UNIVERSITAT DE BARCELONA

Final Degree Project

Biomedical Engineering Degree

“Comparative study of operating room infrastructures and installations“

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Abstract

This report presents a comprehensive comparative study on the Operating Rooms (OR) infrastructures and installations in various hospitals in Catalonia. By examining four prominent institutions, this study aims to unravel the diverse approaches and unique considerations involved in OR facilities design and construction.

Through documentary review, site visits, and data collection, the author explores the similarities and differences among these hospitals, shedding light on the impact of factors such as hospital context, funding sources, and specialization on OR design. The findings highlight that while there are commonalities aligned with prevailing trends and standards, significant differences exist, primarily influenced by the hospital's specific contexts.

The conclusions drawn from the study, provide valuable insights for future OR design and construction projects, enabling hospitals to optimize resources and enhance patient care within their distinctive environments.

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Glossary of abbreviations

AGSS	Anesthetic Gas Scavenger System
HC	Hospital Clínic i Provincial de Barcelona
HGTP	Hospital Germans Trias i Pujol
HSJD	Hospital Sant Joan de Déu
HUB	Hospital Universitari Bellvitge
HVAC	Heating, Ventilating and Air Conditioning
ICS	Institut Català de la Salut
OR	Operating Room
LAS	Laminar Airflow System
SL	Surgical Light
WBS	Work Breakdown Structure

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1 INTRODUCTION

1.1 Motivation and justification

The healthcare industry is growing by leaps and bounds with advancements in technology, patient care practices and interventional techniques. A great example of this growth is Operating Rooms (ORs), which are continuously evolving and being adapted to the new equipment, technologies and procedures that emerge. As a result, there is a growing need to assess and update OR infrastructures and installation to ensure they meet the current and future requirements of surgical teams, patients, and regulatory standards.

Therefore, the present project is born out of the need to discover and analyze the actual approaches in OR designing and construction in different hospitals in Catalonia. This project is performed as the final degree project of the bachelor's degree in Biomedical Engineering in the University of Barcelona. During the first semester of the fourth curse of the degree, the author visited different surgical areas of the Hospital Clínic de Barcelona. During this experience, and thanks to the visits carried out by different professionals from the hospital, the author came away with the need to further study OR facilities, including the new trends and state of the art of the field. Moreover, the big amount of highly reputed hospitals in Catalonia, motivated the author to undertake this journey through the different Surgical Areas of some of the main hospitals in the region.

The project described in this paper, which is being carried out with the assistance of the Hospital Clinic's department of Infrastructures and Biomedical Engineering, includes the input and participation of various healthcare experts, including clinicians as well as engineers. The study presents a thorough examination of the current OR infrastructures and installations in some of the major hospitals in Catalonia with the goal of finding relevant and meaningful differences and promoting the development of current healthcare facilities.

1.2 Project Goals

The main objective of this project is to compare the infrastructures and installations of the newest Operating Rooms (OR) of different hospitals in Catalonia, specifically in the province of Barcelona. As a result, the analysis pretends to provide a comprehensive understanding of the different approaches to the design and construction of ORs and how different variables and aspects related to its infrastructures and installations are addressed. The study will be divided into two parts. The first part will be related to the information gathering, including the visits to the hospitals, the previous online and paper research and the obtention of the necessary documentation. To achieve this, the following minor objectives related to the process have to be fulfilled:

- Make previous research on papers and documentation.

- Identify the most relevant variables related to ORs infrastructures.

- Contact with the major reference hospitals in the CCAA of Catalonia.

- Get access to the Surgical Blocks and to the latest ORs of each hospital.

- Compile documentation, such as project memories and blueprints of the ORs

The second part will be the analysis of the information gathered in the first part of the study. This comprehends the comparison of the obtained information, as well as the discussion of the results obtained. As a result, the final analysis pretends to:

- Identify commonalities and differences in the infrastructures and facilities of ORs in different hospitals in Catalonia.
- Identify the factors that lead to the differences between hospitals.
- Understand the differences and argument it considering the context of each hospital and the theoretical point of view.
- Explain the patrons followed by the hospitals from a theoretical and practical point of view
- Assess quality of infrastructure and facilities in the ORs studied.
- Identify best practices and potential areas for improvement.
- Generate recommendations for improving the OR infrastructures and installations

Overall, the author aims to understand and describe the differences in the facilities and equipment of ORs in hospitals in Catalonia, evaluating the benefits and drawbacks of different approaches, and generating recommendations for hospitals to optimize their approaches.

1.3 Project Scope and Limitations

Establishing the boundaries of the project is essential for the definition and preparation of the project itself. The project scope refers to the specific goals, deliverables, tasks, and resources that are included in the project, while project limitations, refer to the constraints or restrictions that may impact the project, such as budget, time, resources, technology, among other factors. In this section the scopes and limitations of the project will be clearly and explicitly defined to ensure that the project is achievable, feasible and can be completed within the given constraints.

The actions that comprise the present project include the study of the operating theaters infrastructures from four different hospitals and the post analysis of the obtained information and variables.

The present project is conceived in Catalonia, more specifically in the province of Barcelona and within the Catalan health public system. Due to time and accessibility limitations, the study is only focused on four public Catalan centers: Hospital Sant Joan de Déu (HSJD), Hospital Clínic i Provincial de Barcelona (HC), Hospital Universitari Bellvitge (HB) and Hospital Germans Trias i Pujol (HGTP).

The project will primarily focus on infrastructure variables and characteristics of the installation of the Operating Room, such as dimensions, materials of the construction, illumination, gasses, electrical installation, audiovisual installation, HVAC, etc. The medical equipment of the ORs, except from the operating table and the lamps, will be excluded from the analysis.

It is important to remark that the study will be limited to a merely theoretical categorical and numerical comparison, excluding statistics and other data analysis. However, in the future, if more data from other hospitals is collected a more complete data analysis can be effectuated.

The project has several limitations that should be taken into consideration. Firstly, the project is limited to the comparison of the infrastructure and facilities of operating rooms in hospitals in Catalonia only. The findings of this study may not be applicable to hospitals in other regions or countries. Secondly, the project is limited to the variables and aspects of the infrastructure and facilities of ORs only. Other factors such as personnel or waste flows, and equipment are beyond the scope of this study.

Furthermore, the study relies on data obtained from hospital repositories or directly from ORs, which are subject to restricted accessibility. Therefore, it is important to acknowledge that the project's scope may be constrained by the availability and reliability of data supplied by hospitals, which can impact the accuracy and comprehensiveness of the conducted comparisons. This, together with the time limitation, implies only being able to focus on a limited number of hospitals and ORs.

Since technology in this field is moving forward very quickly, the infrastructures of OR significantly depend on the date of construction. Consequently, we will only consider those OR that have been built within the previous 10 years from the realization of the study. Notwithstanding that general surgery OR are preferred to perform the study, the specialty of the OR will not be a limitation since the study is focused on the installations and the infrastructures and not in the equipment. If ORs from different specialties are studied, the differences related to the specialty will be discussed.

Below is presented a detailed list of the aspects covered by the study:

- Study, market analysis and state of the art of operating theaters
- Design of the study and variables to assess
- Analysis and comparison of the variables between different hospitals
- Discussion of the results by arguing the differences and similarities

The TFG excludes:

- Study on fully private Hospitals or Healthcare centers
- Hospitals out of the region of Catalonia
- The study of ORs older than 10 years
- Statistical or data analysis of the obtained variables

1.4 Structure of the project

The project will be developed in three main parts. Firstly, the research and theoretical study on the topic, followed by the visits to the hospitals and obtention of the necessary data, and finally the analysis and final discussion of the results obtained.

Section 2 of the following document details the main concepts surrounding OR infrastructures, installations, and equipment, as well as the state of the technology in most recent ORs, and the research and evolution involving this technology. Moreover, a market analysis is developed in section 3, where the specific market and its characteristics and future trends are described, as well as the main companies dominating the design, construction, and installation of ORs in Catalonia.

Section 4 explains in more detail the methodology used during this study with its main stages. It is important to note, that the present study differs from the main engineering projects where a conception and detailed engineering are developed. On the contrary, as the study have a comparative character, a results and discussion section have been included. In the results (section 5), the data from the different hospitals is displayed and compared, finding the relevant similarities and differences. In the following section, the discussion, the results are analyzed, and meaningful conclusions and relations are extracted.

To organize the different stages and activities needed to accomplish the objectives of the project a Work Breakdown Structure (WBS) and a GANTT diagram have been designed in section 7.

Finally, an analysis of the legislation and regulation surrounding the OR facilities has also been carried out in section 11.

2 BACKGROUND

2.1 General Concepts

This section presents the theoretical background necessary for a global understanding of the project's more technical aspects. Therefore, a brief look into the evolution of ORs and the basis of its infrastructures, installations and equipment are exposed. This theoretical framework enables laying the foundations to support achieving the project's objectives and help interpreting the results.

2.1.1 Operating Rooms Evolution

Operating Rooms (ORs), also known as operating theatres or operating suites, are sterile facilities within a hospital, where surgeries are performed. These sterile environments are designed to provide a safe and controlled space for surgical procedures, allowing surgeons to operate on patients without the risk of infection.

In this subsection, we will explore the history and evolution of operating theaters, tracing their development from the earliest known surgical procedures to the most advanced, technology-driven operating rooms of today.

