Revista ARACÊ
ISSN: 2358-2472

OFF-SITE CONSTRUCTION IN HOSPITAL ARCHITECTURE: A CASE STUDY ON THE QUALITY OF MODULAR VOLUMETRIC CONSTRUCTION

https://doi.org/10.56238/arev7n2-053

Submitted on: 01/06/2025 **Publication date:** 02/06/2025

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ABSTRACT

This article is part of the author's master's thesis and emphasizes the techniques of Modular Volumetric Construction applied in hospitals, through a case study. The relevance of the technique applied to hospitals occurred with the advent of the pandemic, in 2020, this quick assembly technique, already widespread and consolidated in the residential and service market (hotels and offices), has its attention and application focused on the hospital area in response to the immediate demand for inpatient beds. The general objective of this work is to understand the quality of the processes of the off-site modular construction system, applied in adult hospitalization units. Also as specific objectives, we can address: characterization of environments from the points of view of function, flexibility, adaptability, growth and performance; understand the current market scenario of this system in the hospital area in the country; and analyze the benefits and challenges of this technique. As methodological procedures, bibliographic research, case study recognized today, technical visit, data collection and analysis were adopted. The case study refers to an annex block for hospitalization in a hospital already built, in the city of São Paulo. The expected results of this research are: presentation and approach of the volumetric modular construction technique; understanding of some concepts of hospital architecture in adult inpatient wards; and in-depth analysis of the case study for knowledge and presentation of the technique, concepts and design.

Keywords: Modular volumetric construction. Hospital architecture. Inpatient unit. Metal structure. Off-site *construction*.

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ISSN: 2358-2472

INTRODUCTION

The health area is dynamic and complex. In Brazil, the relationship between supply and demand for hospital beds is disproportionate to the safety standards recommended by the WHO (World Health Organization) and the Ministry of Health. A hospital bed is understood to be a bed intended for the hospitalization of a patient in the hospital. In this account, observation or auxiliary beds (for diagnosis, recovery or supervision purposes) are not considered.[3]

The WHO recommends 3.0 to 5.0 hospital beds per 1,000 inhabitants. The Ministry of Health, through Ordinance MS No. 1,011/2002, recommends 2.5 hospital beds per 1,000 inhabitants.

A survey carried out by the *Brigh Cities* platform in 2020 shows that about 10% of Brazilian cities meet the WHO recommendation.[4] However, observing the example of the study on Fortaleza, which is listed among these 10% of Brazilian cities that meet the WHO recommendation, in reality it has beds referred to other cities that still do not serve the entire population of the metropolitan region, which involves 19 municipalities.

Another aspect that can be addressed in relation to the types of emergency constructions is their relationship with the project. Some industrialized construction systems have a standard design technique that can dispense with the development of a project, as it has already been defined as a standard and can be applied in most contexts of implementation.

> In the face of the new coronavirus pandemic, the need arose to build field hospitals in record time to serve the most affected population and, among the alternatives, modular construction proved to be an effective solution, bringing to light the importance of modular projects and agile management. (Guimarães; Santos, 2022 – p. 04)

In the cut of the modular volumetric system, companies have to consider the relationships between cost-benefit, flexibility, durability, large-scale deployment, customization and functionalities. It is also a system that allows permanent construction and makes it possible to transport it to another location or its disassembly. Once the pandemic and the emergency nature are over, it is possible to systematically approach the

[3] ANVISA, 2002 (p. 154)
[4] Survey carried out by the *Bright Cities* Platform, with access for subscribers. Call aired on: https://blog.brightcities.city/pt-br/hospitais-brasileiros-covid19/

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modular system for more satisfactory results, considering other problem parameters: resources, quantity, costs, quality, and time (Rosso, 1980).

> ... The greatest obstacles in the way of the industrialization of construction are not of a technical nature, in the elaboration of projects, manufacture and assembly of architectural organisms, but of an economic, administrative and political nature. (Bruna; 2013, p. 144).

Modular volumetric construction has a history dating back to the 19th century, but it has established itself as a modern and efficient technique in the 21st century. This technique continues to gain popularity around the world. In Brazil, as a light construction system, it spreads slowly, in view of the predominance in the market of other constructive solutions.

OBJECTIVES

The main objective of this work is to understand the quality of the processes of the modular *off-site* construction system applied in an adult hospitalization. Such processes of design, execution and management.

Figure 1 – Volumetric module factory

Source: Brasil ao Cubo[5]

The specific objectives are:

- Characterize the environments of an adult hospitalization unit, built with the modular volumetric system, analyzing function, flexibility, adaptability, growth and performance;

[5] Available at <https://brasilaocubo.com/portfolio/hospital-vila-santa-catarina-21>. Accessed on: 01 set. 2024

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- To analyze what are the positive and negative specificities of the use of this constructive technique in hospital admission environments;
- To understand the current scenario of the volumetric construction market focused on the hospital area in the country.

Hospital environments have several characteristics and specific needs, which need to be met. Each environment has its own functions, operations and services are constantly growing and changing; the hospital building needs to be well inserted in the local and urban context; spaces need to be flexible for contingency cases and change of use; and finally, comfort and safety performances need to be met. The tensioned and pneumatic construction systems meet the deadline requirements, but are very limiting to the requirements described in this paragraph, without having the character of permanent constructions.

In order to enable predictive maintenance and safety, the hospital must be assured of various forms of flexibility and accessibility, such as: inter-floor spaces, technical floors, technical walls, structure with outdated modulation of architectural modulation, duct passages, horizontal and vertical technical spaces, as well as slabs and beams subject to present and future drilling, others. (KARMAN; 2011, p. 41).

METHODOLOGICAL PROCEDURES

The bibliographic research for this article considered works and publications mainly referring to the subject of off-site modular construction. Topics on industrialized construction, hospital architecture, prefabricated construction, among others emphatic to the theme, were also researched.

The work is also based on a very representative case study in the context of the community, as highlighted by Robert Yin (1999) about the importance of defining the case study from the point of view of three contexts: hospital, community and systemic. Yin (2009) defines that the research process of a case study is linear, from Planning to Sharing of results, however, in the middle of this linear process, the stages interact with each other in an order that is not necessarily linear, with the objective of constant review aiming at the quality of the results.

The case study was built in the midst of the first wave of the pandemic, on an emergency basis, increasing the installed capacity of Hospital 1 by another 100 inpatient

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beds. The data collection was based on a technical visit with the annex built and occupied, in addition to published bibliographic research and material provided for research by Hospital 1. Currently, the annex operates as adult surgical hospitalization beds. The construction was financed by a group of partner companies that donated the building to the Health Department of the Municipality of São Paulo. The construction was carried out by the company Brasil ao Cubo.

Figure 2 – Case study 1 – Hospital Annex 1 (2020)

Source: Tecverde, 2020 – p.1.[6]

As a method, project analysis will be developed through redesigns and analyses using the concept of decomposition, of the main and secondary structures, the fences and the infrastructure necessary to implement a work in terms of adapting to the new technologies necessary in a state-of-the-art hospital.

The article was developed through the methods of historical, comparative and monographic procedures. Also as a methodological procedure, a hypothetical-deductive approach method is used, in view of the available knowledge on a subject in recent development: the off-site modular construction applied in hospitals.

VOLUMETRIC MODULAR CONSTRUCTION

We will approach the topic of Volumetric Modular Construction in different but connected views. We will talk about: historical view, concepts, uses and a deepening of the Volumetric Modular Construction technique.

[6] Available at <https://www.tecverde.com.br/2020/04/27/entrega-hospital-mboi-mirim/>. Accessed on: 01 set. 2024

Housing is man's first need in terms of environmental comfort, leading him to carry out a construction to protect himself. Therefore, it is not surprising that the first examples of prefabricated construction were residences. Volumetric modular construction originated in the construction of residential buildings, but today it opens up a range of applications and uses, such as in hotels and hospitals (Smith, 2010). Today's modular constructions not only fulfill their basic functions, but can also be customized to meet the comfort needs of residents.

To understand the process of the emergence of volumetric modular construction, it is important to consider that this history is part of the evolution of prefabricated construction. Therefore, we will distinguish in this work the emergence of prefabricated construction from the emergence of volumetric modular construction, as a branch of the previous one.

