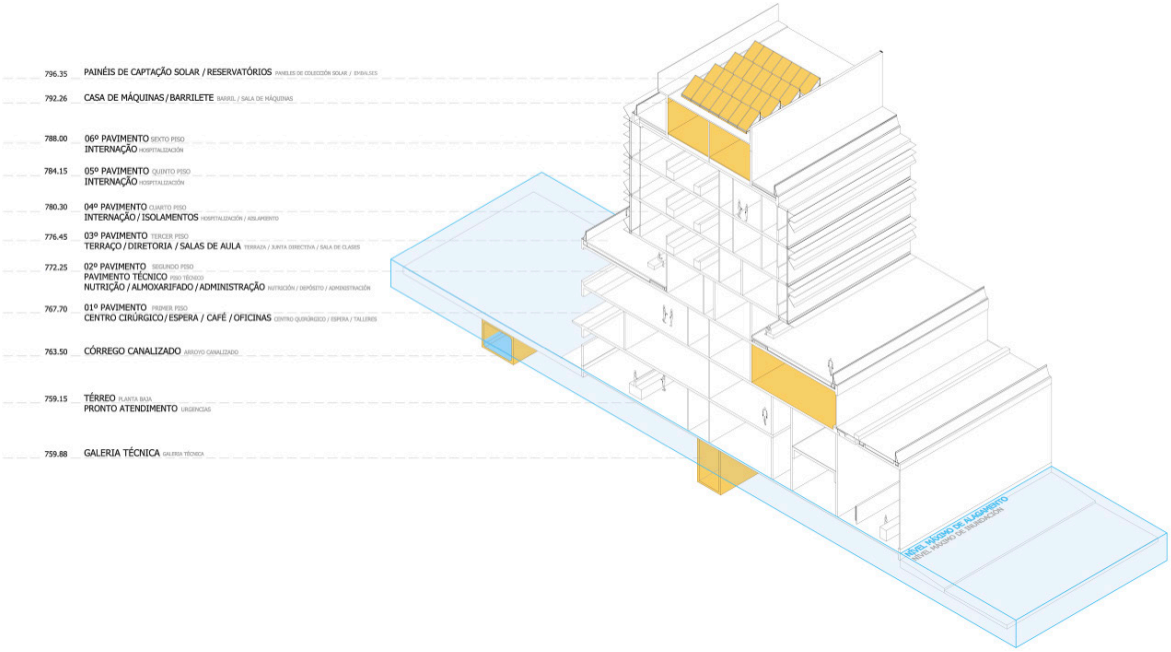
This approach dialogues with the concept of infrastructural urbanism proposed by Stan Allen (1999), in which the building is not seen as an isolated object, but as a system that organizes the territory and generates environmental flows. EHSBC acts as an urban adjustment device that, instead of denying the vulnerability of the terrain, uses it to define its tectonic structure. In line with SBC *Sustainable Projects and Works Manual*, the project raised the ground floor level above the historical flood level, transforming the basement, which defines the ground level, into an active protective barrier.





The decision to locate the utility plants (chillers, generators and gases) on suspended technical floors (second technical floor) subverts the traditional hospital typology, which historically buries its "technical heart" in vulnerable basements. Here, architecture takes on a critical resilience, as discussed by Kenneth Frampton, in which the form responds to the site through a clear and functional structural "carpentry." As highlighted in the Descriptive Memorial (ARQ-PE-0020):

> The elevation of the machines to the upper body of the building ensures that, in the event of a collapse of the urban drainage system, the hospital maintains its energy autonomy, operating as a refuge of resilient infrastructure for the city.

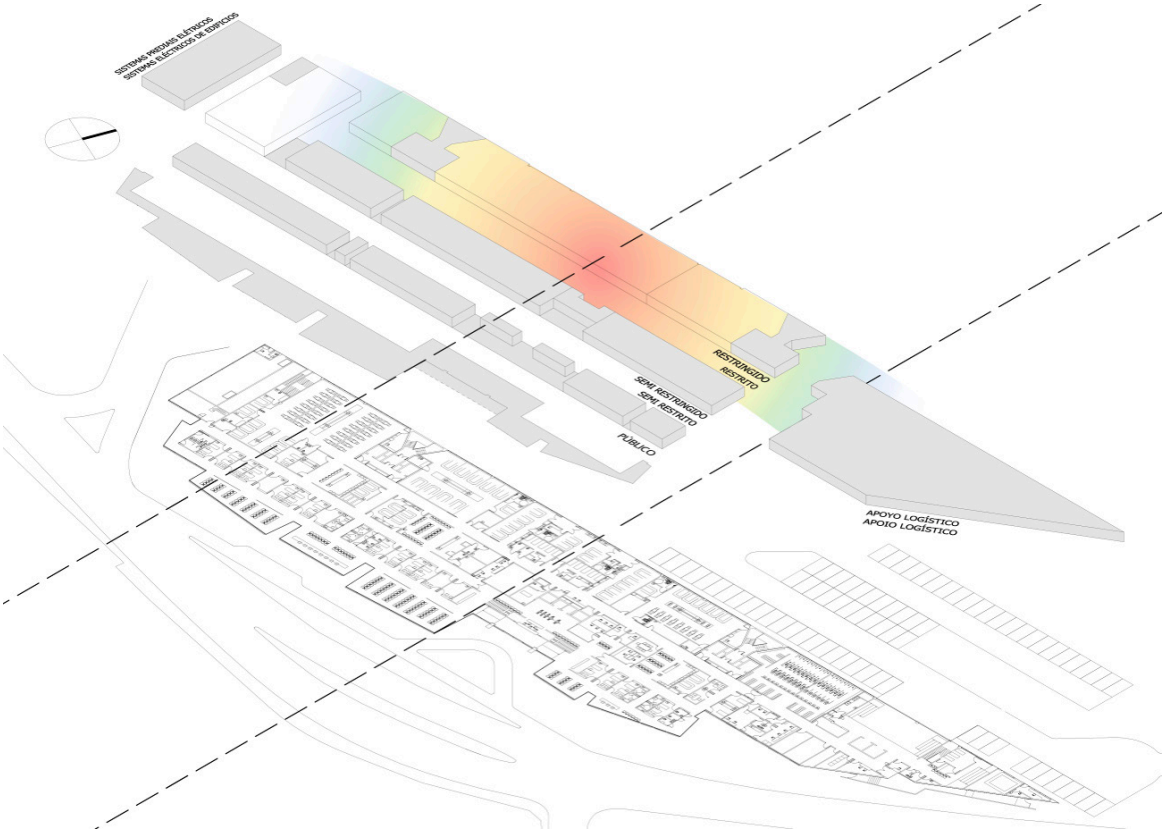


This resilience is materialized by the structure of flat slabs in prestressed concrete, which, without beams, gives the hospital full freedom of interlining. This flexibility is what allows the building to face what Keller Easterling (2014) defines as the "infrastructure space": an ever-evolving system that must accommodate technological upgrades without compromising the continuity of the essential public service.



4. Architecture as triage algorithm – The Manchester Protocol

The spatial organization of the EHSBC is not merely functionalist, but the physical translation of the **Manchester Protocol**, a triage system that classifies clinical risk in colors (red, orange, yellow, green, and blue). In the project, architecture assumes the role of flow manager, minimizing intersections and optimizing response time, a critical factor in an emergency unit.



Unlike the "infinite corridor" hospital model, the structure adopted at EHSBC organizes flows through a clear division by sector. The emergency flow (red and orange)[1] has direct and segregated access from the general public lounge, allowing critical patients to reach the stabilization room without interference[2]. This logic, widely discussed in contemporary literature on hospital management, which is internationally known as Fast Track, is materialized into a technical circulation backbone that vertically connects diagnostic and surgical floors.

The effectiveness of this system lies in the clarity of physical and visual barriers. According to the *Environmental Comfort Manual*, signage and lighting act as guidance devices (cognitive map or wayfinding), reducing user anxiety and increasing the accuracy of the medical team. Architecture,

1 Further reading: MALKIN, Jain. Hospital Interior Architecture: Creating Healing Environments for Special Patient Populations.

2 HERD Journal (Health Environments Research & Design): Search for articles using the prompt "Emergency Department Throughput" and "Triage Spatial Configuration".

therefore, is not only an expression of the protocol. It is through hospital's architecture that the protocol is carried through by enabling the patient to undertake the healthcare path intuitively.