The concept of surgery has existed since ancient times, with early examples of surgical procedures dating back to as early as 3000 BCE in ancient Egypt. These early procedures were performed in unsterilized environments with limited anesthetics and were often crude and painful. In antiquity and the Middle Ages there was no place specially reserved for surgical operations. The Greeks and Romans also performed surgical procedures, but the practice was largely abandoned during the Middle Ages due to religious beliefs and superstitions. [1], [2]

The Renaissance saw a renewed interest in medicine and surgical procedures, and the first dedicated surgical theater was built in Padua, Italy in the late 16th century. Amputations and other surgeries on live patients began taking place in front of a live audience by the early 19th century. As shown in *Figure 1* surgical theaters were based on anatomical theaters, where bodies were dissected to illustrate and teach anatomy. The design of the hospital ORs intended to accommodate large audiences who could observe surgical procedures. [3]

Figure 1 Ernst von Bergmann operating in an amphitheater. Painting by F. Skarbina, 1906.

As surgical procedures became more complex and the need for sterility became better understood, dedicated operating theaters began to emerge in hospitals in the middle 19th century. These early ORs were often small, cramped spaces with poor ventilation and lighting, and the risk of infection was high. Surgeons and staff would often wear street clothes and surgical masks were not yet in use.

In 1884, the German surgeon Gustav Neuber designed and built the first aseptic operating theater where the walls, floors, shelves, and other surfaces were all washable, and all instruments had flat surfaces and were sterilized. Staff underwent a pre-surgical ritual of washing their hands, arms and faces with antiseptic mercuric chloride. By the end of the century sterile gloves, masks and gowns were added to the ritual of preparing to perform surgery in the operating theater. Within the many surgical instruments, the operating table underwent improvements. There were models with a central pillar and wheeled legs, such as the Morton table from Pennsylvania (1887), the Trendelenburg table (1890), and the J. Pean table (1892). Tables were manufactured with the capability to change the patient's position using handles, levers, wheels, and pedals with hydraulic mechanisms. The patient could be positioned in supine, lateral, or prone positions, with the head lowered (Trendelenburg position, 1890), elevated torso (Fowler position), and seated position (De Martel, 1913). [4], [5]

In the early 20th century, the development of antiseptics and anesthesia greatly improved the safety and success rates of surgical procedures. The introduction of Laminar Airflow Systems (LAS), which allowed for the circulation of clean, filtered air in the operating room, also greatly reduced the risk of infection. To illuminate the operating field, electric lighting replaced gas lighting, which was incompatible with anesthesia by inhalation of volatile substances. Several types of lamps were manufactured, and, in some branches, light bulbs were used for small work fields. By the mid-20th century, operating theaters had become more sophisticated, with specialized equipment and dedicated teams of surgical staff.[2]

Nowadays, modern ORs are highly specialized environments designed to maximize patient safety and surgical outcomes. They have cutting-edge monitoring and imaging technologies in addition to specialized tools for a variety of surgical operations. Robotics and other advanced technologies are being used more frequently in operating rooms as well, enabling minimally invasive operations with lower risks and quicker recovery times.

2.2 Operating Room infrastructures

The physical structure of an OR has as its main objective to provide a safe and efficient environment for the patient and the healthcare personnel, with the purpose of performing the surgery in the best possible conditions. Therefore, the establishment and functioning of an OR require meticulous planning and execution. This collective endeavor is driven by the requirements, preferences, and safety considerations of the medical and surgical team. In this section, different aspects regarding the construction are going to be addressed from the materials of the walls, flooring and ceiling to the dimensions and architectural designs of the OR.

2.2.1 Dimensions

The dimensions used in ORs play a crucial role in ensuring the safety and comfort of both patients and surgical teams, allowing the performance of any type of surgical procedure. Thus, ORs need to be large enough to accommodate the patients, staff, and medical equipment, as well as enough room for circulation and movement.

The ideal recommended dimensions for an OR are between 35 and 60 square meters. Less than $35m^2$ is too small for the equipment and the comfort of the staff, whereas larger than $60m^2$ is too large as the equipment installed on the walls would be too far away from the operating area. The ceiling height should be between 2.70 and 3.30 meters and should allow the installation of all machinery on the ceiling for comfort. Corridors are recommended not to be less than 2.85m width for easy movement of professionals, stretcher, and machines.[6]

2.2.2 Materials

To maximize infection prevention, the materials used to build and cover the infrastructures of ORs must meet certain minimum requirements.

The walls and ceilings should be made of hard, non-porous, waterproof, and washable materials. They should be free of cracks, continuous, smooth, and non-reflective as well as stain-proof and fire-resistant. In addition, it will be avoided to select materials with tiring colors to the eye, and it will be preferred the choice of colors that provide a greater contrast with blood and other tissues so that surfaces can be easily cleaned. There should be no rails or elements that can accumulate dirt, and wall-mounted fixtures should be flush with the surface.

The floor will be anti-static, conductive, and connected to the grounding system to dissipate the electricity from the equipment and personnel and prevent the accumulation of electrostatic charges. Moreover, they must be made of flat materials, non-porous, impermeable, unalterable, hard, and resistant. At plinth level, corners should be rounded to facilitate cleaning, and avoid the deposition of germens.[6]

Some common materials used in the construction of operating theaters include:

- Stainless Steel: Surgical-grade stainless steel is often used for surfaces, walls, and cabinets due to its non-porous nature, resistance to corrosion, and ease of cleaning. Laminar Flow Panels, for example are commonly made up of this material or aluminum.
- Homogeneous sheet Flooring: Specialized seamless flooring materials, such as epoxy or vinyl, are used in operating theaters. These materials offer a slick, non-slip surface that is simple to keep up. They can withstand both chemical exposure and microbial development.
- Glass: Glass is used in operating theaters for windows and observation panels and can also be used for the walls covering. It is a non-porous material which offers a higher resistance to scratching, chemical, UV radiation, and heat compared with other common materials. It also offers a higher design flexibility allowing for customized decorative patterns such as printed panels.
- PVC Wall Cladding: PVC wall cladding is a common choice for covering walls in operating theaters. It is hygienic, resistant to moisture, and easy to clean.
- Anti-microbial and anti-fungi paint: Anti-microbial and fungi paints with low VOC (volatile organic compound) content are used on walls and ceilings to prevent the growth of bacteria and other microorganisms and maintain a sterile environment. This can be combined with materials such as gypsum board, commonly named as Pladur.
- Acoustic Ceiling Tiles: Sound-absorbing ceiling tiles help to reduce noise levels in the operating theater, creating a more comfortable environment for the surgical team.

2.2.3 Doors

Regarding to the entrances to the operating rooms four necessary elements can be underlined: hygiene, airtightness, functionality, and safety. OR doors must by airtightness to avoid external contamination. For this reason, nowadays the main type of doors used in this kind of facilities are hermetically sealed automatic doors, which provide a strong seal against dust and other harmful airborne elements, minimizing their movement and the transmission of particles, virus pathogenic bacteria and other contaminants, which keep operating rooms perfectly insulated [7], [8]. These spaces have controlled humidity levels and temperature and require special conditions to ensure that the air is free from pathogenic bacteria, dust mites and dust. Rooms like these are subject to a higher pressure than that found outside, which prevents contaminated air from entering from the outside when the door is opened. Doors can be made of a wide range of materials, however the last models installed in the Catalan Hospitals are manufactured by Manusa and are made of materials such as stainless-steel, High-Pressure Laminate, glass, or Aluminum [9]. Furthermore, doors can be sliding, swing or lead-lined, to accomplish the different necessities from each surgical area.

On the other side, the door opening system is also very important in an OR as it must be fast, safety and the most hygienic as possible. There are different door opening systems, but the two stablished opening systems are push buttons or contactless systems. Push buttons are simple buttons that activate the door when they are pressed. These buttons are designed with a specific shape and size that allows them to be pushed with the forearm or elbow, reducing the need to use the hands, which are the main carriers of bacteria. On the contrary, touchless switches, equipped with movement sensors, allow the user to open door without the need for physical contact, which makes the system easier and safer in terms of contamination.

Finally, new systems are being applied to the operating room doors. A project done by Manusa in the ophthalmology surgical block in the Hospital Clinic is an example (*Figure 2*) [10]. The hermetic automatic doors installed in this work include in their top part a color light system that indicates whether the OR is in use, empty or being cleaned. This and further advancements are examples that technology, even in simple systems such as doors, is still evolving. [10]

Figure 2. Operating Room Door in the ophthalmology surgical block in Hospital Clinic by Manusa

2.2.4 Pendants

OR pendants are overhead support systems that are installed above the surgical area. These pendant systems typically consist of movable arms or columns suspended from the ceiling, which are designed to hold and organize various medical equipment and utility services required during surgical procedures (*Figure 3*). Pendant systems allow relocation of the equipment within a certain area defined by the size and construction of the pendant. They ensure efficient use of space to provide staff with a method of transporting required medical services to the patient quickly and effectively, allowing for easy access to equipment and supplies without obstructing the workflow.

The pendant system of the surgical lights (SL) is composed of a horizontal arm, a spring arm, a spindle, and a yoke. The connection between the ceiling and the whole system is provided by the spindle, while the arms are connected by rotational joints that offer two degrees of freedom in the horizontal plane. On the other side, the spring arm provide one degree of freedom in the vertical plane and balances the weight of the light. The yoke provides two or three rotational degrees of freedom to the light, depending on the type. Overall, SL can be adjusted over five or six degrees of freedom over a large working range, constrained by the dimensions of the pendants.[11]

Figure 3 Surgical Pendant

The state-of-the-art ORs usually contain at least three pendants, one for the anesthetic equipment, another for the medical equipment such as the electrosurgical unit, and a third one for the SLs. Monitors can be attached to these pendants, as well as other pendants can be attached to the ceiling. Apart from its medical equipment pendants are equipped with a variety of attachments, such as shelves, trays, electrical outlets, gas outlets, data ports, and medical gas outlets. [12]

By providing a centralized and flexible support system, pendants contribute to improved ergonomics, efficiency, and organization in the operating theater. They help create a safe and sterile environment by minimizing the need for equipment to be placed on the floor or on movable carts, reducing the risk of contamination.