The process of industrialization in civil construction, with reference to the long history of construction itself as a human need, is something very recent. It is challenging to define a point of convergence between the research bases to demarcate a place or historical period of the emergence of prefabricated construction. Prefabricated houses in England were sent to the USA in 1624, for the construction of the fishing village of Cape Anne (Arieff *in* Oliveira e Vale, 2018).

In the research developed for this work, it is worth highlighting two records of prefabricated hospitals built in wood. One of them is in the West Indies, in 1801. John Rollo (1750-1809), a Scottish military surgeon, pioneer in the treatment of diabetes, makes this record in his notebook entitled "*A short account of the Royal Artillery Hospital at Woolwich",* specifically on page 32 (Rollo, 1801). This record is interesting for this research that involves modular construction applied to hospital architecture.

> "There are also temporary hospitals and they are preferable to the hut and the tent. They are, however, suitable only for expeditions of an island nature, as they would require a land support, with a proportion of carts and horses that would be impracticable. Such a hospital was built by the West India Company and being approved, many were produced and shipped to the islands. During the tests, they were heavily criticized. The heat penetrated the sides and the roof, especially this one, which, being made of copper, diffused an intense heat, in fact so intense that they became uninhabitable, until the installation of another roof raised to twelve inches, with tiles". (Rollo, 1801 – p. 35).

In 1801, Rollo documented the thermal comfort problem of the modular hospitals he visited in the West Indies. Even today, this remains a challenge in volumetric modular construction. A recent English study, by Fifield, Lomas, Giridharan and Allinson, addresses summer overheating in hospital inpatient wards built using the volumetric modular

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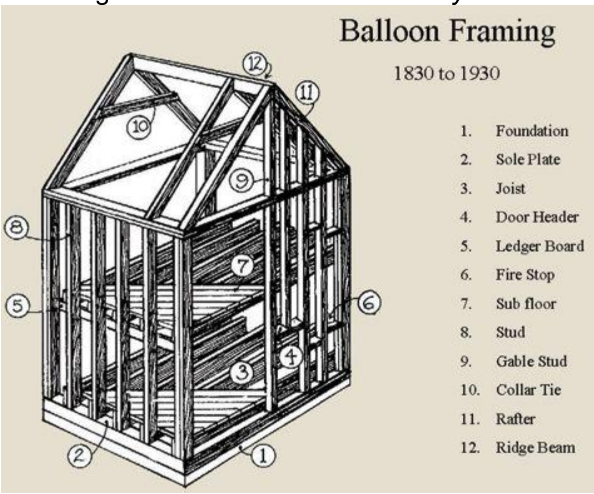
technique. In this study, carried out in a hospital in England, there are conclusions about energy inefficiency and lack of natural ventilation.

The other record of prefabricated wooden hospitals was around 1790, built in England to be sent to Australia. There, hospitals, warehouses and houses were built. The construction system became known as *Balloon Frame* (Herbert in Oliveira and Vale, 2018).

Figure 3 – The *Balloon Frame System*



Fonte: Small Step Energy Solutions LLC, 2012 – p.1. [7]

The Balloon Frame *construction system* consisted of wooden structures with uprights at the total height of the building, usually up to two floors. The beams, also in whole uprights, were part of the slab structure.

The industrial revolution was very favorable for prefabrication, enabling the development of new connection systems, development of materials, technological processes and logistics for transporting prefabricated elements. In this period we have some events and demands that influenced the development of construction: industrial revolution, quality control, systems thinking, world wars, British colonization and the beginning of modernism in architecture. In the following table (adapted from Smith, 2010), this evolution is summarized in events, concepts and periods.

[7] Available in <https://smallstepenergy.wordpress.com/tag/balloon-framing/>. Accessed on: 23 nov. 2024

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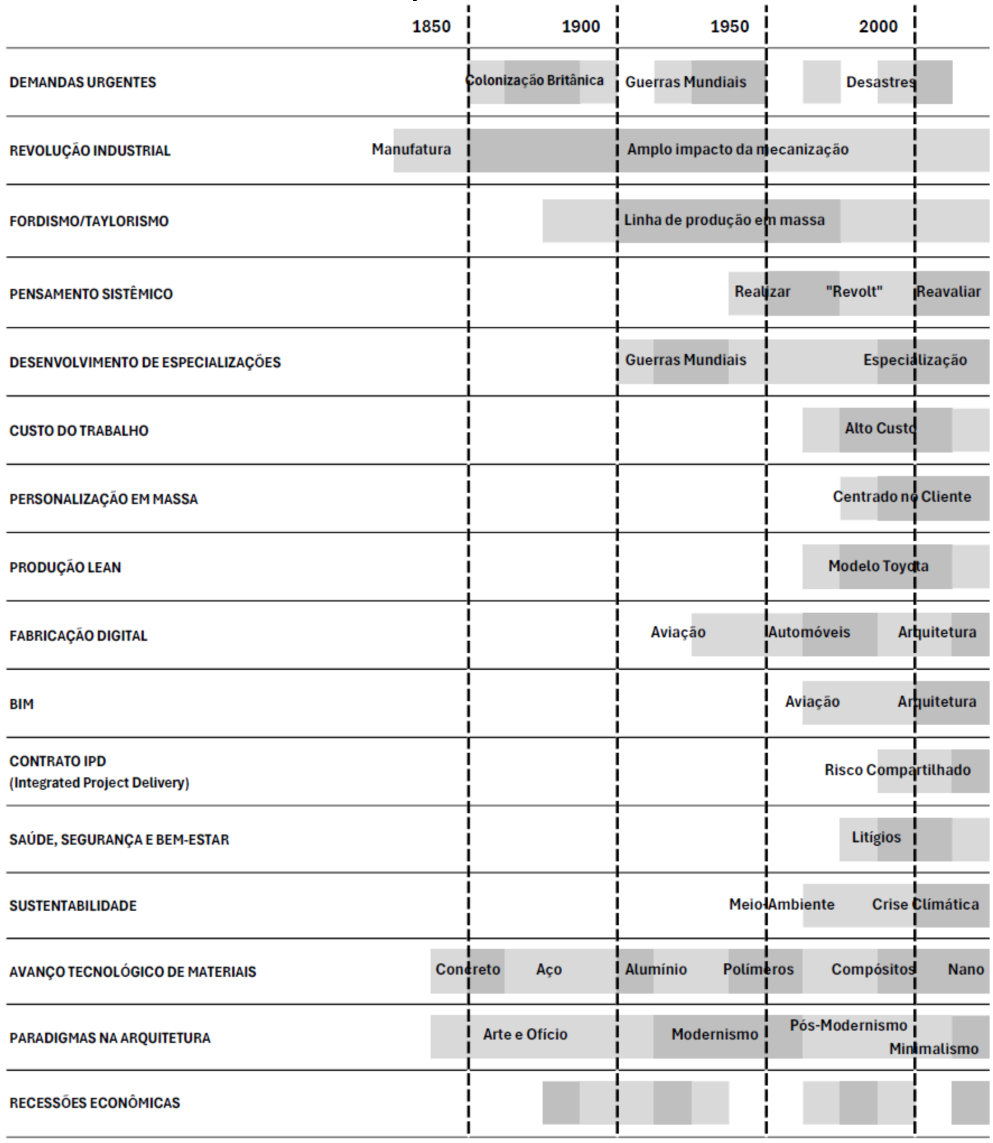
Table 1 – History of industrialized construction



Source: Beltramini, from (Smith, 2010 – p. 4)

In this work, we will delimit a historical milestone of great value and importance for architecture, considering the historical components presented in the previous table. And we will develop the analysis and research from *the Packaged House* by Walter Gropius and Konrad Wachsmann, a proposal for a prefabricated house from 1941, with concepts very close to what we know today as volumetric modular construction.

Walter Gropius (1883-1969) was a German architect, founder of the Bauhaus, a school that marked the world history of art, design and architecture. Konrad Wachsmann (1901-1980) was also a German architect. In the United States they had great recognition, where they migrated due to Nazism during World War II.