5. The inpatient unit – The 4-in-2 model and the dignity of the scale

One of the points of attention in EHSBC design project is the typology of the wards, the so-called **4-in-2** model. While the conventional SUS standard often adopts wards with six or more beds — which compromise privacy and infection control — the EHSBC reference demanded four beds per room. The proposed architectural solution subdivided the environment of each room into two environments, by placing the toilet in the middle.

This solution dialogues directly with the tradition of humanist modernism. We can draw a parallel with Alvar Aalto's Paimio Sanatorium (1933), whose project started from the patient's cellular unit to define the shape of the building. At EHSBC, the reduction of ward scale seeks to minimize what the Evidence-Based Design (EBD) literature identifies as "environmental stress." By fragmenting the visual perception of the room, noise is reduced and the patient's sense of control over his surroundings is increased.

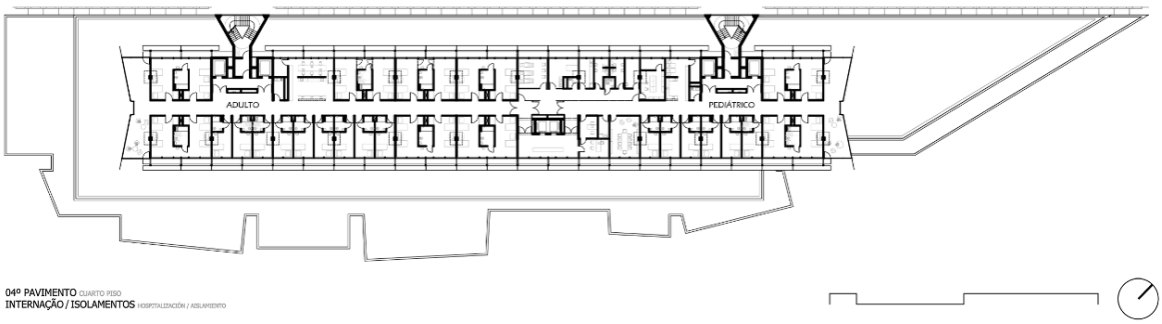
The technical precision of this unit is reinforced by the suppression of the interlining, allowing each bed to have an independent gas and electrical infrastructure, always located on the walls, allowing an environment without lining, with more generous ceiling height and easy maintenance. The design of the ward also prioritizes transparency and natural light along the entire length of the facade, elements that, according to Roger Ulrich (1984), are decisive in reducing the length of hospitalization. The project takes up Jan Duiker's functional purity in the Zonnestraal Sanatorium (1928), where light and air are not only complements, but fundamental health building materials.

> The proposition of low windows and the guarantee of a view to the outside transform the ward into a space of reconnection with the outside world, essential for the maintenance of the circadian cycle and the psychic stability of the patient in a state of emergency. (Adapted from the Architecture Memorial – ARQ-PE-0020.)

In addition to the clinical benefit, the 4-in-2 model offers an operational advantage of flexibility: in isolation scenarios due to specific pathologies, the hospital can block only two beds instead of an entire wing, optimizing the occupancy rate of public equipment.



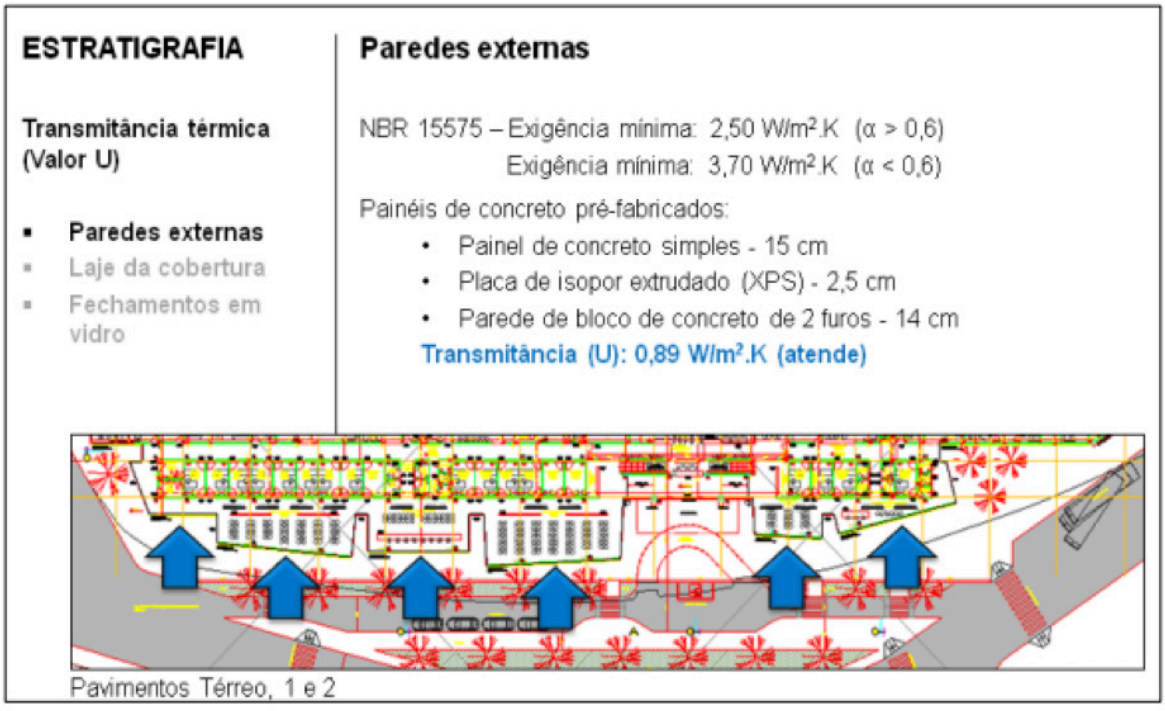
Although the access to adult and pediatric sectors are strictly separated since the ground level, the barrier that separates them on the three floors of the ward can be opened to integrate the entire corridor of rooms in the same unit. This strategy aims to use the seasonal demand of children's hospital to free up beds for adults, both by demand and to enable the ordinary maintenance of inpatient rooms.



6. Bioclimatic performance – The science behind passive comfort

One of the pillars of EHSBC's operational sustainability is its ability to offer thermal comfort with passive systems, that is, with little dependence on mechanical air conditioning systems, especially in inpatient areas, consequently, with low energy consumption. Since, according to the guidelines of the SBC *Manual of Sustainable Projects and Works*, the reduction of energy consumption in public buildings is a metric of management efficiency. At EHSBC, this goal was achieved through a rigorous analysis of its external covering.

The Report prepared by Mitsidi (2017), which subsidized the executive project and carried out thermo-energy simulations, validated the effectiveness of the sunshade system (*brises*) on the facades with the highest solar incidence (east and west). The brises were designed to prevent the incidence of sun on the illuminating facades, allow light and bar heating, and ensure that the internal thermal load remained within the comfort zones established by NBR 15575.



ESTRATIGRAFIA

Fator Solar (FS)
Transmitância térmica (Valor U)

- Paredes externas
- Laje da cobertura
- **Fechamentos em vidro**

Fechamentos em vidro

NBR 15575 – Não há exigência mínima para vidros

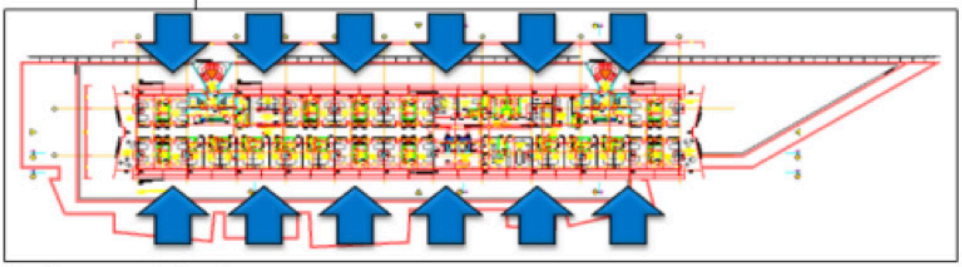
Vidro laminado simples:

- Laminado (4mm / 4mm)