2.3 Operating Room Installations

2.3.1 Environmental illumination

Environmental lighting systems in ORs are of utmost importance as they establish a secure and productive work environment for surgical teams. Effective illumination mitigates the inherent environmental, operational, and visual challenges associated with surgery. Efficacious surgical illumination combines enough ambient light with the ability to apply focused light at specific operative stages and angles. To avoid vision adaption problems when changing the line of sight between the operating field - where levels of 100,000 lux can be reached - and the surrounding area, the illuminance must reach a minimum of 2,000 lux in the vicinity of the operating table, while the general illumination of the room may not be less than 1,000 lux. [13], [14]

To ensure optimal conditions, the spectrum provided by lighting tubes should closely resemble daylight, with an emission temperature ranging from 4000 to 5000 K. It is advisable for the décor in the OR to have a neutral and uniform color. Regarding intensity, general illumination should reach levels of up to 325 lumens per square meter (lm/m^2) within the OR. It is essential for the lighting to be diffuse, minimizing the presence of glare that could impede visibility and cause discomfort for the anesthetist and surgical team.[15]

RGB technology is being introduced in the sector of OR environmental illumination and is growing considerably. RGB LED technology allows more visual comfort, lighting performance and significant savings in energy and maintenance. They can be used to enhance color differentiation during surgical procedures or to adjust the color white to a purer white. By adjusting the color balance and intensity the surgeons can improve the visibility and contrast of certain tissues or structures. For example, specific colors can help to distinguish blood vessels or tumors from surrounding tissue. On the other hand, the use of customized color temperatures, intensities and tonalities can contribute to the visual comfort, as well as can have a psychological impact on both patients and medical staff [16], [17] [18].

2.3.2 Medical Gasses

The utilization of medical gases has expanded significantly, encompassing a wide range of clinical applications. The design, installation and operation of medical gas pipeline systems plays a crucial role in patients' safety, as it must be operational round the clock, with the least downtime and its failure can be fatal. These systems must accomplish a large list of standards from the source of the gas to the final delivery point at the OR. [19]

The medical gases commonly used in operating rooms are oxygen, nitrous oxide, medical air, and sometimes nitrogen and carbon dioxide. Apart from these gases, although technically they are not considered a gas, vacuum pipelines and Anesthetic Gas Scavenger Systems (AGSS) are also used for suction and for waste anesthetic gas disposal, respectively. [20] In *Figure 4* we can see a schematic table displaying the color codes from the different medical gases in both US and ISO standards. Note that within the mark of this project the standards followed will be the ISO. [21]

Gas	U.S. Color Code	ISO Color Code
Carbon Dioxide	Grey	Grey
$He-O_2$	Brown & Green	Brown & White
Instrument Air	Red (USA Only)	
Medical Air	Yellow	Black & White
Nitrogen	Black	Black
Nitrous Oxide	Blue	Blue
O_2-He	Green & Brown	White & Brown
Oxygen	Green	White
Vacuum (Suction)	White	Yellow
WAGD (Evac)	Purple	Purple

Figure 4 Medical Gases Color codes from US and ISO standards

Consequently, in Figure 5 we can see the outlets, with its respective colors, of the main used gases in Operating rooms, Nitrous Oxide, medical Air, Vacuum, Oxygen and Carbon Dioxide, from left to right.

Figure 5 Gas Outlets according to the ISO Color Code

Oxygen

Oxygen is the most crucial medical gas and is used for respiratory support. It is administered to patients who have difficulty breathing or require supplemental oxygen. It is a component of anesthesia administration as it is combined with other anesthetic agents to deliver a precise and controlled mixture of gases during general anesthesia. It is also crucial for mechanical ventilation used during most of the surgeries to support the patient breathing. Additionally, it is employed in laparoscopic procedures to compensate the injected carbon dioxide and maintain the patient's oxygen saturation levels within the desired range. [20], [22], [23]

Medical Air

Medical air is obtained by compressing purified and filtered atmospheric air or a mixture of oxygen and nitrogen in proportions of 21% and 79% respectively. It is primarily used for respiratory support and powering medical devices like ventilators and nebulizers. But can also be utilized in anesthesia equipment as a transport element to atomize water, administered to the respiratory tract and as a propellant for surgical equipment. Medical air is clean and free from contaminants, ensuring patient safety during inhalation therapies. According to the ISO standards medical air outlets in Catalonia are labeled with the color black and white. [20], [22]

Vacuum
Vacuum is simply a depression of atmospheric air. Nowadays, as it is part of centralized medical gas installations, it is considered as such. The pressure may vary throughout the installation, but is generally around -75 kPa, which stands for -450 mmHg. Vacuum systems are mainly used as surgical suction systems to remove blood, bodily fluids, and other materials from the surgical site during procedures, maintaining, thus, a clear and visible surgical field. It is also used to remove the smoke provoked in the surgical area during the use of electrocautery or laser devices [20], [22]. According to the ISO standards medical air outlets in Catalonia are labeled with yellow.

Anesthetic Gas Scavenger System
Anesthetic Gas Scavenging System (AGSS) are commonly employed in hospitals to collect gas or aerosolized medication that is exhaled by the patient or released from the patient's vicinity. Its primary purpose is to gather waste gases, including anesthesia, ensuring they are not inhaled by healthcare personnel. [24]

Specifically in the Operating Room, the AGSS is utilized to collect and eliminate waste gases generated from the patient breathing circuit and the patient ventilation circuit. Adherence to legal requirements in most jurisdictions necessitates the implementation of waste gas scavenging systems to maintain the concentration of waste gases within the Operating Room below the legally acceptable limit [25]. According to the ISO standards AGSS outlets in Catalonia are labeled with color purple. Note that in Catalonia these systems are also called EGA which stands for *Evacuació de Gasos Anestesics*.

Nitrous Oxide
Nitrous Oxide is combined with oxygen (21% of oxygen by volume) and used as an inhalable analgesic and anesthetic agent. It is administered to patients to provide pain relief and reduce anxiety during certain surgical procedures. It is characterized by having an excellent pharmacokinetics, a low toxicity and low physiological alterations referred to heart rate, blood pressure and respiratory rate [26]. According to the ISO standards Nitrous Oxide outlets in Catalonia are labeled with blue.

Carbon Dioxide
Carbon dioxide gas is mainly used in laparoscopies to provide insufflation during this type of surgeries. It is commonly used to create a pneumoperitoneum, where the abdomen is inflated with carbon dioxide to create a working space for the surgeon [27]. According to the ISO standards carbon dioxide outlets in Catalonia are labeled with color grey.

Nitrogen
Nitrogen gas is not typically used for direct patient care but is employed for other purposes in healthcare facilities. It is commonly used for cryopreservation of biological samples, in laboratory settings, or for powering pneumatic systems.[22] According to the ISO standards carbon dioxide outlets in Catalonia are labeled with color black.

2.3.3 Heating Ventilation and air-conditioning

Heating, ventilation, and air-conditioning (HVAC) systems in ORs have the complex task of fulfilling multiple, potentially conflicting objectives. They must ensure the comfort and safety of patients, minimize the circulation of various chemical and biological pollutants, and create a comfortable environment for the surgical team. To achieve these goals, ventilation systems in ORs are designed to enable independent control of temperature, humidity, ventilation rates, and the removal of waste anesthetic gases and other pollutants.[28], [29]

ORs can employ two types of airflow patterns: conventional diffuser systems and laminar diffuser systems. Laminar Airflow Systems (LAS) are the main used nowadays. LAS theoretically offer benefits in reducing surgical site infections; however, their optimal airflow pattern can easily be disrupted by factors such as fixtures, overhead lights, personnel movements, and drafts from equipment like forced air warmers, opening, and closing of doors, and staff traffic.[30]

Alongside air-filtering devices are used to reduce air contaminants such bacteria, dust, and electrocautery smoke. The suggested filtering system for special care areas like operating rooms comprises of two filter beds connected in series. The efficiency of the first filter bed is 30% whereas the efficiency of the second filter bed is 90%. Together, they have a 99.7% total efficiency in the removal of airborne particles with a size of 0.3 m or bigger.[30]

Standard requirements

In healthcare facilities, ventilation and air conditioning must comply with a series of specific requirements inherent to their functions and considering the susceptibility of patients. In addition to maintaining the environmental climate, one specific task of the air conditioning system installation is the reduction of the concentration of contaminants, such as microorganisms, dust, narcotic gases, disinfectants, odorous substances, or other substances present in the environment. [31]There are different specific standards applicable to the design, control, and maintenance of air conditioning systems in healthcare facilities. Regarding the standards applicable to operating rooms, it is worth mentioning the UNE-100713:2005 standard on air conditioning installations in hospitals, UNE-EN ISO 14644 on cleanrooms and associated controlled environments, CDC Criteria, as well as general recommendations for the prevention of surgical infections, drafted and promoted by the competent labor authority of the different autonomous communities where the healthcare facility is located.

Due to the high demands for environmental quality required by the type of work carried out in operating rooms, they receive a differentiated treatment based on their specific utilization characteristics.

Based on the UNE-EN ISO 14644-1:2000 standard, ventilation can be unidirectional or turbulent flow, and the number of external air injections must be equal to or greater than 20 air renewals per hour. In class A operating rooms, both unidirectional and turbulent systems are allowed, although the unidirectional system is recommended. In this case, air recirculation is allowed, which must be from the same operating room and treated in the same way as the outside air. A minimum of 35 movements/h is recommended. In class B and C operating rooms the turbulent regime is allowed and in the case of class B operating rooms the air movements should be 20 per hour, being 100% outside air. In class C operating rooms, the air movements must be equal to or greater than 15 per hour and with 100% outside air.