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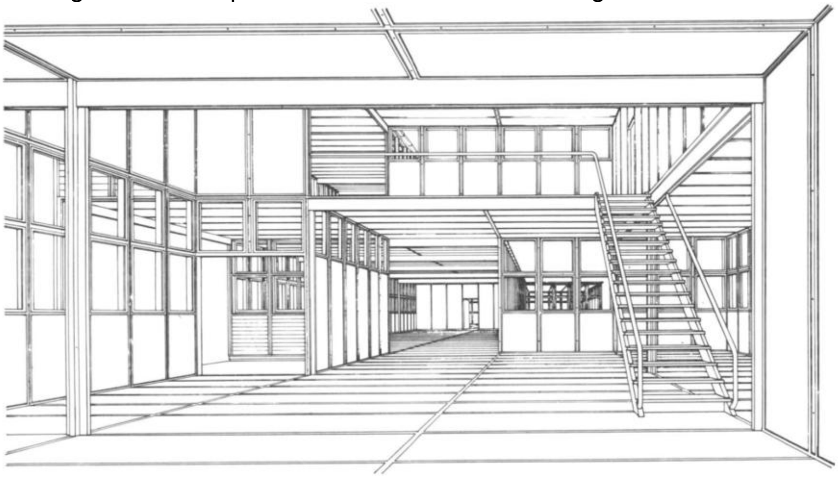
Gropius and Wachsmann have developed a universal modular building system for houses with components, panels, structures and connections. Giving rise to three-dimensional elements in prefabricated construction, which we know today as Three-Dimensional Modular Construction.

Figure 4 – Perspective in section – *The Packaged House* 1941



Fonte: Herbert, 1984 – p. 251

Gropius, still at the Bauhaus, argued that the architect should design the construction industry and not be shaped by it. There was a sincere desire in the architect and a great interest in industrialized construction (Rupnik *in* Valério, 2017). When Wachsmann arrived in the United States as a refugee and with few belongings, in September 1941, he met Gropius and presented him with some drawings on a steel construction system and some studies on modular construction (Herbert, 1984). A working and research partnership was born that evolved into Packaged *House*. Today a reference in the studies and history of prefabrication and volumetric modular construction.

> [...] it seems evident that the solution envisaged by W. Gropius of a "large-scale builder's game", composed of standardized pieces of industrial production, would not limit the variety of specific compositions and the resulting spaces, but rather, depending on the creative talent of the architect, would allow the creation of new rhythms and express the individual or national character of architecture. (Bruna, 2002 – p. 25 and 26).

For entrepreneurs and builders, there are a number of justifications for choosing the off-site modular volumetric construction system, including: deadline, cost, safety, waste reduction, quality control, and control of the construction schedule. All these justifications are related to the sustainability of the work, so it can be said that *off-site* construction is more sustainable than conventional *on-site construction*.

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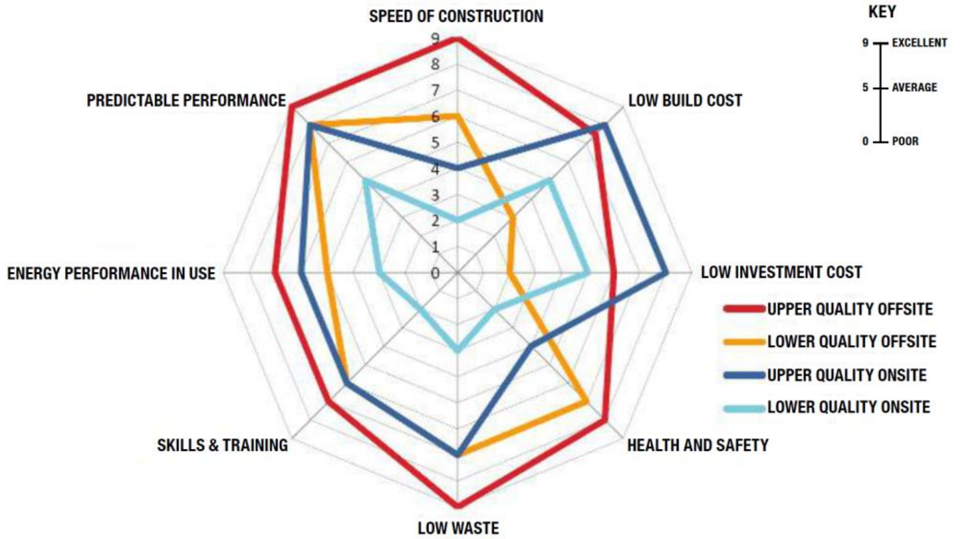
Graph 1 – Performance of *off-site* and *on-site constructions*



Source: Hairstans, 2014 – p. 15

> Off-site *construction* refers to the part of the construction process carried out off-site, in a facility suitable for production. This methodology's main characteristics are the high speed and reduction of *on-site* activities, avoiding the management of a large number of people on site, obtaining more assertive planning. (RCDI+S, 2023 – p. 21)

We show in Graph 1, by Hairstans (2014), a quality comparison between the two types of construction processes. To delve deeper into the topic of sustainability, Krug and Miles (2013) conduct research with eight case studies (three *off-site* and five conventional *on-site*) with the following conclusions:

Table 2 – Benefits of *off-site* construction for sustainability

ATTRIBUTE	POTENTIAL IMPROVEMENT	SOCIAL BENEFIT	FINANCIAL BENEFIT
Social development			
Health and Safety	>80%	High	Not applicable
Working Conditions	Considerable	Considerable	Not applicable
Environmental Development			
Transport Reduction	>60%	Considerable	Small
Energy Reduction (Construction)	>80%	Small	Small
Waste Reduction	>90%	Considerable	Considerable
Energy Reduction (Operation)	>25%	Considerable	Small
Economic Development			
Fast construction	>60%	Considerable	High
Improved cash flow	Considerable	Small	High
Reduction of failures	>80%	Small	Considerable

Source: Prepared by Beltramini from (Krug and Miles, 2013 – p. 4)

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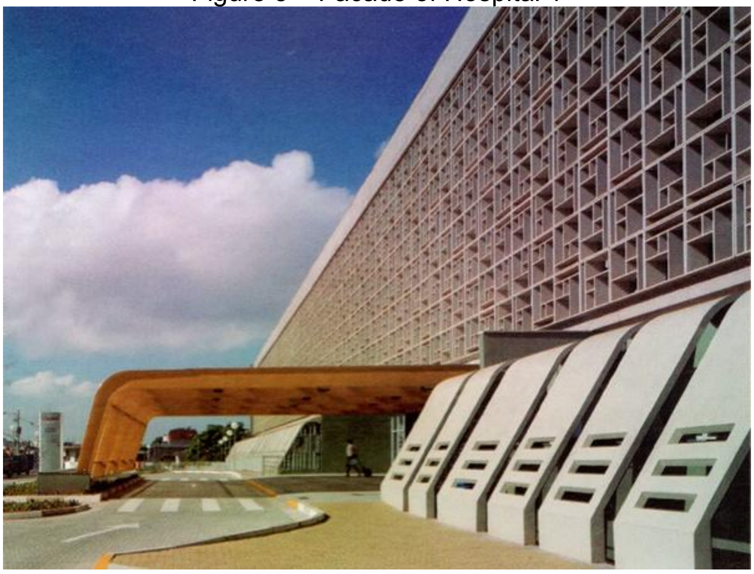
CASE STUDY

Hospital 1 is located in the South Zone of the city of São Paulo, was inaugurated in 2008 and is a municipal hospital with indirect private administration since its inauguration. Originally, the hospital was designed with 200 inpatient beds and 40 ICU beds. It has emergency services, outpatient clinic, hospitalization, birth center, obstetric center and surgical center. It had, before its expansion, approximately 27 thousand square meters.

Figure 5 – Facade of Hospital 1



Source: Healtharq, 2013

It is a very important health care establishment in the region, which lacks health services. The hospital is referenced for a population of about 700 thousand inhabitants, corresponding to the neighborhoods of Jardim Ângela, Jardim São Luis and Capão Redondo. Before its inauguration, this population was assisted by another equivalent EAS (General Hospital of Itapecerica da Serra), inaugurated in 1999, about 10 kilometers away from Hospital 1.