Fator Solar (FS): 82,0%

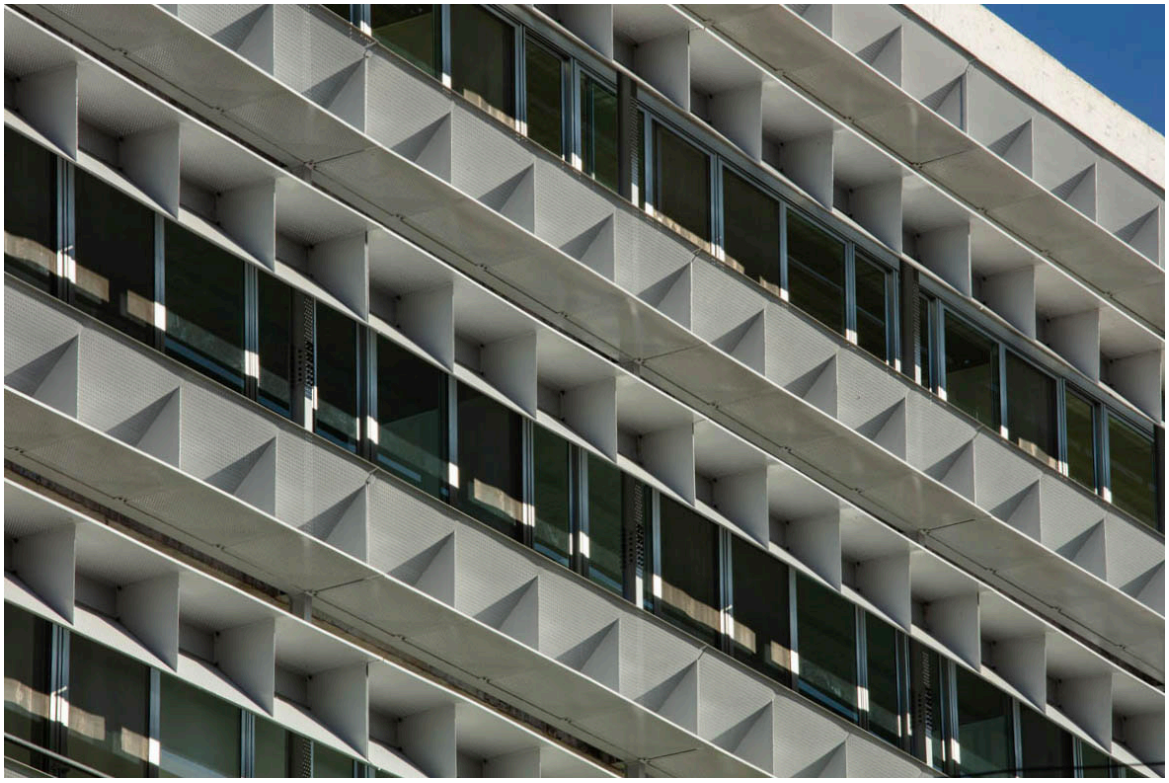
Transmitância térmica: 5,63 W/m².K

Sombreamento com brise horizontal

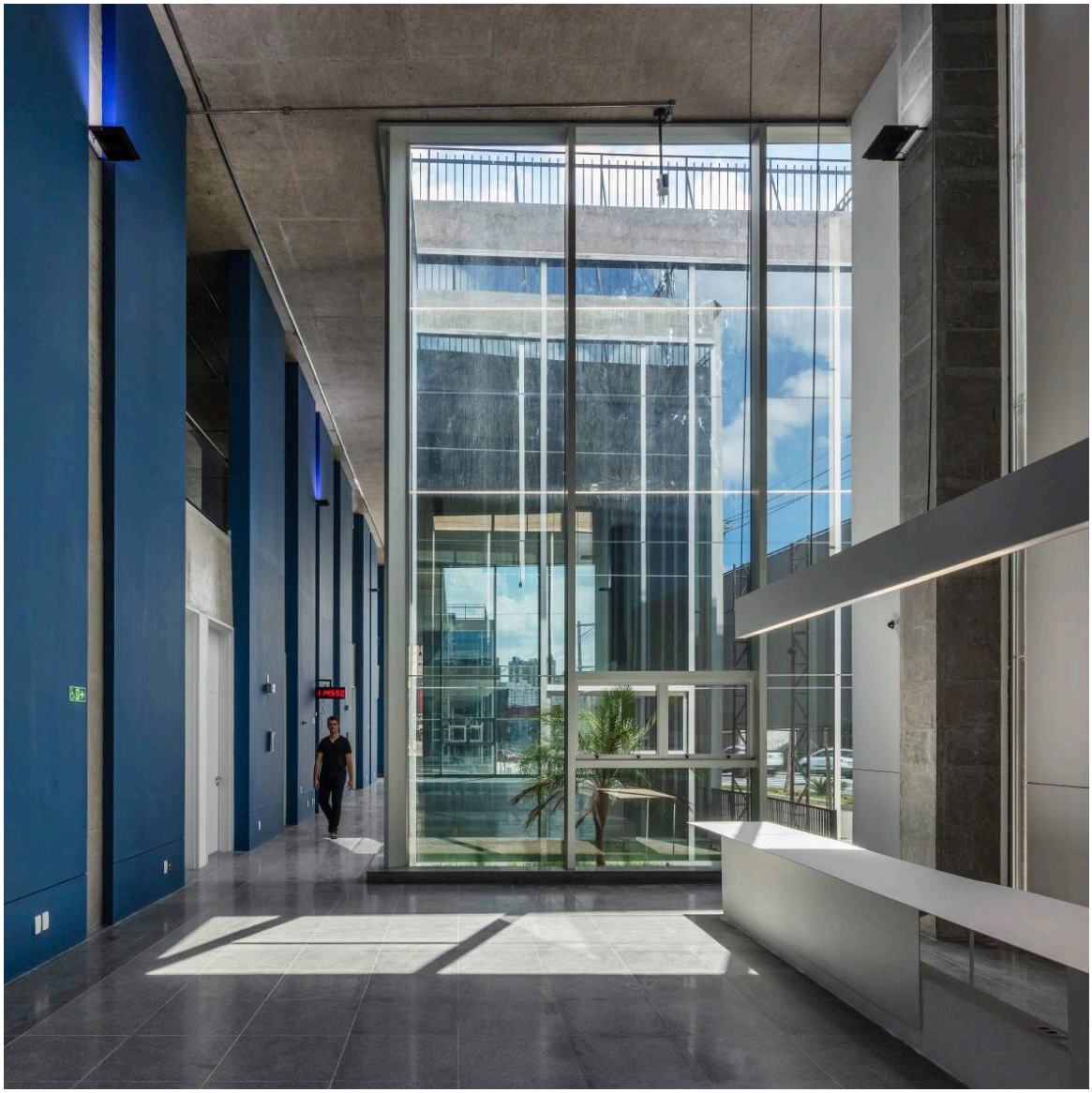


Pavimentos 4, 5 e 6





The bioclimatic strategy is based on the concept of induced natural ventilation and the use of thermal inertia of the concrete structure. As Victor Olgyay (1963) points out in his theory of bioclimatic design, the building should act as a filter between the external climate and the internal metabolic needs. In the hospital context, this "filtering" gains a layer of complexity: the guarantee of air renewal for infection control. The use of operable windows and the double-height ceiling with zenith openings, strategically positioned in the reception and living areas on the ground floor, allow the hospital to "breathe", reducing the proliferation of pathogens and, simultaneously, avoiding the use of air conditioning in areas of low criticality, which generates significant savings in maintenance and energy costs.