The UNE 100713:2005 standard indicates that a minimum external air flow of 1200 m3/h must be supplied. This standard also indicates that for operating rooms with high demands regarding germs, it is necessary to supply a minimum of 2400 m3/h when they are equipped with an air mixing diffusion system, with a minimum of 20 movements per hour.

Figure 6 summarizes the ventilation flow rates, as well as the thermo-hygrometric overpressure conditions and filter types according to operating room class.

Tipo de quirófano	Caudal mínimo de aire impulsado	Movimientos/hora (MH)	Temperatura Humedad	Presión	Filtros
Clase A	2400 m^3/hora 1200 m^3/hora (aire exterior)	Mínimo 30	18ºC-26ºC 45- 55 % de humedad	+ 20 Pa a + 25Pa	F5/F9/H14
Clase B		Mínimo 20	22ºC-26ºC 45- 55 % de humedad		F5/F9/H13
Clase C	1200 m^3/hora (aire exterior)	Mínimo 15			

Figure 6 Ventilation flow, hourly air movements, temperatures, pressure, and filters suitable for operating rooms.

2.3.4 Electrical installation

Reliable and uninterrupted power supply is essential to ensure the safety and effectiveness of surgical procedures. Since certain medical equipment cannot tolerate any interruptions, ORs are equipped with Uninterruptible Power Supply (UPS) systems which provide backup power in case of an electrical grid failure or power interruption. Typically, UPS systems are powered by backup generators located at ground or lowest levels. These generators are alimented by gasoline or other fuels and can provide energy during long periods of time until the failure is solutioned. [32]

According to the ITC-BT-38, ORs in Spain must accomplish with the following electrical requirements to ensure safety of both patients and the medical staff. [33]

The OR's electrical installation shall have a three-phase supply with neutral and protective conductor. Both the neutral and the protective conductor shall be copper conductors, insulated type, throughout the installation.

All accessible metallic parts must be connected to the equipotential bonding busbar by means of independent insulated copper conductors. The green-yellow marking should be used for equipotential bonding and protection conductors (*Figure 7*). The potential difference between the accessible metal parts and the equipotential bonding busbar must not exceed 10mV.

Figure 7 Equipotential Bonding in OR

It is mandatory the use of isolation or circuit isolation transformers, at least one for each operating room, to increase the reliability of the power supply to that equipment where an interruption of the supply may endanger the patient, or the staff involved. The transformer itself and the circuits fed by it, will be adequately protected against overcurrent. There must be a control and protection panel for each OR, located outside the same, easily accessible and in its immediate vicinity. This panel shall include the overcurrent protection, the isolation transformer, and the insulation level monitoring device. In addition, high sensitivity (<30mA) and class A differential protection devices will be used for the individual protection of those equipment that are not fed through an isolation transformer. [32]

In summary, a well-crafted electrical system that guarantees protection in an OR should have the following elements: [34]

- Ground connections
- Batteries and isolation transformers
- Hospital earth panels and electrical outlets
- For surgical lamps, an emergency supply unit is required
- IT power systems, to detect electrical grounding failures and locate them easily and quickly
- Isolation monitor, for continuous monitoring of the isolation resistance of IT medical systems
- UPS systems, allowing emergency power supply of specific charges

2.3.5 Technology Integration

Operating rooms (ORs) are highly intricate environments, encompassing a multitude of technological equipment and installations. On one hand, the continuous progression of technology has led to an increase in the number of devices specifically designed to address various surgical challenges. Thus, modern ORs are often replete with stand-alone devices, add-on systems, and monitors, each possessing its own interface or hardware for data display. This diverse array of devices includes monitors, surgical cameras, audio systems, video conferencing systems, as well as an assortment of medical equipment such as microscopes and endoscopes, all of which generate audiovisual data.[35]

Consequently, the integration of information technology (IT) plays a vital role in contemporary ORs, facilitating the consolidation of pertinent data required for procedures onto a unified platform. This integration encompasses a wide range of video and hardware sources, including endoscopes, microscopes, image acquisition equipment, operating room cameras, robotic devices, and navigators. Through a centralized control platform, medical images, software content, and videos can be efficiently routed, displayed, transmitted, recorded, and processed. These sources are displayed on a primary screen and can be seamlessly directed to any screen within the operating room as needed.[36], [37]

Finally, one of the essential objectives of digital operating rooms is to facilitate, simplify, and consolidate the massive flow of data to save time for both the surgeon and the surgical and IT team of the hospital. These systems enable comprehensive data management, allowing for easy data storage, instant availability of patient data, centralized data management, among others.

2.4 Operating Room Equipment

2.4.1 Surgical lights

Surgical lights (SL), also known as operating room lights or surgical lamps, are essential components of any operating room as they provide optimal illumination and visibility during surgical procedures. A surgical lighting system basically consists of a large, heavy luminaire suspended from the wall or ceiling by a two-arm pendant system. The pendant systems are designed to allow great flexibility in positioning of the luminaire and to stabilize the position of the luminaire in a certain position, avoiding non desired movement of the lamp and allowing a wide range of different positions around the patient [14], [38]. In *Figure 8* it is shown a surgical light with its pendant system.

The luminaire must be designed such that high-intensity light is supplied to the wound while minimizing shadows of heads and hands of the surgical team.

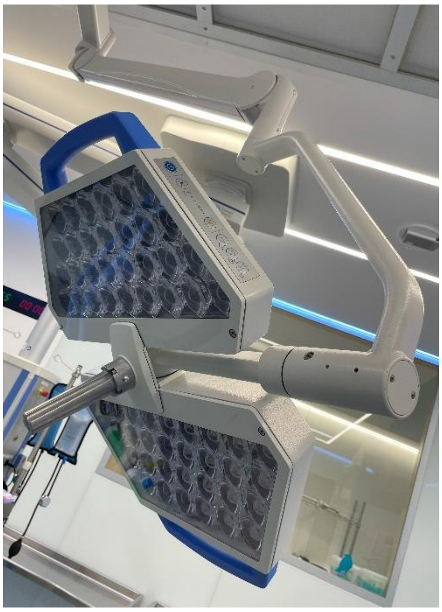

Figure 8 Surgical light from HSJD OR

On the other hand, there are also floor-standing SLs which are not installed on the ceiling of the operating room. This type of lamp is auxiliary and usually have only one light bulb offering, thus, less illuminance or illumination level. The characteristics of this type of lamp usually depend on the manufacturer and the specific model but they do not usually differ much. Normally, they offer a halogen power of 3x50W and an electrical connection of 230/240V at 50Hz. Surgical floor lamps therefore require a power connection.[13]

Nowadays, the most common SL systems are the pendant systems as they provide more maneuverability, and they are more hygienic as they do not have to be placed in the ground and moved from one place to another.

2.4.2 Operating Table

The operating table, also called surgical table, is one of the indispensable tools in the OR as it is the place on which the patient lies during the surgery. It is generally placed at the center of the OR on the operating field. The usage of an operating table will be determined by its specifications and design. The goal of a surgical table is to keep the patient immobile while the surgical team performs its work. [39]

Operating tables can be either stationary or mobile to move room to room. In stationary operating tables the column is firmly anchored to the floor. Stationary tables may have built-in features or attachments to facilitate the integration of surgical equipment, such as imaging systems.

Operating tables are equipped with various mechanisms to allow for precise adjustments. These include height adjustment to accommodate different surgical positions and operating team heights, as well as length adjustment to accommodate patients of varying sizes. Additionally, they can be tilted in multiple directions to facilitate specific surgical requirements. This includes lateral tilt, which allows the patient to be positioned on their side, as well as Trendelenburg and reverse Trendelenburg positions, where the patient's head or feet are tilted downwards or upwards, respectively [40].

Figure 9 Mobile operating table from HSJD OR

Another feature that many operating tables offer is radiolucency, allowing X-rays and other imaging technologies to pass through the table without interference.

Finally, additional elements can be attached to the operating table. The flexibility brought by these accessories is very important since it enables the table to be adapted to suit the relevant patient or the surgical discipline providing access to the surgical site. These may include headrests, arm boards, leg holders, and body supports.[40]

2.5 State of The Art

During the last few years, surgical activity has undergone changes derived from technological innovations applied to surgery that point to minimally invasive surgery, image-guided procedures, robotic surgery, and tele-surgery continue to replace traditional surgical procedures. The OR of the future expands or augments its reality, away from the pure building characteristics, towards an intelligent and communicative space platform.

Integration of the ORs has been one of the major developments in the field. In the context of an operating room, “integration” refers to functionally connecting the OR environment. This includes patient information, audio, video, SL, and environmental lights, building automation (HVAC), and medical equipment. When integrated, all technology can be manipulated from a central command console by one operator. [41]

Besides, one of the main trends in the design of OR is the incorporation in the market of Hybrid Operating Rooms (HORs) which combine interventional radiology departments, minimally invasive surgery, simultaneous usage of endoscopic and laparoscopic techniques, and the application of various intraoperative imaging systems. HORs are equipped with advanced technologies, including computer-assisted navigation systems, electronic medical records, and high-definition imaging equipment such as fixed C-Arms, X-ray computed tomography (CT) scanners or magnetic resonance imaging (MRI) scanners. [20] HORs are larger than common ORs as not only the imaging system requires some additional space, but they must be prepared for a team of 8 to 20 people. Depending on the imaging system chosen, a room size of approximately 70 square meters including a control room is recommended. The room must also be prepared with a 2-3 mm lead shielding and potentially enforcement of the floor or ceiling to hold the extra weight of the imaging system which can go from 650kg to 1800 kg approximately. [42]

On the other hand, modular operating room construction (MOR) is a relatively new concept that aims at improving architectural and engineering design as well as ergonomics of the occupied space. Various marketed advantages of MORs include increased functionality, sterility and cleanliness, comfort, safety, flexibility, durability, and aesthetics. Aspects such as ease of maintenance and renovation and the possibility of making swift modifications and upgrades to existing utilities are also emphasized. This ORs are constructed using prefabricated modules, which can be quickly assembled on-site to create a fully functional OR. [43]

Talking about surgical lighting, advanced lighting systems are being developed. State-of-the-art surgical lighting systems provide optimal illumination with features such as adjustable intensity, color temperature, and shadow reduction. Smart lighting systems can help to reduce eye strain and fatigue for surgical staff while improving visibility and reducing the risk of errors. [13]

Infection control is a critical aspect of operating theater infrastructure and installations. New technologies are being developed that can help to reduce the risk of infection, such as antimicrobial coatings on surfaces, ultraviolet light disinfection systems, and advanced air filtration systems. New cleanroom designs use advanced materials, coatings, and airflow systems to reduce the risk of airborne and surface contamination.[41]

Subsequently, OR are being designed with ergonomic principles in mind to improve the comfort and safety of surgical staff. OR are designed with careful consideration of layout, workflow, and infection control measures. The physical layout ensures adequate space for equipment, surgical teams, and patient movement, while adhering to principles of asepsis and minimizing the risk of contamination.