Designed in partnership by Borelli & Merigo (architects José Borelli Neto and Hercules Merigo) and Makhohl Arquitetura (architect Walter Makhohl), Hospital 1 was built and inaugurated in 2008. It is a medium-sized general hospital and has four floors that house the care services: psychiatric hospitalization (basement); emergency room, outpatient center and diagnostic center (ground floor); surgical center, obstetric center, birth center and intensive care units (1st floor); inpatient wards (3rd floor). The second floor is a technical floor dedicated to the positioning of machines and equipment that serve the critical areas located on the lower floor. Its total built area is approximately 27,000 m².

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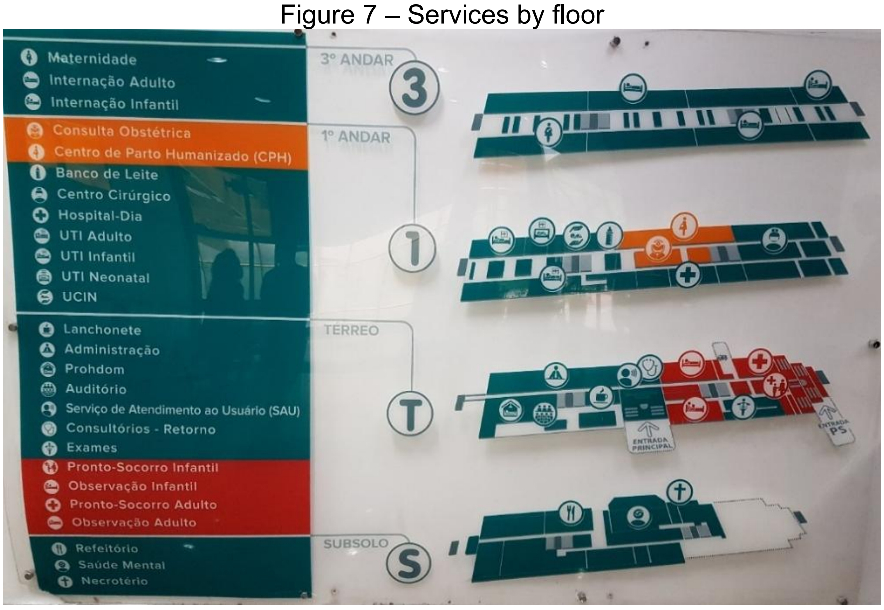
Figure 6 – Implementation of Hospital 1

1. Access Parking
2. Main Block Access
3. Visitor Parking
4. Triage Center
5. Pronto-Socorro
6. Staff Access
7. Parking Staff
8. Supply Block
9. Loading/Unloading
10. Access Services
11. Reception Garage
12. Garage Building
13. Helipad

Source: Healtharq, 2013

The hospital has a horizontal and pavilion characteristic, with two elevator towers and four stairs towers. The sectors were very well implemented in the building both from a horizontal and vertical point of view. The result observed on site is the high availability of elevators that are required for short trips. Ten large internal garden atriums were also positioned that allow natural light and ventilation to enter from the third to the first floor.

Figure 7 – Services by floor



Source: Beltramini, panel photographed at the site on 12/09/2020

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CONTEXTUALIZATION

In March 2020, the Covid-19 pandemic began. With the imminence of an increase in cases and the need for a quick and immediate response from agents of society, the assembly of the field hospital attached to Hospital 1 was quickly organized, initially designed with 100 inpatient beds, divided into 16 wards.

However, the path to the project to be executed in 34 days would start with a very different idea. Brasil ao Cubo, the construction company that designed and executed the Hospital 1 annex, originally conceived the idea of modules for residential hospital beds, which could be installed or attached close to people's homes, as presented in the video 100 beds in 33 days (Brasil ao Cubo, 2022a). This type of module was not executed and replaced very quickly by a new idea: building modular hospitals.

Figure 8 – Original design for a residential hospital bed

Source: Brasil ao Cubo, 2022b

The new idea presented modules of hospitalization rooms clustered and organized in such a way that a characterization of a hospital hospitalization unit was initiated. The modules were arranged in two corridors. Figure 29 illustrates this arrangement in 22 connected modules for the formation of 08 inpatient wards, with 05 beds in each ward and totaling 40 beds. This was the initial conception for the project of the Annex of Hospital 1.

Figure 9 – First conception of hospitalization in modules for the implementation unit

Source: Brasil ao Cubo, 2022b

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DESIGN

One of the challenges for the implementation of the annex was its connection with the existing hospital, considering that at the time the hospital had been referenced for the care of patients with Covid-19. However, other services such as the obstetric center and the birth center were maintained. It was essential to adapt the access of these patients and their internal referral within the hospital.

Figure 10 – Annex implementation patio

Source: Ateliê Urbano[8]

The annex was implemented in a parking area, close to the access to the Emergency Room. The layout of the building would need to facilitate the connection with the main block of the hospital, since all support services and other care services are positioned in the existing building. Services such as: clothing processing, kitchen, operating room, diagnostic center, laboratory, maintenance and intensive care unit.

This connection with the main block was solved with two walkways that connect the existing building and the annex, with a smaller walkway on the ground floor level and a larger walkway, with visual prominence, on the first floor level. In the following figure, the location of the annex is highlighted in red and the existing building in blue.

[8] Available at <https://www.atelieurbano.com.br/portfolio/paisagismo-hospital-m-boi-mirim/>. Accessed on: 24 nov. 2024

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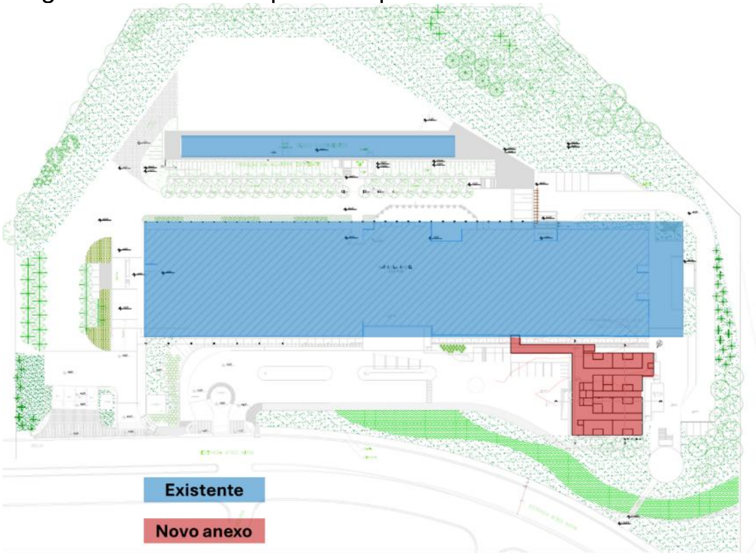
Figure 11 – Situation plan – implementation of the new annex



Source: Hospital 1, adapted by Beltramini

The new annex building has a built area of 1,640m² divided into two floors (ground floor and upper floor) and two walkways that connect with the hospital. In all, it consists of 70 volumetric modules produced in the State of Santa Catarina in three different factories of Gerdau and Tecverde. These ready volumes were transported by vehicles that traveled about 400 kilometers and each vehicle with the capacity to hold up to two modules, so at least 35 transport vehicles (trucks) were needed for the logistics of this *off-site construction*.

It is interesting to point out that the original project has significant differences from the executed project. This can be classified into two types of adjustments: one to meet demand without meeting a technical standard and another because of financial-operational feasibility.

Each floor consists of two inpatient wards with a shared support area. In each wing there are four rooms, originally, three wards of 04 beds and a room of 01 isolation bed. Therefore, in total, according to the plan presented below, the annex building would have an installed capacity for 52 inpatient beds. However, it was executed and inaugurated with 100 inpatient beds.