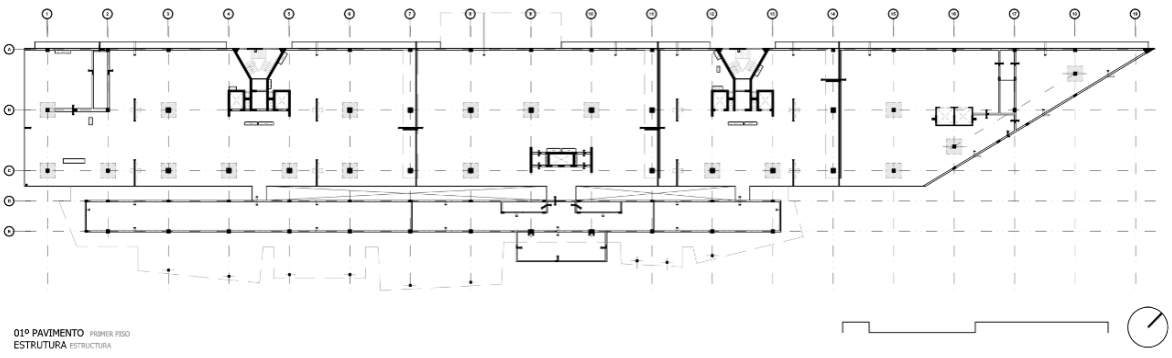


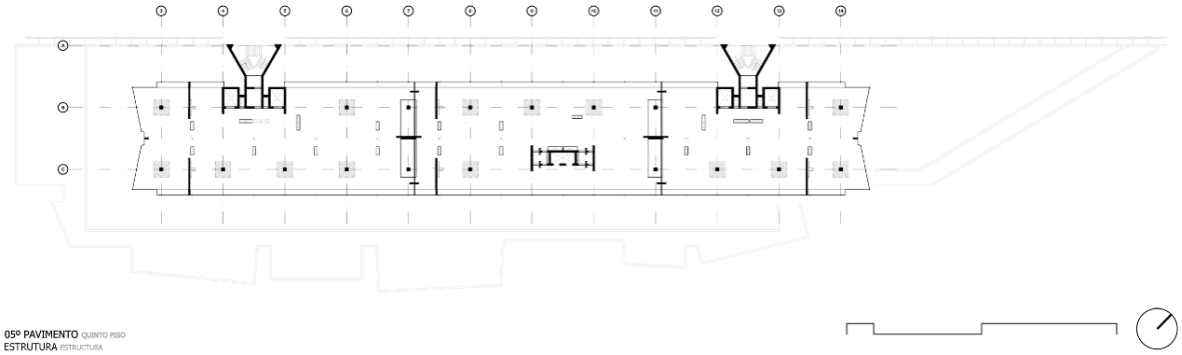
7. Tectonics and longevity – Prestressed concrete as constructive ethics

The materiality of the HUSBC is defined by the reduction of the palette, with the extensive use of reinforced and prestressed concrete for the structure and, as a rule, kept apparent to avoid the unnecessary overlapping of services so often performed out of pure habit (uncritical design). This choice has the meaning of a pragmatic decision focused on speed of execution, low maintenance and durability, or simply *tectonics*, as theorized by Kenneth Frampton (1995). In a public building, low maintenance is an ethical imperative.



The prestressed concrete structural system allowed the execution of large spans and, consequently, the creation of full freedom of interlining, without the interference of beams. The ten-meter intercolumn, considering the depth and type of foundation, is also an economic decision. This technical solution, detailed in *Memorial ARQ-PE-0020*, ensures the hospital's systemic flexibility. By concentrating the facilities in a generous technical void, between the slab and the ceiling, the project allows future technological upgrades of medical infrastructure to take place without the need for destructive interventions in the main structure.





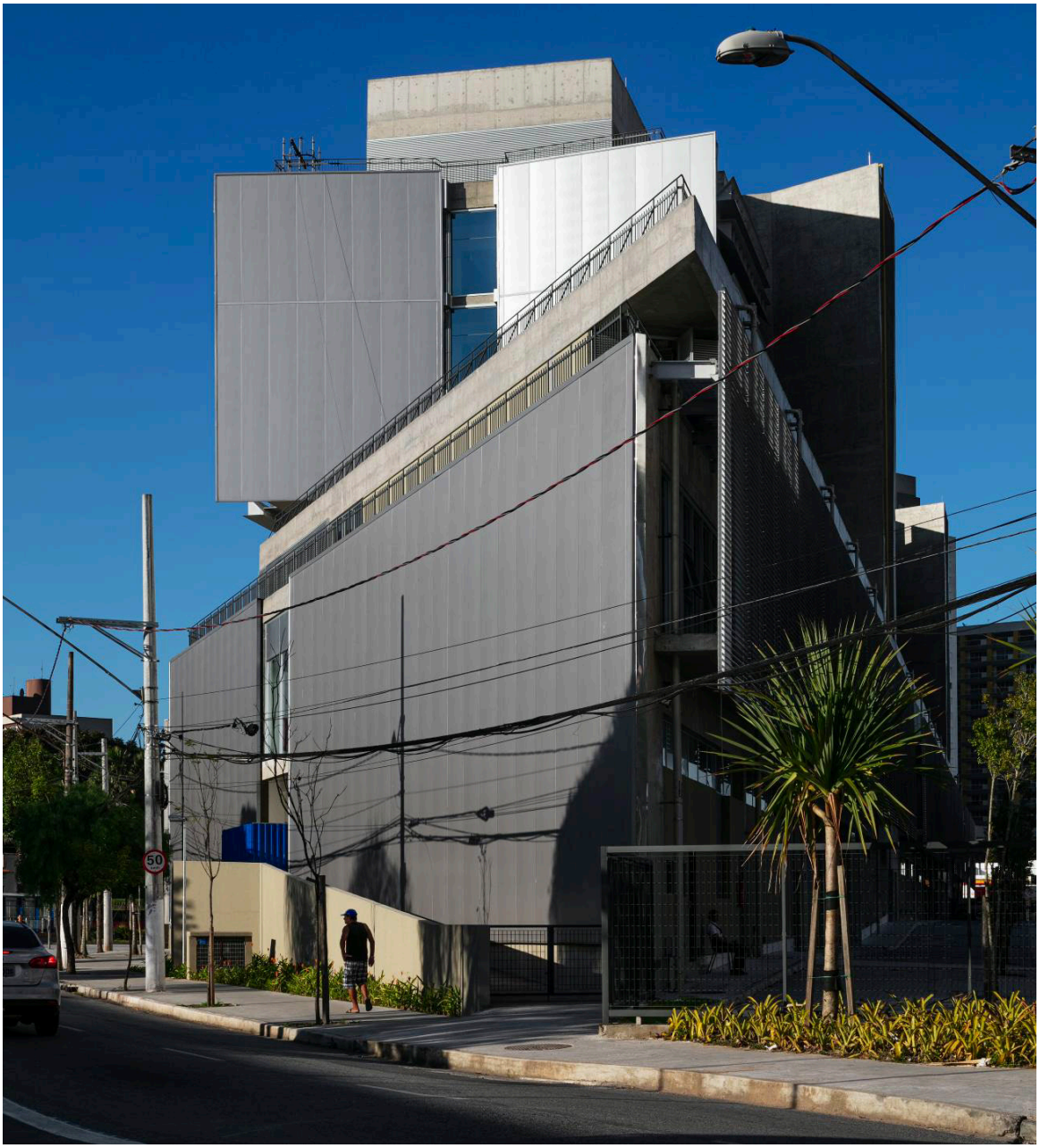
05º PAVIMENTO QUINTO PISO
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The building's outer coating, composed of precast panels and aluminum frames, responds to the need for watertightness and acoustic insulation in a noisy urban environment. The technical backbone — the vertical axis that concentrates the shafts and the circulation of utilities — was designed to be externally accessible at strategic points, facilitating preventive maintenance without invading sterile or service areas.

> The technical clarity of the building assembly, in which structure, infrastructure and sealing are read as independent systems, gives EHSBC a constructive intelligence that extends its useful life and minimizes functional obsolescence. (Adapted from the Executive Project Memorial.)

This architectural integration, between the rigor of engineering and the sensitivity of hospital design, results in a building that not only works, but that communicates with the city through its robustness and transparency, reinforcing the role of public architecture as an enduring cultural asset.




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8. Post-Occupancy Evaluation (POE) – Resilience in real operation

The transition from the design to the built building is the moment when design hypotheses are put to the test. In the case of the EHSBC, the post-occupancy evaluation (POE) proves to be a fundamental management instrument. According to Wolfgang Preiser (1995), POE should not be seen only as a diagnosis of failures, but as a cyclical process that feeds knowledge for future interventions. At EHSBC, the operation started in 2020 allowed us to observe how critical infrastructure responded to extreme demands.

The vertical division of sectors and clarity of supply flows (technical backbone) drastically reduce the time it takes to move materials and waste in-house. The logistical efficiency, provided for in the *Project Memorial ARQ-PE-0020*, materialized in a leaner and safer operation. The strict separation between dirty stream (waste and contaminated materials) and clean stream (inputs and patients) — facilitated by architecture — proved to be a competitive advantage in the management of biological risks.

The system of open and ventilated safety stairs naturally meets both safety demands and the agility of vertical movement, providing employees with a view of the city at different levels of observation.



9. The COVID-19 pandemic as the ultimate stress test

EHSBC opened to the public in May 2020, and it was immediately converted into a referral center for the treatment of COVID-19. This scenario of crisis was a maximum “stress test” for the architectural structure. The flexibility of the 4-in-2 inpatient unit proved superior to traditional group ward models. The possibility of subdividing the four-bed rooms into smaller two-bed units allowed to isolate groups of patients with different levels of severity and infectious profiles, without compromising the total capacity of the ward.