Finally, in some Hospitals, printed panels are being introduced. The aim of implementing printed panels in the OR walls is to improve the experience of the surgical staff and the patient by providing a more familiar and comfortable environment

All in all, the state of the art in the infrastructures and installations of operating rooms is continuously evolving, driven by advancements in technology, research, and best practices. These advancements aim to optimize surgical environments, improve patient outcomes, and enhance the overall surgical experience.

3 MARKET ANALYSIS

In this section, a market analysis has been carried out. Through this analysis the main characteristics of the specific market, as well as the current trends and future perspectives are described. Moreover, it has been included a list with the main companies dominating the market, outlying their main projects regarding to healthcare facilities.

3.1 Analysis of the demand: the need of new Operating Rooms

The project is situated within the sector of designing and constructing operating rooms (ORs), which encompasses the complete installation of OR facilities. The primary end-users in this market segment are primarily hospitals and healthcare facilities that conduct surgical procedures. However, our market niche may also include other stakeholders such as government entities and private institutions.

Because of the aging population, the increasing demand for healthcare services, and the growing prevalence of chronic diseases, the number of surgical procedures performed in Hospitals has substantially risen in the last decades. According to the Statistics Institute of Catalonia, during the year 2017 more than 1 million surgical procedures were performed in Catalonia, from which 781317 were performed in public healthcare centers. [44]

Simultaneously, advancements in medical technology, particularly in areas such as minimally invasive surgery and robotic surgery, are having a huge impact on the market. This, together with the increasing complexity of advanced surgeries, has forced many hospitals to invest in technological developments in operating rooms equipment, installations, and infrastructures. [45]

This market is mainly dominated by companies that offer the services of designing and constructing the ORs. However other types of companies also participate in this market as product or materials suppliers. Healthcare companies dedicated to the production and manufacture of surgical lights or operating tables, are an example of this secondary companies [46].

Finally, although hospitals are the major end-users of operating theater construction, owing to the increasing number of surgeries performed in hospitals, the ambulatory surgical centers segment is also expected to grow in the coming years due to the rising trend of same-day surgeries.

3.2 State of the Situation

Spain has a modern healthcare system, and its operating theaters are generally well-equipped and meet high standards of safety and quality. The country has made significant investments in healthcare infrastructure and has been actively upgrading its operating theaters in recent years.

In Spain, operating theaters are subject to strict regulations and guidelines regarding hygiene, sterilization, and the use of medical equipment. The National Healthcare System in Spain is responsible for overseeing the quality and safety of the country's healthcare system the including its operating theatres. However, it is characterized by a high degree of management decentralization. The system is organized at three levels, the first being the Ministry of Health, followed by the organization of the Autonomous Communities, which is in turn divided into health areas [47]. Health care competencies have been transferred to the Autonomous Communities, so that differences in public spending are uneven.

The CatSalut is the Catalan Healthcare System, which guarantees the provision of public health care, which is structured in several lines of care [48]. One of these lines of care is the specialized acute hospital care, which is provided through the hospital network and, thus, includes the Operating Theatres management [49]. Catalan hospitals use a range of advanced technologies and techniques, including minimally invasive surgery, digital imaging, and robotic-assisted surgery. The use of such technologies has helped to reduce surgical complications, shorten recovery times, and improve patient outcomes.

Catalan OR construction market is driven by several factors, including the increasing demand for healthcare services, the aging population, and the growing prevalence of chronic diseases. [50] Additionally, the Catalan government's initiatives to improve healthcare infrastructure and facilities are also contributing to the growth of the market. Particularly, the government has made a commitment to investing in healthcare infrastructure and it has identified the modernization of existing hospitals and the construction of new facilities as a priority area. It is also noted that the private sector is playing an increasingly important role in the market, with private hospitals investing in new facilities and equipment to meet the growing demand for healthcare services. This is expected to lead to the development of more private healthcare facilities, which could create opportunities for companies in the construction sector.

On the other side, like in many other countries, Spain's healthcare system and, thus the Catalan system faces challenges such as funding constraints and staff shortages, which can impact the quality and efficiency of healthcare services. Additionally, in recent years the COVID-19 pandemic has put an unprecedented strain on healthcare systems globally, including Catalonia, and has affected the functioning of operating theaters due to the need for additional infection control measures and the prioritization of COVID-19 patients [51]. However, most of the hospitals have recovered well from this situation.

3.3 Public hospital purchasing and contracting system

In this section we will review the system that public hospitals use to purchase new equipment or to, for example, contract an architecture company to construct their ORs. As public institutions, they are obliged to comply with a series of regulations that guarantee the free occurrence and transparency of their processes.

In the case of the provision of medical equipment or the contracting of a service by a public hospital, hospital consortium or research center, the procedure for carrying it out must be regulated by the State Procurement Act (Directive 2004/18/EC). [52]

In order to set out the needs required by the public entity, in this case, a hospital or a research center a hospital or a research center, a Technical Specifications Sheet is drawn up. A Technical Specifications Document formulated in the medical field establishes the conditions under which the performance of the supply and installation of medical equipment and/or the contracting of a maintenance service and technical support service for the equipment of a hospital must be developed. In addition, a document with a scale of charges is also provided. This scale is the one that will be used as a guide in the scoring and decision of the product.

With the Technical Specifications Document and the Scale document, the companies competing for the required product or service become aware of this need, and therefore, they can formulate their offer and compete to sell their product or service.

Once the competing companies have presented their offers to the hospital, an evaluation of theses offers through the scale is performed, and one of the companies is selected to provide the product or service.

In the frame of this project, this is the protocol which any public hospital must follow in order to contract an architecture or engineering company to execute a project of construction, renovation or ampliation of the Surgical Area.

Note, that due to the non-public character of Sant Joan de Déu and Hospital Clínic, these are not always obligated to follow the Public Services Contracting Law (LCSP) [53]. They are only obliged to apply it when the requirements established in this law in relation to subsidized contracts are fulfilled, or when so required in the agreements or conventions formalized with subjects of the public sector.

3.4 Main companies in the design and construction of OTs in Spain

In terms of the competitive landscape, this section provides insights into the market share and key strategies of the major players in the market.

Some of the major players in the Spanish market for this sector are depicted in the following subsections. A wide variety of services are offered by these companies, including construction, engineering, facility management, and project management. In addition, there are also several specialized companies in the market that provide materials and equipment for OR construction, such as INDUMEDICA, MEDITECH España, and Medical Supplies and Services, such as ventilation systems, surgical lights, and surgical tables. [54]

Below we have a more detailed list with the main companies in the sector of healthcare facilities design and construction in Catalonia and Spain:

AHEAD PSP

Ahead PSP is a Catalan company based in Barcelona, which has worked in the field of healthcare architecture for more than 20 years by projects such as, new hospital designing, expansion and renovation of existent hospitals and its different areas, and other healthcare facilities. Its performance includes everything from the initial proposals, feasibility studies and analysis of alternatives, to the complete development of projects and construction management, with quality, time, and cost control.[55]

Some of its recent and actual projects are:

- Bloc Quirúrgic d'oftalmologia. Hospital Clínic de Barcelona
- Nou bloc quirúrgic, URPA i UCI. Hospital Clinic
- UCI Hepàtica. Hospital Clinic
- Hemodinàmica Hepàtica. Hospital Clínic
- Pla director del nou Hospital Clínic a l'Av. Diagonal
- Reforma de la Unitat de Cardiologia. Vall d'Hebron
- Unitat d'Hospitalització Pediàtrica. Vall d'Hebron
- Unitat de Neonatologia. Vall d'Hebron
- Nou bloc quirúrgic i UCI. Hospital Vall d'Hebron
- Ampliació i reformes de l'Hospital de Sabadell. Parc Taulí
- Edifici Provença. Hospital Clínic de Barcelona
- Clínica Anglo Americana a Lima, Perú
- Hospital de Sant Joan de Déu de Manresa

CASA SOLO arquitectos SLP

Casa Sólo Arquitectos SLP, is a company created in 2008. It is part of the holding Casa Consultors i Arquitectes SL, established as far as 1987. It follows up the path set up by CASA during the last 25 years, mainly in the field of health care building planning and design, both for private and public sector. They carry out projects of all types, from management plans to project design or construction management. [56]

Some of its recent and actual projects are:

- Reformas Hospital Universitario Mutua de Terrassa, Spain
- Nuevo edificio satélite Hospital Clínic Granollers, Spain
- Hospital Comarcal de l'Alt Penedès Vilafranca del Penedès, Barcelona, Spain
- Concurso nuevo Hospital Infantil HUG, Ginebra, Switzerland
- Nuevo Hospital de Tercer Nivel El Alto Sur El Alto, Bolívia
- Reforma y ampliación Hospital Manuela Solís Quart de Poblet – Mislata, Valencia, Spain
- Reforma y ampliación Complejo Hospitalario Universitario A Coruña Galicia, Spain
- Reforma del Hospital Verge del Toro Maó, Menorca, Spain
- Ampliación Hospital de Sierrallana Cantabria, España
- Concurso nuevo Hospital Materno-Infantil en Tongzhou, China
- Hospital Nostra Senyora de Meritxell Escaldes-Engordany, Andorra
- Nuevo Hospital Universitario Santa Lucía Santa Lucía, Murcia, Spain

Albert Vitaller arquitectura SLP

Albert Vitaller arquitectura SLP, is a company based in Barcelona with more than 20 years in the field of architecture. They develop healthcare architecture projects.[57]

Some of its recent and actual projects are:

- Hospital Sociosanitario y de salud mental, Martorell
- Centro de Salud Mental, Hospital de l'Esperança – BCN
- Reforma de la UCI Neonatales, al HUAV – Lleida
- Servicio de Urgencias y CMA, Granollers
- U.H. Hospital Duran i Reynals – Hospitalet de Llobregat
- Edificio Delta, Hospital de Bellvitge
- Reforma y rehabilitación del Hospital Clínic Barcelona
- Ampliación del Hospital Santa Caterina Salt (Girona)
- Hospital de crónicos, larga estancia y salud mental, Mislata, Valencia
- Nueva clínica Oberig, Kiev
- Reforma del Hospital de Figueres, reforma quiròfans (Girona)
- Reforma de Urgencias i UCIN de Hospital Universitari General Dr. Josep Trueta, Girona
- Ampliación Urgencias Hospital General Universitario de Valencia
- Ampliación del Hospital de Santa Maria, Lleida

Sanabria & PlanasGallego arquitectes SLP

Sanabria & Planas Gallego arquitectes SLP is an architecture studio based in Barcelona since 1980. They are specialized in BIM and LEAN methodology. They are a member of BuildingSmart, an international organization that drives the digital transformation of the construction industry through open standards.[58] They have done several projects related to healthcare facilities which are depicted in the following list:

- Nou Hospital Joan XXIII, Tarragona
- Camerun Hospital, Yaoundé, Camerún
- Hospital d'Olot i Comarcal de la Garrotxa
- Ampliació de L'Hospital Viladecans
- Centre de Salut i Urgències i CMA, Granollers

JG Ingenierios SA

JG Ingenierios SA, is an engineering company based in Barcelona, which provides consulting and engineering services for highly complex building construction. This company develops its activity in four business areas: complete building projects, technical installation engineering, consulting (environmental, operation and maintenance, technological, energy) and digital solutions (Manttest, maintenance software and Iris JG, smart buildings management platform). They have executed over 7100 projects around 48 different countries. JG Ingenieros has participated in the design and supervision of more than 150 hospital projects in Spain and abroad, in which their commitment to efficiency and care in the design of especially sensitive infrastructures in their operation phase has always stood out. [59]

It is a company that works at both sides of infrastructures and installations, with the following recent projects:

- Hospital de Chulucanas Piura | Perú
- Hospital Fremap Barcelona | España
- Nuevo Edificio Wellness Kliniek Barcelona | Spain
- 8 Regional Hospitals in Camerún Ebolowa, Bafoussam, Buea, Garoua, Maroua, Bamenda, Ngoundere, Bertoua | Camerún
- Hospital General Santa Lucía de Cartagena Murcia | Spain
- Clínica Delgado Lima | Perú

Enero Arquitectura SLP

Enero Arquitectura SLP is an architecture, engineering and consultancy study specialized in hospital projects. They are based in Madrid in 2006, counting with more than 15 years of experience and 2000000 m2 of conducted projects. They are leaders in development and construction hospital projects with 340937 m2 constructed in this field, and abording both sides of construction and infrastructures and complec installations. [60]

Some of their recent projects regarding healthcare facilities are:

- Ampliation of the Hospital Universitario Rey Juan Carlos I, Móstoles, Madrid
- Concurso for the Hospital Universitario La Paz, Madrid
- Olympia, medical center for care and health optimization, Madrid
- Hospital Architecture of innovation At Al Ansar Hospital, Arabia Saudita
- Hospital QuirónSalud Valle del Henares, Torrejón de Ardoz, Madrid
- Hospital General Universitario de Collado Villalba, Madrid
- Hospital Universitario QuironSalud Madrid
- Hospital QuirónSalud Córdoba
- Integral Remodeling of the Hospita Universitario Fundación Jiménez Díaz, Madrid
- Integral Remodeling of the Hospital QuirónSalud Ciudad Real

PGI Engineering SL

PGI Engineering SL is a global engineering services company based in Barcelona with 30 years of experience and more than 5000 projects developed. They work in the area of complex installations for all type of buildings and uses and they have a specialized section on hospital centers. They work together with different architect companies to provide a better solution.[61] Below we show a list of their main projects related to this section:

- Operating Rooms reform, Hospital de Figueres, Girona
- Hospital of the National Police of Lima, Perú
- Hospital Center of Sud-Seine Et Marne, Fontainebleau, France
- Hospital Vall d'Hebron Research Institute, Barcelona
- Hospital Sinse, Angola
- El Alto Sur Tertiary Hospital, Bolivia
- New Clinica Girona,

- Al Jahara Hospital, Kuwait
- Hospital Sant Pau, Barcelona
- Hospital del Mar, Barcelona
- Hospital Universitari Sant Joan de Reus
- Hospital Joan XXIII Tarragona
- Extension and Renovation of the Hopital Du Valais, Switzerland

Armengol & Ros Consultors i Associats SLP (ARCbcn)

ARCbcn is a company based on Barcelona which is a leading engineering firm in the field of complex installations. In 2023, they began a process of joining forces with the energy and sustainability consultancy ERF. Nowadays they are offering services from project engineering, to legal, technical, energy or sustainability consulting. In project engineering they design, plan, coordinate and manage all type of projects related with complex installations. [62]Some of their projects around the healthcare field are:

- Renovation of the pediatric hospitalization unit and the Cardiology Unit of Hospital Vall d'Hebron, Barcelona
- Renovation of maternal emergency department, Nuclear Medicine Unit and Radiodiagnosis a rea, ampliation of the heating and cooling plant and reconstruction of the hydraulic system. Hospital Germans Trias I Pujol, Badalona
- Rennovation of the UCI of Hospital Joan XXIII de Tarragona
- Renovation of surgical area and climatic installations in Parc Sanitari Pere Virgili, Barcelona
- Installations of new microbiology and pathological anatomy in Hospital Universitari Bellvitge, Hospitalet.
- Electrical Installations in Clínica Corachan, Barcelona
- Installations and Rehabilitations in Hospital de la Santa Creu I Sant Pau
- UCIs and Operating Theatres installations in Clínica ServiDigest, Barcelona
- Installations of Hospital iCovid Bellvitge, Hospitalet.
- Installations new Hospital de Santa Creu I Sant Pai, Barcelona
- Rennovation of the UCI installations, Hospital Josep Trueta, Girona
- Installations for a new Operating Theatre and esterilization area in the Surgical Block of Hospital Parc Taulí Sabadell

3.5 Evolution and Future Perspectives of the Market

3.5.1 Global

The global operating theater construction market is expected to grow in the coming years. As commented before, this growth is driven by various factors such as the increasing demand for healthcare services, rising awareness about advanced medical technologies, and the aging population. Furthermore, the surge in chronic diseases and the increasing number of surgical procedures also contribute to the growth of this market.

In terms of OR integration, the global operating room integration market size, valued at over USD 1.5 billion in 2021, is expected to exceed USD 4.2 billion by 2030, growing at a compound annual growth rate of 10.96% between 2022 and 2030. Increasing demand for advanced technological applications, rise in the number of medical procedures, patient safety concerns, and growing desire for minimally invasive surgeries are expected to be the key drivers for the growth of the global operating room integration market. [63]

The hospital segment is the largest end-user segment, accounting for most of the market share, due to the increasing number of surgeries performed in hospitals. However, the ambulatory surgical centers segment is expected to witness the highest growth rate during the forecast period, owing to the rising trend of same-day surgeries.

3.5.2 European

Following the steps of the global market the European, and thus the Catalan and Spanish operating room solutions market, comprising surgical lights, surgical tables, and pendants, is primarily a replacement market. Although tightening budgets are hindering market prospects, the need for state-of-the-art operating rooms are creating lucrative growth opportunities. The rising number of surgical procedures is creating an urgent demand for technologically advanced operating room equipment, notes the analyst of this research. The need to ensure enhanced hygiene, infection control and safety is also fueling market growth. [64]

Operating rooms are the revenue generating space for hospitals. As a result, hospitals are seeking state-of-the-art operating theatres that will support optimized performance and efficiency. Safety concerns are at an all-time high, with infection control emerging as a major issue in operating rooms. The rising awareness about the need to minimize human errors and promote the effective management of operating rooms is pushing the uptake of innovative and advanced operating room solutions.