The first impact observed and experienced at the site because of the implementation of the annex block is in the access to the Hospital's Emergency Room. Previously, this access was facilitated, with the possibility of stopping for boarding/disembarking and minimally close to the entrance on rainy days. The attached block changed this dynamic, conditioning the patient in the emergency room to take a longer turn, on foot, in bad

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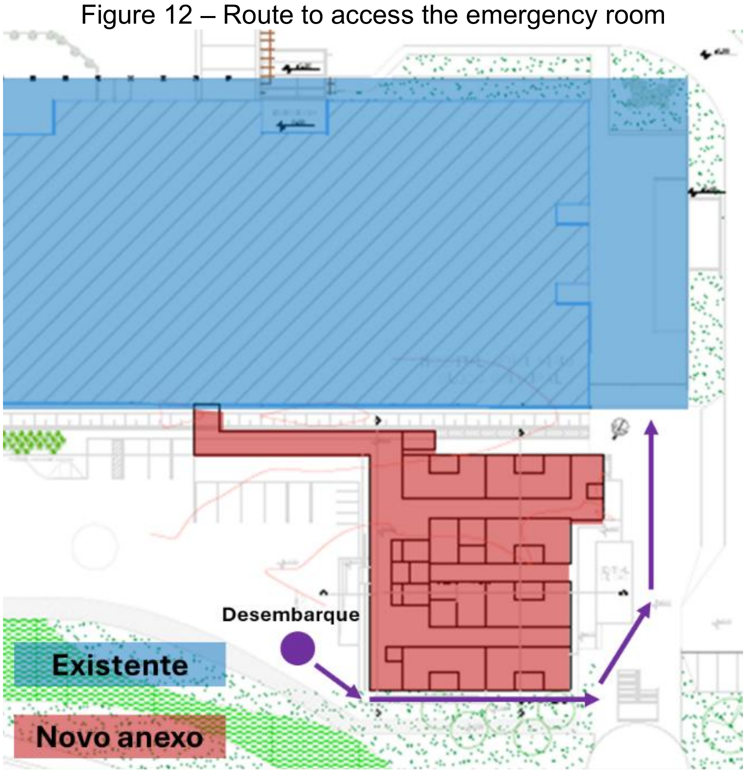
weather and without the possibility of vehicle approach. This has become a daily challenge in the emergency room routine.

Figure 12 – Route to access the emergency room



Source: Hospital 1, adapted by Beltramini

The flow of patients who use the annex block comes from inside the hospital with the entire access interface exclusively through the walkways that connect the two blocks. Doors that look like patient entrances are just escape routes in the event of a fire. In the previous figure, the flow drawn in purple represents the patient who will use the emergency room service, located in the existing block.

Another consequent problem of the implementation of the annex is the exit from the emergency room, also observed during a technical visit. The patient from the emergency room who has been discharged, leaves through the same entrance door, and sometimes some are unable to walk. The simple act of requesting a car by app and meeting the driver at the door is not possible, because vehicles can no longer reach the door of the emergency room. The patient should be taken to the boarding/disembarking area of the emergency room, represented by the purple ball in the previous image.

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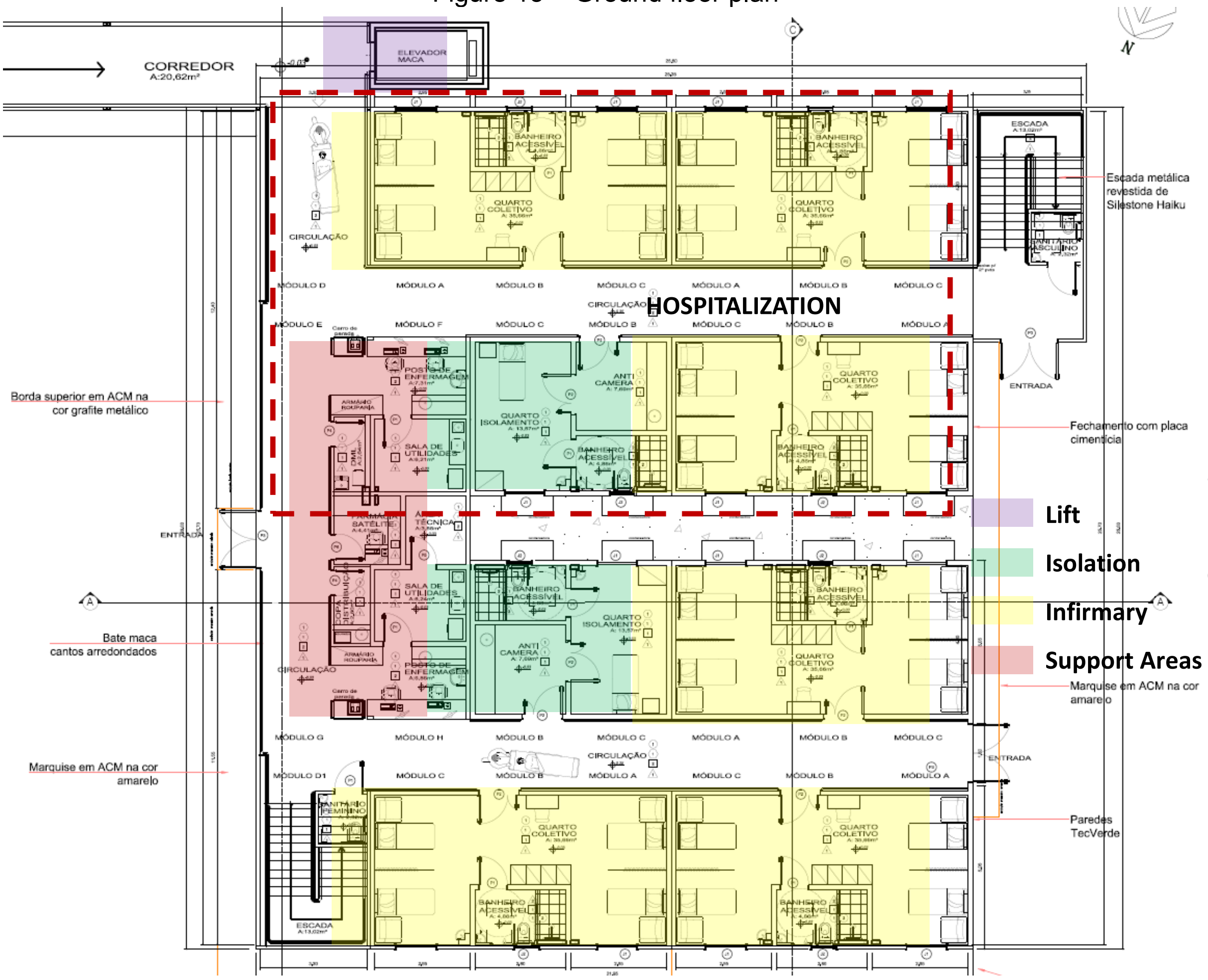
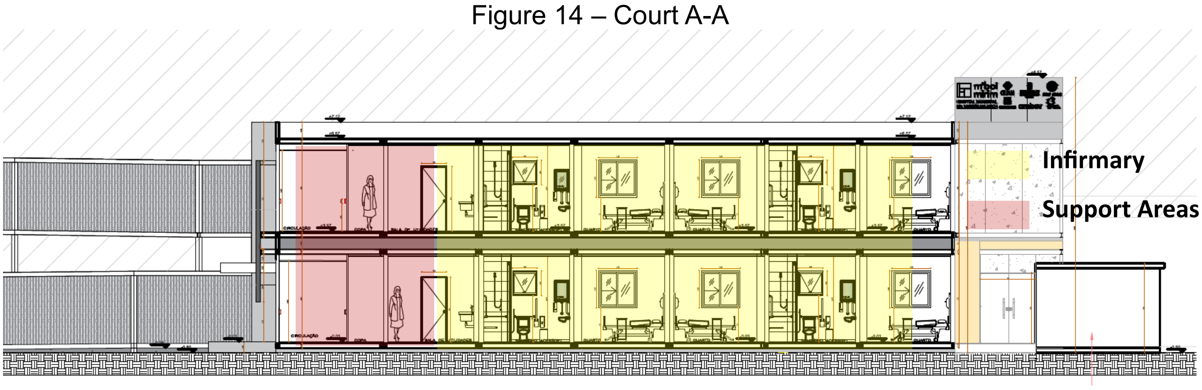
Figure 13 – Ground floor plan



Source: Hospital 1, adapted by Beltramini

The plan of the upper floor practically repeats the plan of the ground floor, only the toilets located near the stairs change position a little.