The resilience of the infrastructure, mentioned earlier as the “dike hospital” concept, was validated by the autonomy of the systems. The positioning of the suspended technical pavements ensured that maintenance teams could intervene in the medical gas and air conditioning systems without accessing the contaminated red areas. This external maintainability reduced the risk of cross-contamination between support professionals and care teams.

> The building’s ability to adapt to an unknown and highly transmissible pathology, without requiring emergency structural renovations, demonstrates that design flexibility is ultimately a public health strategy. (Report of the Clinical Board, 2021.)

10. Humanization and user perception – The impact of Evidence-Based Design (EBD)

In addition to technical efficiency, POE sought to measure the perception of well-being of users (patients and employees). Due to the use of Evidence-Based Design (EBD), the project prioritized natural light and visual connection with the skyline and built-up area.



Qualitative reports from patients indicate a reduction in the perception of confinement, a common phenomenon in emergency hospitals with purely artificial lighting. The strategy of low windows in the wards, allowing a view of the horizon even for bedridden patients, corroborates Roger Ulrich's theses on reducing cortisol and improving mood.

For nursing staff and physicians, the ergonomics of the workstations — positioned in such a way as to ensure direct visibility to the beds, but with adequate acoustic treatment — resulted in a decrease in work fatigue. Architecture, therefore, ceased to be a passive scenario to become an active agent in the patient's recovery and the worker's mental health. According to the *Environmental Comfort Manual*, the integration of sober colors, controlled natural ventilation and efficient acoustics transformed EHSBC into a paradigm that "the public building can and should offer the same environmental quality as private centers of excellence".

11. Comparative analysis – From the pavilion to the hospital podium-tower

The evolution of hospital typologies reflects the change in the conceptions of hygiene, medicine and urbanism. To understand the scientific relevance of EHSBC, it is necessary to situate it in the debate between the pavilion model, the vertical single-block structure, and the hybrid solution of basement and blade.

Historically, the pavilion model (such as Lariboisière Hospital in Paris)[3] prioritized cross-ventilation and isolation of pathologies but proved inefficient in terms of flows and logistics in scarce urban terrain. With the advent of air conditioning systems and elevators, hospital architecture migrated to the single-block structure, a compact high-density box. However, the single-block structure often suffers from technological blindness: the heart of the building becomes inaccessible, and the technical areas end up compressed underground, which compromises the maintenance and adaptability of the system — a critical flaw that EHSBC seeks to correct.

The EHSBC opts for the podium-tower typology, with a technical transition floor. This solution allows for the dissociation of two distinct temporal rhythms within the building:

1. Foundation (*podium*) – with logistical and diagnostic nature, requires large horizontal areas and direct connections with built-up urban areas.

2. Hospitalization blade (*tower*) – demands repetition, silence and contact with the outside (light and view).

3 For further information: BOUDON, Françoise. "Système de la brique et de la pierre : l'hôpital Lariboisière". In: *Revue de l'Art*, n. 29, 1975. A detailed technical article on the construction and symbolism of materials (brick and stone) in Gauthier's design.

The superiority of this choice for EHSBC lies in the introduction of intermediate technical flooring. While dense urban hospitals often suffer from infrastructure conflict (beams that block ducts, insufficient shafts), EHSBC creates a spatial truce. As Stephen Verderber (2010) argues, in *Innovations in Hospital Architecture*, the longevity of a hospital is linked to its "capacity for systemic updating without trauma". By raising the tower on a technical floor, EHSBC allows all network complexity (gas, electrical, HVAC) to be managed horizontally and independently, a significantly more resilient solution than traditional single-block rigid stacking.

12. The dialectic of Fast Track – Care efficiency vs. spatial quality

Another turning point in the technical discussion is the implementation of the Fast Track system in emergency care[4]. If the Manchester Protocol[5] organizes the flow by color and gravity, Fast Track is the acceleration algorithm for cases of low complexity but with high turnover.

Scientifically, the hospital management literature demonstrates that the bottleneck of emergencies is not only in the lack of beds, but in the poor management of outflows[6]. EHSBC architecture responds to this with the creation of independent circulation circuits that operate in parallel. At EHSBC, the project is not just a container, it is a "flow device".

Compared to contemporary international projects, such as Herzog & de Meuron hospitals (Rehab Basel) or Alvar Aalto clinics, EHSBC maintains the European functionalist rigor but adapted to the reality of Brazilian public health. While Aalto utilized shape to "cure" the individual through the phenomenology of space, EHSBC utilizes structure to "cure" public operation through logistical efficiency.

> "The modern urban hospital must operate as a 'health factory' on the ground, but as a 'space of humanity' on the top. The success of EHSBC lies in not allowing the industrial logic of diagnosis to contaminate the dignity of the rest space." (Extracted from the theoretical foundation of the participatory project).

This duality reinforces the thesis that high-complexity hospital architecture should be understood as a socio-technical system. The choice of prestressed concrete, discussed earlier, is not only structural; it is what ensures that this dialectic between the logistics base and the hospitalization tower can exist without the constraints of an excessively dense network of pillars, allowing the emergency flows to breathe with the necessary fluidity.

4 For further reading: ZILM, Frank. "*The Future of Emergency Department Design*". In: *Journal of Ambulatory Care Management*. GROUP2 ARCHITECTURE. "Lean Design in Healthcare: Emergency Department Case Studies".

5 For further reading: MACKWAY-JONES, Kevin; MARSDEN, Janet; WINDLE, Jill. *Emergency Triage: Manchester Triage Group*. BMJ Books.

6 BOSCH, Sheila J. *et al.* "The Effects of Healthcare Design on Patient Outcomes".

13. The ethics of materiality: durability and maintainability

In the context of public health, the choice of materials transcends the visual dimension to become an asset management decision. At EHSBC, the specification followed the trinomial durability-maintainability-material immunity. As the hospital operates on a 24/7 basis, the interruption for corrective maintenance reforms generates incalculable social and financial losses.

The adoption of reinforced and prestressed concrete as a language and structure reflects what Kenneth Frampton (1995)[7] describes as the "ontology of construction". By exposing the structure, the project eliminates layers of coatings (such as plaster and paint) that would be vulnerable to pathologies and would require periodic repainting. The concrete, treated with water-repellent varnishes and surface protection, offers a robust overlay that is resistant to the aggressiveness of the urban environment.

14. The high-performance outer coating – brises, prefabricated, and impermeability

The EHSBC outer coating is designed as a multi-layer system. For the external seals of the base facing the street, prefabricated concrete panels were used, which guarantee fast assembly and superior quality control in comparison with conventional masonry. These panels have a high level of acoustic insulation, essential for patient comfort in beds facing high-traffic roads.

Aluminum frames with high-performance laminated glass were specified to meet the criteria of impermeability and thermal insulation. The technical highlight is the fixed metal brises, whose geometry was defined by the simulations of the environmental comfort carried out by Mitsidi consultancy. The choice of electrostatically painted aluminum for the shading elements is justified by its resistance to corrosion and structural lightness.

Unlike mobile *brise* systems, which often suffer mechanical failures in public buildings due to lack of maintenance, the fixed *brises* at EHSBC guarantee the effectiveness of passive shading on a permanent basis. According to the *SBC Sustainable Projects and Works Manual*, this passive solution reduces the thermal load by up to 30%, allowing the air conditioning system to operate at lower power regimes, extending the useful life of compressors and *chillers*.

7 For further reading: FRAMPTON, Kenneth. *Estudos sobre a cultura tectônica: a poética da construção na arquitetura dos séculos XIX e XX*. São Paulo: Cosac Naify, 2012.

15. Interior materials and compliance with RDC 50

Internally, the specification of materials strictly followed Anvisa's RDC 50, but with an eye toward humanization. In critical areas, such as the operating room and ICUs, conductive and monolithic vinyl flooring was used to avoid the accumulation of dirt and facilitate asepsis.

For the circulation and lounge areas, the use of natural stones (granite) and high-density melamine panels (in controlled areas) seeks to break the traditional clinical coldness. The interface between architecture and engineering is manifested in the detailing of the modular and removable ceilings, exclusively installed in the technical and circulation areas. This choice allows immediate access to the interlining, allowing new data networks or medical gases to be installed without breaking walls or generating dust.

> The technical specification at EHSBC is not an isolated act, but a seam between the sanitary standard and operational efficiency. Every joint, every material, and every surface encounter is designed to withstand harsh use and facilitate sanitation, which is the first line of defense in hospital-acquired infection control. (Extracted from the Specifications Memorial - ARQ-PE-0030.)