4 METHODOLOGY

4.1 General approach

With the aim to analyze what are the possible factors that differ on the infrastructures and design of OR and which are the common patrons between them, as defined in the project objectives, the structure of the present study is developed as follows. (*Figure 10*)

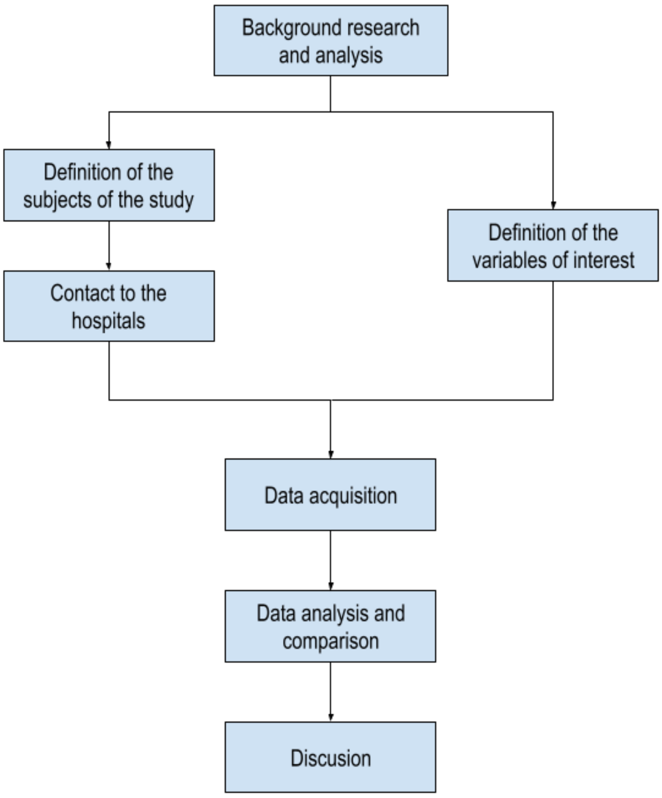

Figure 10 Methodology flux diagram

As it can be seen in *Figure 10*, the methodology followed in this project will start by a theoretical background research and analysis, then the both definition of subjects that will participate in the study and variables that will be analyzed, followed by a phased of contacting all the hospitals and getting access to them, the visits of the Surgical Areas and the data acquisition, and finally a data analysis and comparison and a final discussion of the results obtained.

4.2 Background research and analysis

The first step to follow during the project is to perform a theoretical background research to acquire the necessary knowledge for the realization of this project comprehending and understanding the current trends in the installation and design of OT. During this stage an extensive literature review has been conducted to identify relevant sources of information aiming to obtain a holistic understanding of the subject and collecting data that can be useful for the comparative study of OTs.

Firstly, brief research of past studies that have been carried out within the theoretical framework of the research has been made. The aim is to identify possible similar studies that give us information about possible limitations or approaches to our study.

Secondly, a compilation of information related to the infrastructures, installations and equipment of OR has been done. To gather this information, a wide range of sources have been used. These sources include academic papers, research articles, industry reports, hospital guidelines, regulatory documents, books, and any other material that provide insights into the design, layout, equipment, and infrastructural aspects of OT.

Once the compilation has been completed, the next step consists in selecting the crucial information that is most relevant for the study. This selection process involves an evaluation and identification of the key findings, facts, and data that are directly applicable to the objectives of the research. In the context of this project, crucial information will include details about:

- Variables associated with the infrastructures of the OTs such as, dimensions, materials, layout, and designs.
- Variables associated with the installations of the OTs such as, illumination, Heating, Ventilation and Air Conditioning systems (HVAC), gasses installations and outlets, power supply and audiovisual systems.
- Specifications of equipment and technology used, such as medical imaging devices, operating tables, among others.
- Regulations and standards.
- Other information including general information of OR and surgical procedures, safety and hygiene protocols, future trends, market analysis, etc.

Moreover, there is also a very important part of information compilation and selection related to the Hospitals that will be analyzed in this study, which will be explained in a further section called Subjects of the Study.

4.3 Variables to study

In this stage of the process, having all the information collected in the stage before, the aims of the project, and its limitations, a specific list of all the variables that will be included in the study has been defined. The time limitations and the accessibility limitations have restricted the number of variables to address. Moreover, the measurability of some variables has influenced this variable selection and has been a significant limitation due to the absence of some measuring devices as well as the space and time limitations in the OTs. Note that OTs are continuously operating and must always be prepared for emergencies, therefore variables that require a complex obtaining method, such as some material properties, have been excluded from the study.

Overall, most of the variables selected for the realization of the study have been observable variables, which means any variable that can be extracted without using any measurement device. However, there are some exceptions due to its relevant informative value and its ease of being measured. In *Table 1*, all the variables included in the study with its proper characteristics have been detailed.

Table 1 Variables included in the study

Name of the Variable	Characteristics of the Variable
Medical specialization	Type of OR and medical specializations performed there
Year	Year of construction of the OR (years)
Width	Size between the two closest walls (cm)
Length	Size between the two most separated walls (cm)
Height	Size between floor and ceiling (cm)
W Material	Wall material: type of material or materials used in the walls.
W Color	Type of color used in the walls. It can be more than one.
W Continuousness	Wall Continuousness (Y/N)
W Print Pan	Presence of Wall Printed Panels (Y/N)
W Int Mon	Number of Wall Integrated Monitors
F Material	Type of material used in the flooring. It can be more than one.
F Color	Type of color used in the flooring. It can be more than one.
F Cont.	Flooring Continuousness (Y/N)
Concave joint	Presence of a concave joint between the floor and the wall (Y/N)
C Material	Ceiling Material: type of material or materials used in the ceilings.
C Color	Ceiling Color: type of color or colors used in the ceiling.
C Continuousness	Ceiling Continuousness (Y/N)
Num. Door	Number of Doors
Door Open Sys	Type of Door Opening System. It can be more than one.
Door size	Width and height of the door (cm)
Door Material	Type of material/s used for the door. It can be more than one.
Num. Win	Number of windows
Win Size	Total square meters of the windows. (cm^2)
Num. Pass Box	Number of Pass Boxes
Num. Pendants	Number of pendants
Num. Surg Lamp	Number of Surgical Lamps
Surg Lamp Type	Brand and model of the lamp and technical characteristics. LUXs, depth of field, shade…
Central Illum	Presence of central illumination in the ceiling around the laminar flux and type of illumination (white light, RGB or no presence)
Per. Ceiling Illum	Presence of perimetral illumination in the ceiling and type of illumination (white light, RGB or no presence)
Per. Floor Illum	Presence of perimetral illumination in the flooring and type of illumination (white light, RGB or no presence)
Medical Air	Number of Medical Air Outlets (labeled with B&W)
Oxygen	Number of Oxygen Outlets (labeled with white)
Carbon Dioxide	Number of Carbon Dioxide Outlets (labeled with grey)

Nitrogen	Number of Nitrogen Outlets (labeled with black)
Nitrous Oxide	Number of Nitrous Oxide Outlets (labeled with blue)
Vacuum	Number of Vacuum Outlets (labeled with yellow)
AGGS or EGA	Number of AGGS or EGA Outlets (labeled with yellow)
Air supply	Number and location of air supply outlets
Air return	Number and location of air return grilles.
Laminar Flux	Presence of laminar flux (Y/N)
Num. Power Plug	Number of power plugs
Num. Monitors	Number of monitors both pendant and integrated to the wall
Num. Audio Out	Number of audio outputs
Num. Video Out	Number of video outputs
Num. Network Conn	Number of network connection points
Num. Cameras	Number of video cameras
Surgical Table	Type of the surgical table (fixed to the floor or not)
Speakers	Number of speakers
Corridor size	Width of the corridor annex to the OT
Other	Other specific and differentiative characteristics of the OT, that can give valuable information for the comparative study

4.3.1 Variable classification

The variables present in the study can be classified according to different criteria. In this report we will classify them according to the type of variable (numeric or categorical) and according to the characteristics and the field of the study they belong to i.e., infrastructures, installations, equipment, etc.

4.3.1.1 Classification according numeric or categorical variable

A numeric variable (also called quantitative variable) is a quantifiable characteristic whose values are numbers (except numbers which are codes standing up for categories). Numeric variables may be either continuous or discrete.

Continuous variables can assume an infinite number of real values within a given interval. For instance, considering the length of the OT. The length cannot take any values as it cannot be negative, and it cannot be higher than a given number due to spatial limitations. However, between a given interval, the number of possible values is theoretically infinite. In our study within this type of variables we mainly have the dimensions, which stand for the width, length and height of the OT, the area of the windows, the width and height of the doors and the corridor width. Moreover, variables related to technical characteristics of the surgical lamps, which are the number of LUX, depth of field, color temperature, LED lifetime and color rendering index (Ra), will also be continuous variables.

Discrete variables can assume only a finite number of real values within a given interval. An example of a discrete variable in our study would be the number of plugs, as all possible values can be enumerated, and this number is finite. The discrete variables contemplated in the present study are the number of Power Plugs, gasses outlets, surgical lamps, monitors, audio input and outputs, video inputs and outputs, network connections, Cameras, Speakers, air supply outlets, air return inlets, pendants, pass boxes, windows, and doors.

A categorical variable (also called qualitative variable) refers to a characteristic that can’t be quantifiable. Categorical variables can be either nominal or ordinal.

A nominal variable is one that describes a name, label, or category without natural order. All the categorical variables included in this study are nominal variables. Therefore, we will classify our nominal variables into two main groups: variables with more than two categories and Boolean variables which represent a binary choice: in this case, presence or not presence of a specific item or system.

Categorical variables with more than two categories include walls, flooring and ceiling colors, walls, flooring and ceiling materials, door opening system and materials, central illumination, perimetral ceiling illumination, perimetral flooring illumination, and surgical table type. While Boolean variables in the present study include walls, flooring, and ceiling continuousness, wall printed panels, concave joint, and laminar flux.

4.3.1.2 Classification according to the field of the study.

In this subsection the different variables are going to be classified according to its characteristics and the role they play in the OT. The different types will be Infrastructure variables, Installation variables and equipment variables.

Infrastructure variables pertain to the structural components of the OT. This type includes all the related variables with the walls, floors, ceilings, doors, windows, and pendants.

Installation variables include the presence of adequate lighting and HVAC systems, and the availability and accessibility of utilities such as electrical outlets and medical gas supply. It also accounts for all the audiovisual systems.