Figure 14 – Court A-A



Source: Hospital 1, adapted by Beltramini

The references of the support services are the central offices of the existing block of the hospital. Services such as central pharmacy, warehouse, kitchen, laboratory,

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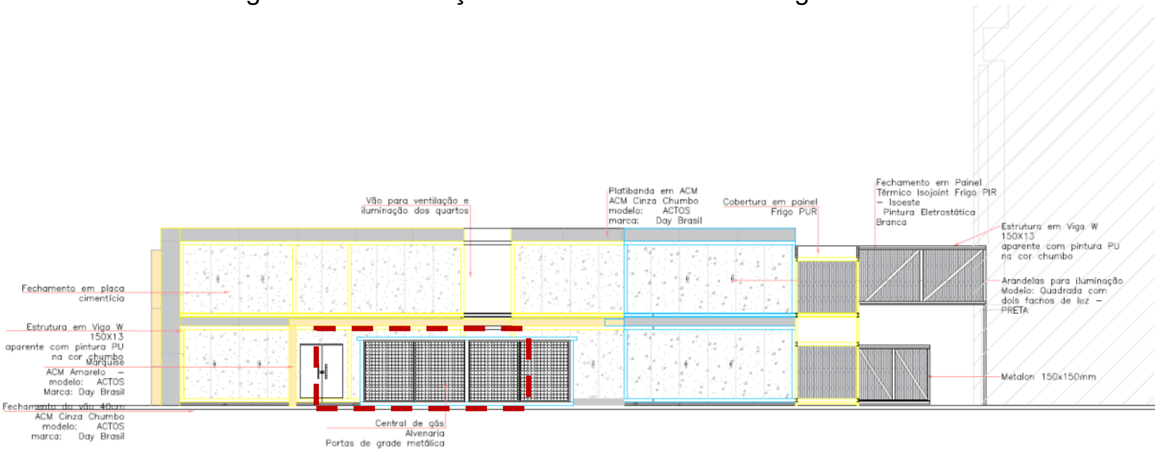
maintenance, clothing processing supply and collect daily in the hospitalization rooms of the annex block. It has an exclusive center for medical gases, which has a compressed air compressor and an oxygen cryogenic tank. The central is positioned at the back of the annex and has a lesson learned verified in a technical visit.

Figure 15 – Rear façade of the annex – medical gas shelter



Source: Hospital 1

During a technical visit to the site, it was found that the medical compressed air compressor, equipment that is located on the outside of the annex (demarcated in the previous drawing), emits a very loud periodic noise every 10 or 15 minutes. Inside the annex block, whether in the corridor or in the hospitalization rooms, this loud noise is perceived by patients and generates discomfort and discomfort, especially during the silence of the night.

In the following plan, represented in Figure 23, it is possible to see the volumetric modules drawn in pink. It can be seen that the dimensioning between the modules has a variation, there are larger and smaller modules, in addition to the specific ones manufactured for the interconnection walkway to Hospital 1. The docking of these modules is done at the place where the annex is deployed. It is estimated that about 80% of the construction is carried out at the factory and the other 20% is done on site (Brasil ao Cubo, 2024a).

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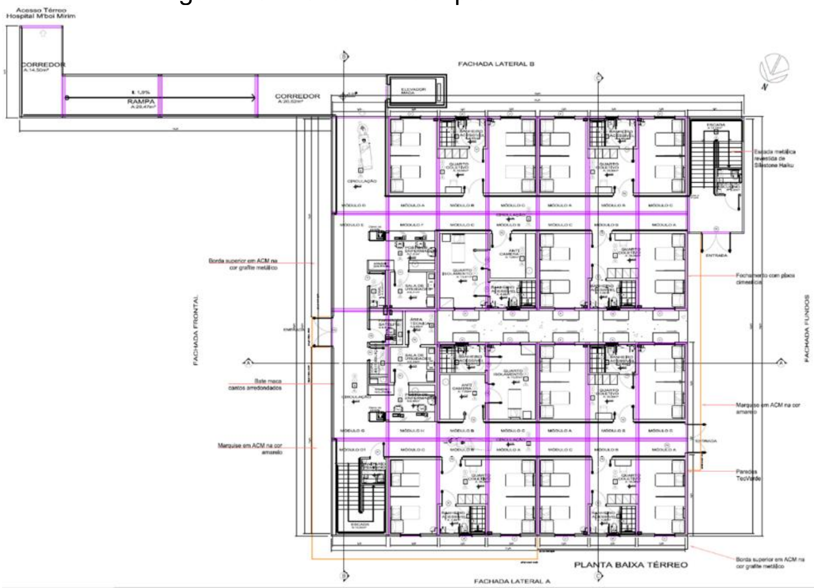
Figure 16 – Ground floor plan of the annex



Source: Hospital 1

It is interesting to observe through the photos of the internal environments, that each module has three beds, unlike the project drawing, which represents two beds. This interferes with compliance with the hospital infrastructure standard, RDC 50 of 2002, in relation to the parameters of lateral distance between bed and wall. This has not been met in practice.

Figure 17 – Nurse photo of 06 leitos (26/05/2023)

Source: Beltramini

Each floor has two inpatient wards, each consisting of three rooms of 06 beds and 01 room of 04 beds. The rooms of 06 beds are made up of three modules: two modules with 03 beds each and one module with the bathroom. Originally in the implementation, there was a seventh bed in the room, to care for Covid-19 cases at the beginning of the

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pandemic. However, it was quickly removed due to the risks of its positioning and exceeding the maximum number of beds per room recommended by the RDC 50/02 standard.

The finishes and coatings are simple. In general, vinyl blanket applied to the floor, white acrylic paint on the walls and removable lining. Wet areas also have vinyl blanket on the floor and acrylic paint on the walls, even if the recommended ceramic finish is recommended. The ceramic was installed only on the floors and walls of the bathroom stalls.

Figure 18 – Photo of the bedroom bathroom (05/26/2023)

Source: Beltramini

Figure 19 – Bedroom photo

Source: Municipal Health Department[9]

In the technical visit made to the site, some differences between the project and the execution could be observed. The main one was in relation to the number of beds per

[9] Available at < https://capital.sp.gov.br/web/saude/w/noticias/296791>. Accessed on: 25 jan. 2025

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room, as already presented. Another important change was that in the project there was an isolation bed, mandatory as a rule for every 30 inpatient beds. None of the rooms in the annex were characterized or built as isolation beds.

Pathologies were also observed from the coupling of the modules in the center of the corridors. One of them had a large crack in the floor, signaled to avoid accidents. Another observation is that if we compare the photos of the inauguration of the building and the photos of the day of the technical visit, we will notice a reduction in illuminance in the environments. Not justified by digital image processing, as technical visits were made regularly between 2020 and 2024.

Figure 20 – Photo of the corridor (05/26/2023)

Source: Beltramini

CONSTRUCTION PROCESS

The volumetric modules were built in Santa Catarina and Paraná, the execution and assembly process was divided into three stages: assembly of the metal chassis used for floor and ceiling, assembly of the wall panels with completion of the modules and coupling on site.

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Figure 21 – Base of the module at the factory – metal floor chassis

Source: Brasil ao Cubo, 2022b

The manufacture of the components and modules was carried out in three manufacturing parks located in Santa Catarina and Paraná, in the cities of Tubarão, Araucária and Curitiba. Two sites owned by Brasil ao Cubo and one site owned by Tecverde. The structure of the chassis and module is in steel and the composition of the wall panels is in the *wood* frame system in composition with isothermal panels.

The first stage was carried out in Tubarão, with the assembly of chassis of 70 volumetric modules, that is, about 140 chassis mounted on a metal structure with a high quality and control production line.

Figure 22 – Brasil ao Cubo factory in Tubarão/SC – chassis assembly

Source: Brasil ao Cubo, 2022b

The composition of the floor chassis is different from the composition of the roof chassis, each with its own functional and structural requirements. The following perspective was reproduced by the author from a partial drawing of Brasil ao Cubo (2022b). The drawing is schematic for understanding, this assembly of the module was done in the stage of assembling the walls.