16. The interface with the installations – The backbone as an architectural object

The greatest interface between architecture and engineering at EHSBC is its technical backbone. It is a vertical axis of visitable shafts that crosses the building. While, in conventional hospitals, the facilities are "hidden" in inaccessible places, at EHSBC, they are the heart of spatial organization.

This design strategy enables predictive maintenance. Technicians can access electrical panels, gas valves and hydraulic plumbs without entering the wards or restricted areas. This technical evidence elevates the hospital to the *status* of a flexible infrastructure, ensuring that the building can evolve technologically over the decades.

17. The project ritual – From qualitative listening to technical formalization

At HUSBC, the co-design methodology was not passive advisory, but a series of flow simulation workshops. During the preliminary design phase, the weekly meetings focused not only on "what" the doctor wanted, but on "how" space could repair human error.

A practical example of this methodological iteration occurred in the definition of emergency and shock rooms. Initially planned in a conventional layout, discussions with the traumatology team revealed that

bed arrangements needed to allow a 360-degree view from the central nursing ward, but with the possibility of rapid isolation in case of invasive procedures. This led to the design of service islands with suspended infrastructure (stands), freeing the floor for the free movement of crash carts and multidisciplinary teams.

This transposition methodology, in which clinical demand is translated into spatial metrics, is based on E.T. Hall's (1966) principles of proxemics. EHSBC's architecture manipulates distances to ensure that, in the stress of urgency, space works in favor of the professional, reducing what ergonomics calls cognitive load. Each layout decision was submitted to virtual flow tests, in which the patient's travel time from trauma to the operating room was timed, resulting in the creation of exclusive-red-code elevators.

18. Architecture in times of the Anthropocene – The hospital as a spot of resilience

By connecting EHSBC to the *SBC Sustainable Projects and Works Manual*, we realized that the project anticipates a vital discussion: the resilience of critical buildings in the face of extreme weather events. The concept of a "dike hospital" gains a political and environmental dimension here. In the context of the Anthropocene, in which urban flooding becomes more frequent and severe, the hospital cannot be a victim of the territory; on the contrary, it should be an anchor point.

The strategy of raising the technical heart of the hospital to the second floor – protecting transformers, generators and medical gas plants – in addition to establishing the ground floor level at the safe level, dialogues with the concept of **amphibious architecture**. While the surrounding urban infrastructure may fail due to overflowing channels or soil saturation (shallow water table documented in the drilling reports), EHSBC remains an island of functionality.

This approach is underpinned by C.S. Holling's theory of evolutionary resilience, adapted for architecture by contemporary researchers. A resilient building is not one that is rigid and indestructible, but one that possesses redundancy and the ability to maintain vital functions under disturbance. By adopting pre-stressed concrete and large spans, EHSBC allows one wing to absorb the function of a compromised one without systemic collapse.

> Sustainability at EHSBC is not only measured by green seals, but by its ability not to interrupt care. In a climate change scenario, the greatest virtue of a hospital is its operational resilience. (Theoretical foundation based on the Manual of Sustainable Works.)

The integration of its own drainage systems, with basins for accumulation and reuse of rainwater, makes the hospital act as a water compensation device for the neighborhood. Thus, the building returns to the city a regulation that the dense and impermeable urbanization of São Bernardo do Campo had removed. EHSBC, therefore, ceases to be just a health building to become a piece of blue[8] and green[9] structure, essential for urban survival in the 21st century.

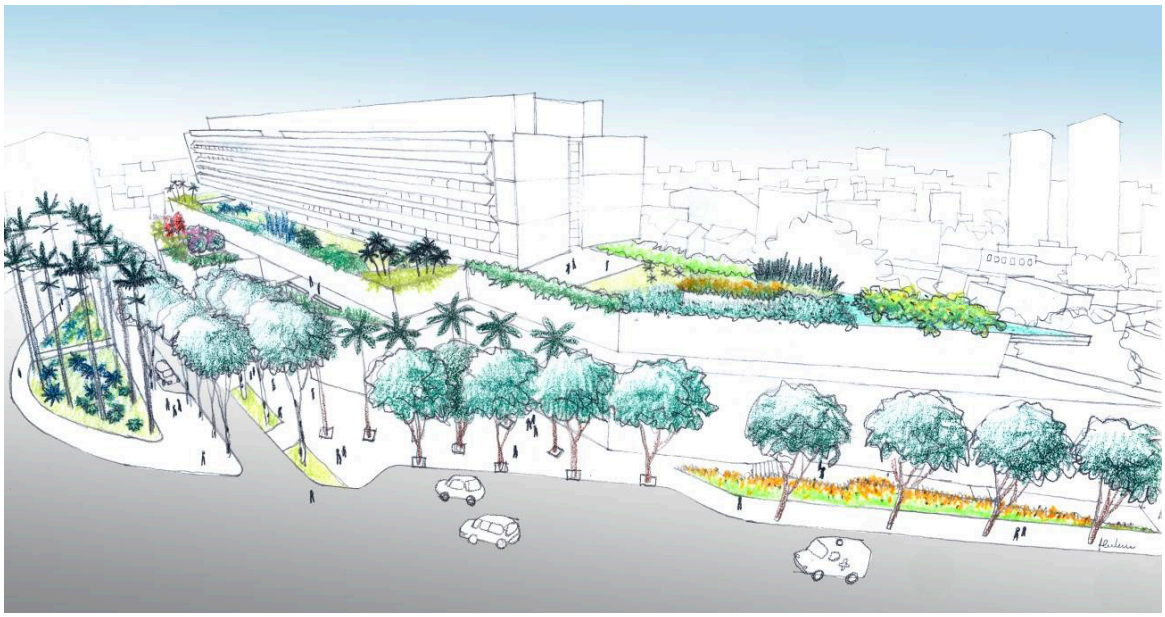
19. The human scale in the metropolitan facility – The hospital and the street

Establishing a 20,600 m² building on a narrow and densely populated lot requires a sensitivity that transcends the hospital program. EHSBC does not behave like an institutional bunker, on the contrary, within its limits, it seeks to establish a new urbanity for São Bernardo do Campo. In line with the guidelines of SBC Manual of Sustainable Projects and Works, the project qualifies the public space by treating the frontage not as a residual void, but as an extension of the sidewalk, promoting what Jane Jacobs (1961) defines as the "eyes of the street".

Unlike the typology of walled hospitals, EHSBC uses the transparency of the basement and the design of the landscaping to smooth the transition between the public domain and the highly complex environment. The access square, protected by the swing of the prestressed structure, offers shade and shelter, functioning as an urban waiting room that welcomes not only hospital users, but pedestrians who transit through the region. This strategy of welcoming architecture is fundamental to relieve the stigmatization of public healthcare facilities, transforming them into an area of civility and care.

8 For further reading: DREISEITL, Herbert. *Waterscapes: Planning, Building and Designing with Water.* Birkhauser, 2001.

9 BENEDICT, Mark A.; MCMAHON, Edward T. *Green Infrastructure: Linking Landscapes and Communities.* Island Press, 2006.



20. The hospitality paradigm – Space as an agent of healing

The concept of hospital hospitality[10], widely debated in the contemporary literature on architecture for health, proposes that the environment should act as psychological support for patients and their companions. At EHSBC, this hospitality is embodied in air quality, an abundance of natural light and acoustic control.

Based on the **Environmental Comfort Manual**, the project uses colors, textures and light as components of the healing environment. As Roslyn Lindheim (1985) points out, loss of control and disorientation are the main sources of stress in hospitals. At EHSBC, the clarity of vertical circulation and the constant view of the outside help patients to situate themselves in time and space, maintaining the link with the reality outside the disease.

The hospitality extends to the clinical staff. Rest environments for doctors and nurses were designed with the same premises of bioclimatic comfort as the wards. Recognizing that architecture must take care of those who care for it is one of the pillars of the equipment's social sustainability. An environment that reduces human fatigue and error is, by definition, a more efficient and cost-effective environment for public management.

21. "City Hospital" – Redundancy and programmatic diversity

EHSBC operates as a microcity. In addition to the clinical areas, the building houses a complex network of services: from waste management and sterilization centers to teaching auditoriums and areas for social gatherings. This programmatic diversity requires an infrastructure that supports intensive use without collapsing.