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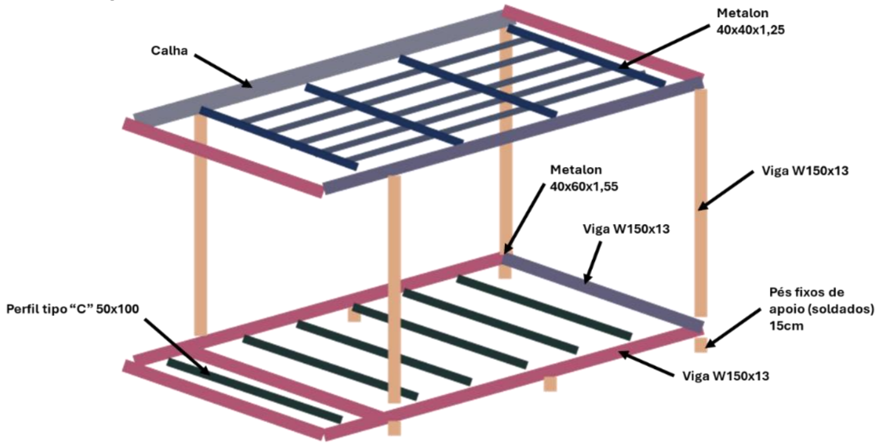
Figure 23 – Volumetric scheme of the module steel structure



Source: Beltramini – reproduction from Brasil ao Cubo, 2022b

The walls of the modules were manufactured in an automated yard in Curitiba, with a production line process for cutting frames (windows and doors). After the assembly of the panels, the modules were assembled in a third factory in Araucária, with the junction of the chassis and panels, which gives rise to the volumetric modules. This composition of the modules can be considered a separate stage, placed between stages 2 and 3, classified by Brasil ao Cubo (2022b).

Figure 24 – Tecverde factory in Curitiba/PR – assembly of the wall panels

Source: Brasil ao Cubo, 2022b

Before receiving and docking the modules (step 3), the site had to be prepared first. A shallow foundation, radier, was made to receive the manufactured modules. All transit logistics in the region were adapted for the stopping of trucks and unloading of modules. In all, 35 trucks were mobilized, asynchronously.

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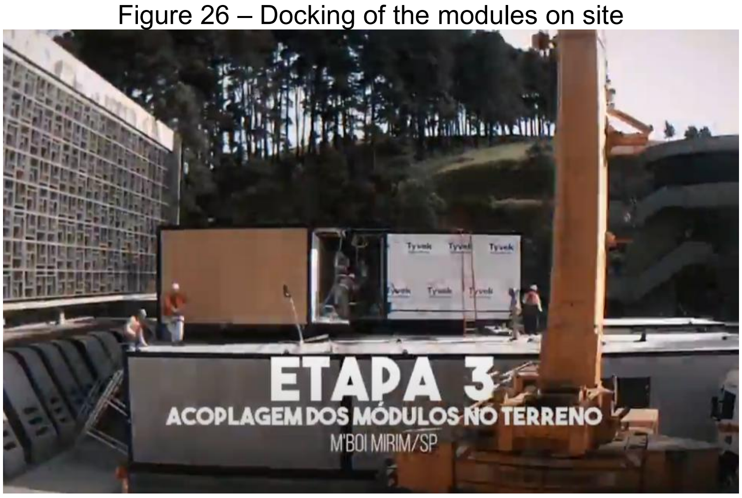
Figure 25 – Preparation of a shallow structure (radier) to receive the modules (04/02/2020)

Source: Beltramini, panel photographed at the site on 10/21/2020

The modules were transported by trucks (two modules per vehicle) to the site of implementation, a distance of just over 400 kilometers. Step 3 consists of coupling the modules at the construction site of the annex.

Figure 26 – Docking of the modules on site



Source: Brasil ao Cubo, 2022b

The coupling is done in a short period of time, compared to a conventional work. The entire manufacturing and docking process was done in 34 days. The modules began to arrive at the site 12 days after the start of production of the modules in the factory. On the 34th day, the annex was equipped and inaugurated, through the effort and commitment of the companies involved in the construction and operation.

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Figure 27 – Coupling of the modules (04/05/2020)

Source: Beltramini, panel photographed at the site on 10/21/2020

FINAL CONSIDERATIONS

It is pertinent to remember that this case study was a pioneer in uniting the technique of modular volumetric construction with hospital architecture. Much needs to be developed and studied. These final considerations are conclusive in the scenario of this research, in the present time. Other academic research, work and market developments will follow that will certainly improve the construction technique, its relationship with the project and the hospital space built itself.

During the development of the research, some analyses and observations were made that we will summarize below, along with the conclusions regarding the theme of modular volumetric construction and its application in hospital architecture and engineering, based on the case study presented.

We return to the results of Guimarães and Rosa (2022), who pointed out as lessons learned by the companies involved, citing the following points for improvement:

- Access to the roof;
- Positioning of the gas plant;
- Waits at the foundation;
- Docking details;
- Logistic order of delivery and coupling of modules according to degree of complexity.

In addition to the points mentioned, from the design point of view, we highlight and reinforce these themes of attention, considering the study of the materials and the technical visit carried out:

- Non-compliance with the RDC 50/02 standard in relation to lateral clearance between beds and walls;
- Use of MDF in the finishing of walls in the corridors to the floor. This material is not recommended on baseboards or heights that may be subject to washing;
- The project does not include a specific distribution pantry for the unit. It is shared with a pantry inside the Hospital;
- Acoustics allows patients to hear the noises generated in the medical gas shelter, especially those emitted by the medical compressed air compressor;
- Air conditioning equipment without adequate filtration for inpatient wards;
- Excessive prolongation of the flow of access to the Hospital's emergency room. The implementation of the annex made it difficult to access the emergency room, however this does not depend on the construction technique;
- The project provides for isolation rooms, but they were not built.

Still in relation to the design process, no positive points, or advantages, exclusive to the construction technique that can improve the design stages were identified. However, it is an advantage of this technique to have modular structuring in the design, especially because it is a hospital project. Perhaps an exclusive advantage may be the possibility of building a dedicated module for factory testing.

From the point of view of construction technique, we highlight other topics of attention verified in the analysis of materials and in the visit to the site. They are:

- The corridors presented pathologies in the coupling joints of the modules after one year of use and occupation of the annex;
- At the beginning of the operation, the hospital's maintenance team was highly dependent on the companies involved in the construction for correction and prevention of construction and installation failures;
- A weak point of this technique is the acoustic and thermal comfort, according to some materials studied. If they are not well observed and treated during design and execution, the building will have chronic pathologies in this sense. The case study presents this problem in acoustic comfort.

The main advantage of modular volumetric construction is the execution time, a record among engineering construction techniques. The market has some resistance to the adoption of this type of construction, as the cost is higher than conventional constructions. It is known that the published investment for the construction of the annex of the case study was ten million reais and that its built area is 1,200 square meters. Therefore, we have an average cost of R$ 8,333.33/m².

For the market that intends to adopt the modular volumetric construction technique, it is not enough to compare construction prices per square meter. It is essential to carry out a feasibility study considering the construction deadlines, the costs per square meter and apply a billing forecast during the months of anticipation of the deadline of modular volumetric construction in relation to conventional construction.

The construction company Brasil ao Cubo designed and executed hospitals and hospital annexes in some states during and after the Covid-19 pandemic. For this research, the authors maintained technical contact with an engineer from the company, whose name we will not disclose in this research. In September 2024, he announced that the company had closed activities for projects and custom works, including hospital ones. The company would be investing and launching residential and hotel models.

ACKNOWLEDGMENTS

The present work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) – Financing Code 001. The authors thank CAPES for their support in the author's master's research and in the publication of this article.

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REFERENCES

1. Aguilar, A. R. D., et al. (2022). Alternativas modulares na construção civil e sua influência sobre a racionalização da obra. Revista Multidisciplinar do Nordeste Mineiro, 10. Available at: https://revista.unipacto.com.br/index.php/multidisciplinar/article/view/1175. Accessed on: September 27, 2023.

2. Andrade, D. P. de, Rosário, R. A. R. D. do, & Fernandes, R. B. (2021). Arquitetura emergencial: considerações sobre respostas projetuais à pandemia da Covid-19. Revista Projetar Projeto e Percepção do Ambiente, 6(2). Available at: https://periodicos.ufrn.br/revprojetar/article/view/23090. Accessed on: September 27, 2023.