The solution of having visitable technical pavements, already discussed, enables this "microcity" to continuously adapt. In a public health context, where demand is always growing and resources are finite, systemic flexibility is the greatest form of savings. EHSBC demonstrates that excellent public architecture is not a luxury, but a strategy for optimizing resources. By investing in a robust and flexible structure, the State avoids the premature obsolescence of the building and ensures that it will serve multiple generations, adapting to new medical technologies that we cannot even imagine today.

22. Synthesis – The ethics of technique in architecture for health

Evidently, Emergency Hospital of São Bernardo do Campo (EHSBC) represents a rupture in the purely descriptive and functionalist model of hospital care. The project establishes a reflection for Brazilian public architecture, in which technique — manifested in the prestressed structure, exposed concrete and hydrological barrier systems — is not an end but a means to enable care and human dignity.

10 MALKIN, Jain. A Healing Architecture. New York: McGraw-Hill, 1992.

Dealing with the confrontation imposed by a vulnerable terrain and an urgent social demand, EHSBC demonstrates that architecture acts as a critical infrastructure. The starting of the "dike hospital" and the elevation of vital systems for suspended technical pavements are not only engineering solutions, but manifestations of an ethical responsibility for the continuity of public service.

23. Contributions and considerations to the scientific and design field

EHSBC's experience during the COVID-19 pandemic served as the final empirical validation of these assumptions. The flexibility of the 4-in-2 inpatient model and the technical independence of the floors ensured that the hospital was not just a building, but an instrument to combat the health crisis.

The potential contributions of this article to the contemporary debate in hospital architecture are summarized in three pillars:

1. Co-design endorsement – the demonstration that the participatory process with the clinical staff results in more efficient operational flows and more human environments.

2. Evidence-Based Design (EBD) effectiveness – the proof that passive bioclimatic strategies, validated by thermal and lighting simulations, ensure comfort and operational sustainability without overdependence on mechanical systems.

3. Resilience as an architectural attribute – the proposition of an urban hospital typology that anticipates climatic and hydrological challenges, maintaining its autonomy in scenarios of environmental stress.

These three pillars gain greater relevance in large-scale and highly complex public facilities such as this one, providing insights and updating the architectural agenda in the current context, especially in the face of sustainability and climate change. Thus, they are also pillars that sustain what is now recognized as architectural quality. However, the judgment that attributes specific weight to each of the specialties that ultimately constitute the architectural fact is not based on any one of them alone. In other words, neither the specialties nor the pillars, in principle, occupy a leading role. The judgment that establishes the appropriate hierarchy among them depends on each case and on all the variables that define it. This ethical judgment, in fact, corresponds to the very definition of architecture.

The conclusion is that EHSBC reaffirms the role of the architect as an articulator of complex knowledge. At the intersection of medicine, engineering, urbanism and social sciences, a building emerges not only to house healing, but to heal the city itself by offering it a referral place of excellence, resilience and beauty. The academic rigor learned at FAU-USP, combined with the avant-garde design practice, leaves this hospital with the legacy that Brazilian public health deserves the best that architecture can produce.

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APENDIX A – Technical Specifications

Emergency Public Hospital

São Bernardo do Campo, SP, Brazil

Project development: 2014 - 2015

Building process: 2015 – 2016

Architects

SPBR Architects

Angelo Bucci

Tatiana Ozzetti, Nilton Suenaga, Beatriz Marques, Victor Próspero

Lucas Roca, Martha Bucci, Beatriz Brandt

ARQLAB

[Hospital Architecture Consultancy]

Sérgio Salles

Ivan Portero, Priscila Segala, Vinicius M. Oliveira, Fernanda V. Santos

SIC ARQUITETURA

[Support for the production of drawings in Autocad]

Fabio Kassai

Bruno Taiar de Carvalho, Ana Carolina Artuzi Aipp, George Ferreira, Renata Ribeiro Lopes, Mariana Ginesi

Consultants:

Structure

Kurkdjian Fruchtengarten

Foundation

ENGEOS Engenharia e Geotecnia

Building installations

MHA Instalações

Landscaping

Raul Pereira Arquitetos Associados

Budget and Costs

Alberto Costa Neto

Specification engineering

Leonardo Katori

Lighting

LUX Projetos - Ricardo Heder

Energy Efficiency

MITSIDI - João Leal, Arthur Cursino, Edward Borgstein

Waterproofing

PROASSP

Industrial kitchens

NUCLEORA

Elevators

ZAPP Consultoria

Fire Protection

Cel. Altino Gianesini

Client

Fundação do ABC/ São Bernardo do Campo City Hall

Program

Emergency Public Hospital

Land area

17,548.16 m²

Total built area

21,831.81 m²

Structural System

Conventional and prestressed reinforced concrete

Main materials

Concrete, steel, glass, and aluminum

3D models

Ricardo Canton

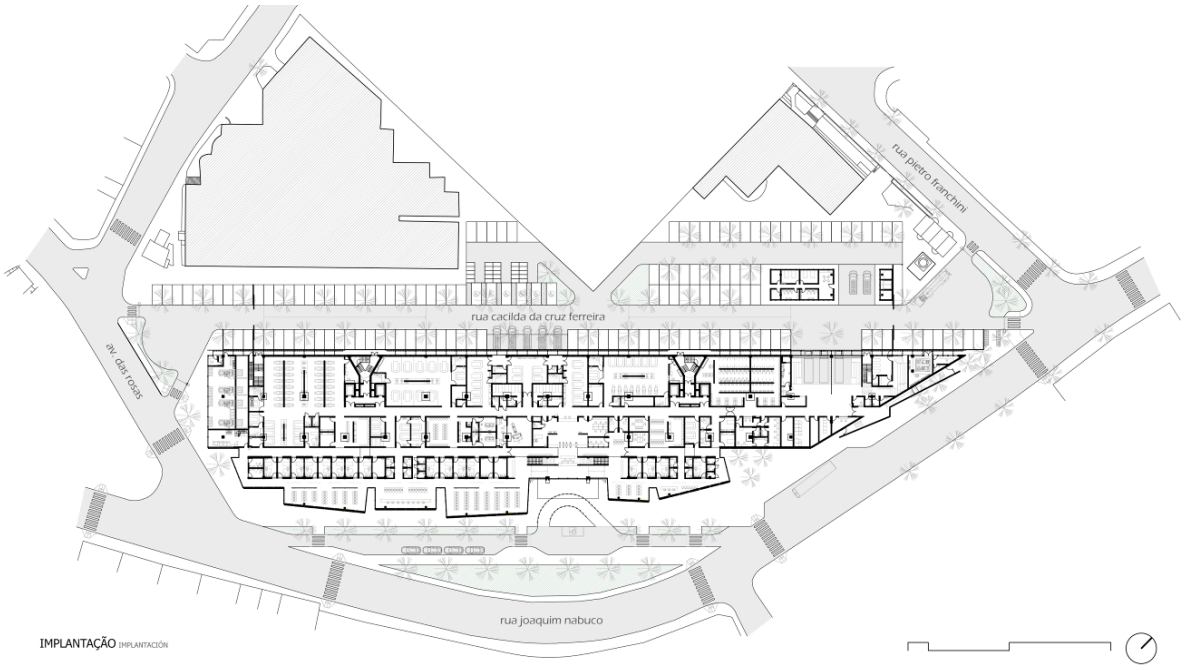
Model

Triviño Maquetes

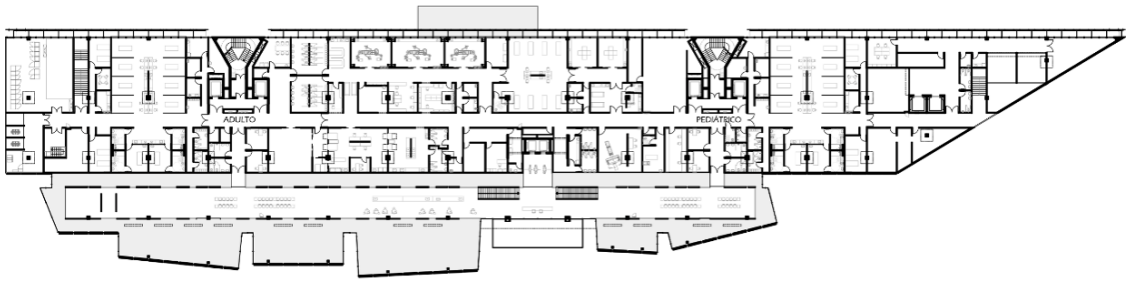
Photos of the building process and of the models

Nelson Kon

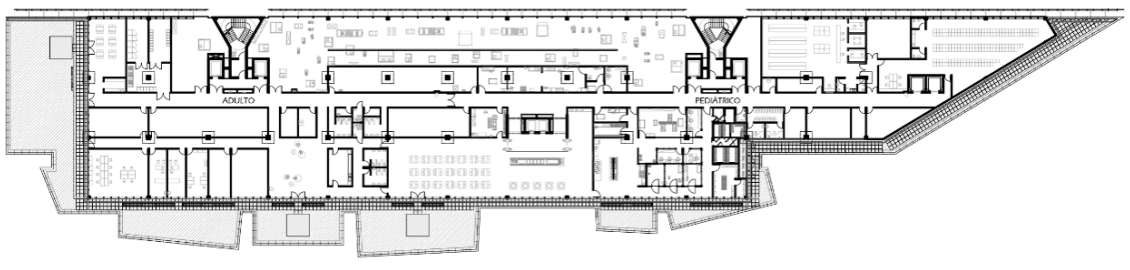
APENDIX B – Blueprints



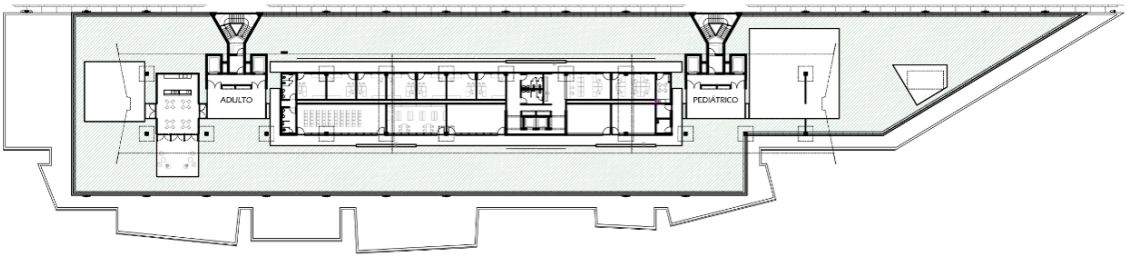
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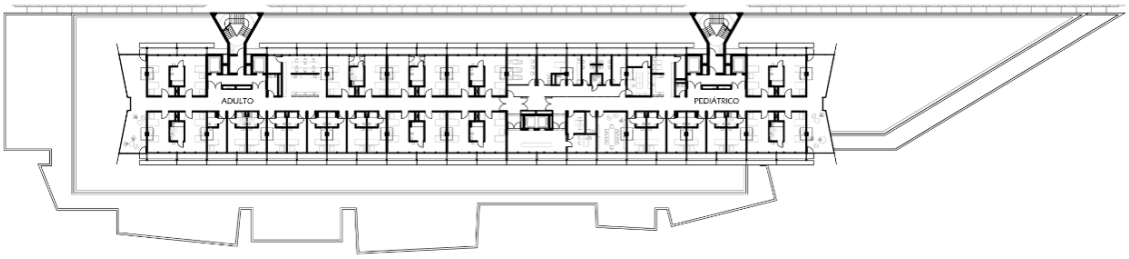
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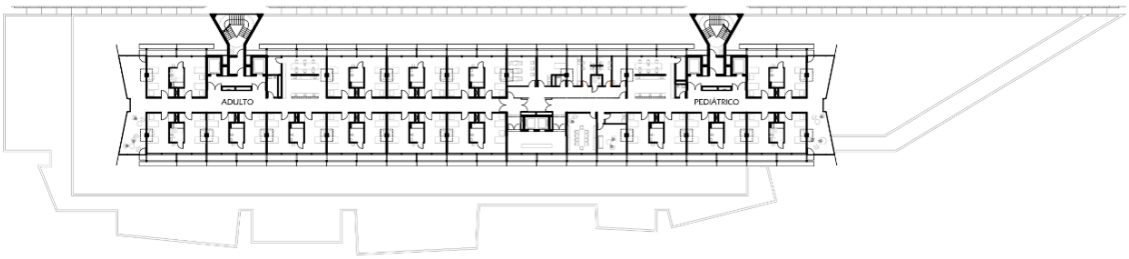
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PAVIMENTO TÉCNICO PISO TÉCNICO
NUTRIÇÃO / ALMOXARIFADO / ADMINISTRAÇÃO NUTRICIÓN / DEPÓSITO / ADMINISTRACIÓN



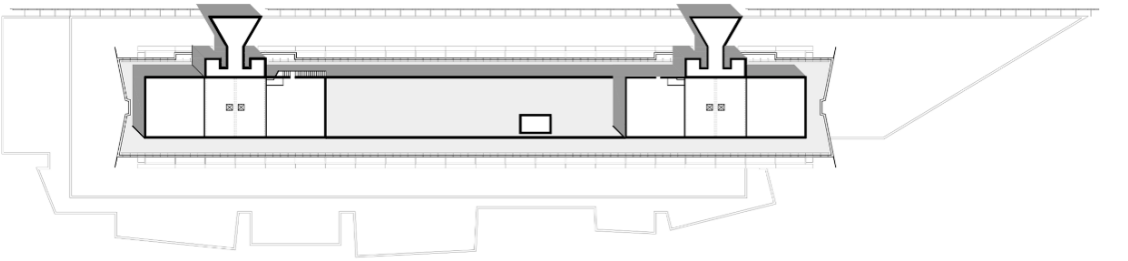
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04º PAVIMENTO CUARTO PISO
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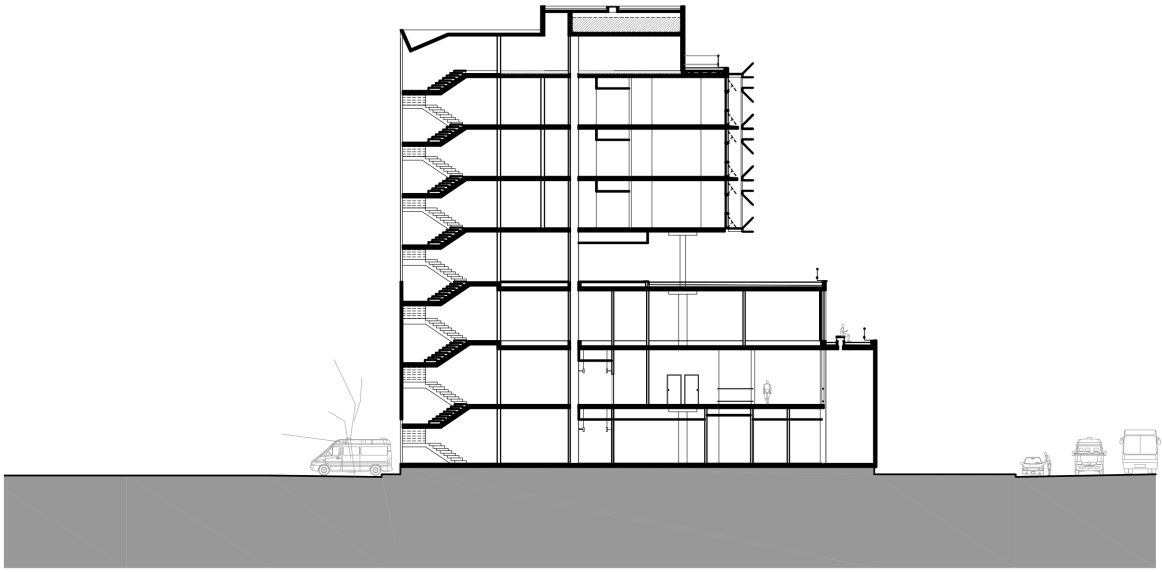
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INTERNAÇÃO HOSPITALIZACIÓN



COBERTURA COBERTURA



CORTE LONGITUDINAL SECCIÓN LONGITUDINAL



CORTE TRANSVERSAL SECCIÓN TRANSVERSAL

Authors

Angelo Bucci founder and director of the SPBR Arquitetos firm since 2003. He is a professor at FAUUSP in São Paulo, Brazil, and a Professor of the Practice at MIT in Massachusetts, United States. He has also taught in Argentina, Chile, Ecuador, Italy, and Switzerland. In 2011, he was named an honorary member of the American Institute of Architects.

Sérgio Luiz Salles Souza a specialist in healthcare architecture, with more than 30 years of hands-on experience focused on highly complex projects for healthcare facilities. His experience includes coordinating projects such as the São Bernardo do Campo Emergency Hospital, where he applied Evidence-Based Design (EBD) principles to optimize care flows and reduce the risk of hospital-acquired infections.

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