3. ANVISA. (2002). Resolução da Diretoria Colegiada nº 50, de 21 de fevereiro de 2002. Dispõe sobre o Regulamento Técnico para planejamento, programação, elaboração e avaliação de projetos físicos de estabelecimentos assistenciais de saúde. Diário Oficial da República Federativa do Brasil. Brasília, March 20, 2002.

4. Bicalho, F. de C. (2010). A arquitetura e a engenharia no controle de infecções. Rio de Janeiro: Editora Rio Books.

5. Bittencourt, F., & Costeira, E. (2014). Arquitetura e engenharia hospitalar. Rio de Janeiro: Editora Rio Books.

6. Brasil ao Cubo. (2020, July 23). A construção modular mais rápida do Brasil – Brasil ao Cubo. YouTube. Available at: https://www.youtube.com/watch?v=UKVJmTaGu3E&t=196s. Accessed on: December 8, 2024.

7. Brasil ao Cubo. (2022, May 15). 100 leitos em 33 dias – Hospital Modular Off-site – Brasil ao Cubo. YouTube. Available at: https://www.youtube.com/watch?v=Pxu-N2I4mPs&t=449s. Accessed on: November 3, 2024.

8. Brasil ao Cubo. (2022, August 23). Hospital M'Boi Mirim – Entregue em 33 dias. YouTube. Available at: https://www.youtube.com/watch?v=71GGi8jDuVY. Accessed on: November 3, 2024.

9. Brasil ao Cubo. (2022, November 8). Soluções Construtivas Ágeis. YouTube. Available at: https://www.youtube.com/watch?v=_ShNM3bGp3Q. Accessed on: November 3, 2024.

10. Brasil ao Cubo. (2022, December 2). A inovação por trás da construção modular – Parte 01. YouTube. Available at: https://www.youtube.com/watch?v=DFhIIR1kRQo&t=2s. Accessed on: November 3, 2024.

11. Brasil ao Cubo. (2023, February 15). A inovação por trás da construção modular – Parte 02. YouTube. Available at: https://www.youtube.com/watch?v=iwxe7zwMZ0M&t=493s. Accessed on: November 3, 2024.

12. Brasil ao Cubo. (2023, March 15). A inovação por trás da construção modular – Parte 03. YouTube. Available at: https://www.youtube.com/watch?v=4ki6m5uW7_A. Accessed on: November 3, 2024.

13. Brasil ao Cubo. (2023). Portfólio Hospitalar. Available at: https://brasilaocubo.com/segmento/hospitalar-9. Accessed on: September 1, 2024.

14. Bruna, P. J. V. (2002). Arquitetura, industrialização e desenvolvimento. São Paulo: Perspectiva.

15. Coelho, G. M. (2020). Arquitetura e industrialização: A influência da filosofia "lean" nos processos de gestão da construção. (Master's thesis). Universidade Presbiteriana Mackenzie.

16. Dutra, J., & Vuolo, A. S. (2021). Industrialização na construção civil: Estudo de caso para construções modulares voltadas para edificações emergenciais. (Bachelor's thesis). Universidade do Sul de Santa Catarina.

17. Fifield, L. J., et al. (2018). Hospital wards and modular construction: Summertime overheating and energy efficiency. Building and Environment, 141, 28-44. Available at: https://www.sciencedirect.com/science/article/pii/S0360132318303081. Accessed on: September 27, 2023.

18. Guimarães, T. de C., & Santos, B. S. M. (2022). Metodologias ágeis na construção civil: Estudo de caso da construção volumétrica modular aplicada no Hospital M'Boi Mirim em São Paulo. Brazilian Journal of Development, 8(1), 2207-2225. Available at: https://ojs.brazilianjournals.com.br/ojs/index.php/BRJD/article/view/42463. Accessed on: September 27, 2023.

19. Herbert, G. (1984). The dream of the factory-made house: Walter Gropius and Konrad Wachsmann. The Massachusetts Institute of Technology.

20. Hairstans, R. (2014). Building offsite: An introduction. Edinburgh: Napier University.

21. Healtharq. (2013). Edição nº 07, Ano 03. Ribeirão Preto: Grupo Mídia.

22. Hoover, S., & Snyder, J. (2023). A new era for modular design and construction. FMI. Available at: https://www.arataumodular.com/app/biblioteca/. Accessed on: November 20, 2023.

23. Horta, B. de A. (2021). Construção modular tridimensional: Pré-fabricação, tecnologia, trabalho, obsolescência e arquitetura. (Master's thesis). Universidade Federal de Ouro Preto.

24. Imperiale, A. (2012). An American Wartime Dream: The Packaged House of Konrad Wachsmann and Walter Gropius. ACSA Fall Conference. Available at: https://www.acsa-arch.org/proceedings/Fall%20Conference%20Proceedings/ACSA.FALL.12/ACSA.FALL.12.8.pdf. Accessed on: August 18, 2024.

25. Ísbilen, E. (2022). The unbearable lightness of an Open System: the Packaged House 1941-47. FOOTPRINT. Available at: https://ojs.brazilianjournals.com.br/ojs/index.php/BRJD/article/view/42463. Accessed on: August 18, 2024.

26. Karman, J. (2011). Manutenção e segurança hospitalar preditivas. São Paulo: Estação Liberdade: IPH.

27. Krug, D., & Miles, J. (2013). Offsite construction: Sustainability characteristics. London: Buildoffsite. Available at: https://www.arataumodular.com/app/biblioteca/. Accessed on: November 20, 2023.

Revista ARACÊ
ISSN: 2358-2472

28. Lawson, M., Ogden, R., & Goodier, C. (2014). Design in modular construction. London: CRC Press.

29. Meirelles, C. R. M., et al. (2023). A gestão da construção civil por meio de inovações tecnológicas. Seven Editora. Available at: https://sevenpublicacoes.com.br/editora/article/view/1425. Accessed on: October 19, 2024.

30. Oliveira, G. de S., & Vale, C. M. do. (2018). Estratégias de flexibilidade na construção pré-fabricada. Cadernos de Arquitetura e Urbanismo, 25(37), 2nd semester. Available at: https://periodicos.pucminas.br/index.php/Arquiteturaeurbanismo/article/download/20433/14930. Accessed on: October 20, 2024.

31. RCDI+S. (2023). REDE CONSTRUÇÃO DIGITAL, INDUSTRIALIZADA E SUSTENTÁVEL et al. Industrialização e Construção Off-site (Vol. 1). São Paulo: CTE. Available at: https://www.arataumodular.com/app/biblioteca/. Accessed on: November 20, 2023.

32. Rollo, J. (1801). A short account of the Royal Artillery Hospital at Woolwich: With some observations on the management of artillery soldiers, respecting the preservation of health. London: J. Mawman, Poultry. Available at: https://books.google.com.br/books?id=lXpbAAAAQAAJ&ots=r4j4KX0rtL&dq=john%20rollo&lr&pg=PA1#v=onepage&q=john%20rollo&f=false. Accessed on: August 18, 2024.

33. Rosso, T. (1980). Racionalização da construção. São Paulo: FAUUSP.

34. Santos, M., & Bursztyn, I. (2004). Saúde e arquitetura: Caminhos para a humanização dos ambientes hospitalares. Rio de Janeiro: Editora Senac Rio.

35. Smith, R. E. (2010). Prefab architecture: A guide to modular design and construction. Hoboken: John Wiley & Sons, Inc.

36. Smith, R. E., & Quale, J. D. (2017). Offsite architecture: Constructing the future. London: Routledge.

37. Valério, T. V. (2017). Pré-fabricação em arquitetura: Projeto de sistema construtivo modular a partir da interação arquiteto/ambiente produtivo. (Master's thesis). Universidade Federal de Ouro Preto.

38. Wallance, D. (2021). The future of modular architecture. London: Routledge.

39. Yin, R. K. (1999). Enhancing the quality of case studies in health services research. HSR Health Services Research, 1209-1224.

40. Yin, R. K. (2009). Case study research: Design and methods (5th ed.). Thousand Oaks: SAGE Publications. (Applied Social Research Methods, Vol. 5).