Equipment variables encompass details about the medical equipment present in the operating theater. Although most of the medical equipment is not contemplated in the project, as we said in the scope, there are some variables that are equipment. These variables are the surgical table, surgical lamps, and pendant monitors.

4.4 Subjects of the study

In parallel with the definition of the variables, it has been made the selection of the subjects for the study, which has involved identifying the specific hospitals that are included to the research

In parallel with the definition of the variables, it has been made a study of the possible subjects for the project, which has involved identifying the specific hospitals that will be included in the research. As it is explained in the scope, this project pretends to work in the Catalan Public Health framework. Therefore, all full-private hospitals or medical centers will be excluded from the comparative study. Another condition for the selection of the possible subjects has been the location of the hospital, limited by the distance between the hospital and the actual living place of the author. Due to time and money limitations, those hospitals at a higher distance than 100 kilometers from Mataró have been excluded. The sample size is also restricted by the resources and available time, so the maximum number of hospitals that will be considered will be 10. Furthermore, other aspects have been considered, which stand for the complexity, size, and reputation of the hospital.

Applying all these conditions, a list of 10 possible candidates that align with the research objectives has been made. However, due to limitations related to the contact with administrations of the shortlisted hospitals and the accessibility to the surgical areas, 4 out of these 10 hospitals have finally participated in the study. These hospitals are all based in or near to Barcelona and are the Hospital Clínic i Provincial de Barcelona, Hospital Universitari Bellvitge, Hospital Sant Joan de Déu and Hospital Germans Trias i Pujol.

4.4.1 Hospital Clínic

Hospital Clinic de Barcelona (HC) is a leading healthcare provider based in the city of Barcelona, Catalonia and founded in 1906. It is considered one of the most prestigious and prominent hospitals in Spain and all over the world. The Clínic is a community hospital for its area of influence, on the left side of the Eixample, with a population of 540,000 inhabitants and, at the same time, operates as a care facility for highly complex cases. It is a public consortium formed by the Government of Catalonia (CatSalut) and the University of Barcelona and it is considered a complex tertiary hospital, developing lines of activity for patients in all Spain and internationally. The hospital maintains strong links to Clínic Foundation for Biomedical Research (FCRB), which is a non-profit organization created in 1989. [65]

It manages several centers, including Hospital Plató, Clínica Sagrat Cor and Hospital Maternitat de Barcelona and it also has a private subsidiary, Barnaclínic, a healthcare center devoted for private patients. The hospital covers virtually all medical and surgical specialties and is made up of Institutes, Centers, and Departments. The department of infrastructures and biomedical engineering is responsible for all the new constructions and equipment of the hospital, including the construction of new OTs.

When talking about numbers, The Hospital Clínic is formed by 763 beds, more than 8449 professionals and a total of 31 ORs. According to the Annual Report from 2021, during the year 2021 the hospital performed 28417 surgical interventions and 47638 discharges [66].

4.4.2 Hospital Universitari Bellvitge

The Hospital Universitari de Bellvitge (HB) is a public hospital based in the town of Hospitalet de Llobregat, near Barcelona and founded in 1973. The hospital, affiliated with the University of Barcelona, is a leading center for healthcare, research, and education. It belongs to the Institut Català de la Salut (ICS) being a high-complexity reference center for 2 million people. It offers a comprehensive range of medical specialties and services, catering to the healthcare needs of the local community and beyond. With a capacity of approximately 1,000 beds, Hospital Universitari de Bellvitge provides inpatient and outpatient care across various medical disciplines, including cardiology, oncology, neurology, orthopedics, transplant surgery, and many more. It accounts for

5200 professionals, and it registers around 20,000 major surgical interventions; 37,000 discharges; 485,000 outpatient visits and 100,000 diagnostic tests annually. [67]

4.4.3 Hospital Germans Trias i Pujol

The Hospital Germans Trias i Pujol (HGTP) is a public healthcare center based in the city of Badalona and founded in 1983. As a part of the ICS, it is considered a high- complexity reference center for 800000 people from the northern part of Barcelonès and Maresme. It accounts for around 2500 professionals and, according to the annual report, in 2019 it registered 36934 hospital discharges, 17161 major ambulatory surgical discharges and 426436 visits to external consultations. [68]

4.4.4 Hospital Sant Joan de Déu

Hospital Sant Joan de Déu (HSJD), located in Esplugues de Llobregat, near Barcelona, Catalonia, is a renowned pediatric hospital known for its excellence in providing specialized medical care for children and adolescents. It belongs to the Província Sant Joan de Déu d'Espanya de l'Ordre Hospitalari. The hospital is a non-profit private institution, with a vocation for public service since its creation in 1867. It is associated with Sant Joan de Déu Research Foundation, and it is a university hospital associated with the Universitat de Barcelona. The SJD Barcelona Children's Hospital provides assistance to society as it is associated with the Catalan Health Service (CatSalut) and the Spanish National Health System. It accounts for 401 beds and more than 4000 complex surgical procedures per year. [69]

4.5 Contact with the hospitals

Once the Hospitals have been selected, the next step of the project stands for contacting the hospitals and obtaining permissions and approvals to then be able to visit their surgical areas and meet the personnel in charge of the infrastructure, electromedicine, surgical area or other similar departments. To do so, it is crucial to contact the administrations of the shortlisted hospitals to request permission to include them in the study and explain to them the purpose and scope of the research, ensuring to comply with any ethical considerations and institutional requirements.

This stage has been a tedious stage of the project, as many hospitals do not have any contact for external people from the hospital, being one of the major challenges for this project. This stage has been a limitation for the project, as the author has not been able to contact some hospitals included in the candidate list and, therefore, the final number of hospitals studied in the project has been reduced, as can be seen in the previous section. Different channels have been used to contact the appropriate personnel from the different hospitals. These channels have been electronic mail, LinkedIn and personal or business phone numbers. The professionals from the hospitals that have been contacted, have been from the electromedical, biomedical engineering and infrastructure departments.

4.6 Data acquisition

For the practical purpose, a field work is carried out around the different hospitals in the region. Once the meetings have been scheduled, it is imperative to proceed with the visits to the surgical areas of the different hospitals to conduct the measurements and observations.

In certain hospitals, two meetings have been scheduled as part of the process. The initial meeting serves the purpose of introducing the project to the responsible professionals within the hospital and entails a thorough examination of their documentation, construction plans, and project records pertaining to the OR areas. Subsequently, a second meeting is scheduled specifically for the purpose of visiting the ORs, where all predefined variables for the study are measured and documented.

Conversely, in the case of other hospitals, only one meeting has taken place, during which the project was explained to the hospital staff, followed by the visitation of the ORs to acquire the necessary data.

All the data has been acquired by visiting the most recent OR in each hospital and conducting measurements of all relevant variables, subsequently recorded in an Excel sheet. During these visits, the author was accompanied by professionals with knowledge in the field of infrastructures and installations of the OR, providing valuable guidance and detailed explanations regarding its distinct characteristics. By combining the information provided by the professional and the data extracted through direct observation and measurement of variables, a full dataset for each hospital was obtained. Below, it is presented a detailed description of the specific assessment methodology employed for the gathering of the different variable types.

As commented before, the continuous numerical variables are the dimensions and the technical specifications of surgical lights. The dimensions will be measured with a laser distance meter, specifically a WURTH WDM 60. While the technical specifications of the illumination will be extracted from the proper documentation and datasheets of the surgical lamps. The brand and model of the lamps will be annotated during the visit to perform future research of its documentation. Besides, the discrete numerical variables will be assessed by visually counting all the items that conform to each one of the variables. The obtained number will be annotated in the Excel sheet.

Within the categorical variables, there are different subtypes such as colors, materials, Boolean and other categories. The color variables will be assessed by pure observation and annotation of the colors complemented with pictures of all the various wall, flooring, and ceiling colors. The material types will be obtained by asking the professionals in charge of the OR infrastructures or from the documentation and project memory of the OR construction. The Boolean variables and other types of variables will also be extracted by observation or asking the professional.

4.7 Data analysis

This section comprises a first homogenization of the different data gathered and a further analysis and comparison of the results, for a future discussion. In this section all the data has been homogenized in an excel, with the same names and variables for each hospital and the same data types. Then we have joined the data of all the different hospitals obtaining a unique data frame. We have joined them by columns, being each row a different variable and each column a different hospital. This complete data frame helped us to have a more global vision of the similarities and differences. However, apart from creating a data frame with all the collected data together, we have also created different tables with just the data from specific categories in order to simplify the analysis of the data and make it more specific. These categories are infrastructures, installations, and equipment and others. Splitting the data has allowed us to analyze it in a simpler way, enabling an easier and clearer discussion of the results.

4.8 Discussion

After having all the tables with the homogenized data from each one of the hospitals, the comparative study has been carried out. Within the comparative study, we have mainly looked for differences and similarities, as well as relation between different variables. Then, having all the differences, similarities, and different traits from each hospital we have proceeded with the discussion. In the discussion we have applied our background knowledge obtained from the degree, the previous research, and the set of visits to the hospitals, combined with our personal criticism and objective view of the question addressed, to extract meaningful conclusions about the architectural, infrastructural, and engineering design of the ORs nowadays in Catalonia. In this stage all the theory researched in previous stages, has been useful for establishing the ORs visited with the actual trends all over the world and the state of the art of the actual construction of ORs. We have also considered the reality of each hospital and differences between them regarding size, funds, complexity, reputation, etc.

5 RESULTS

In the following section, we will review the data obtained during the stays on the four different hospitals visited: Hospital Clínic (HC), Hospital Sant Joan de Déu (HSJD), Hospital Universitari Bellvitge (HB) and Hospital Germans Trias i Pujol (HGTP). As it has been mentioned in the methodology section, one OR per hospital has been included in the study. Therefore, a total of four different ORs will be compared. To provide a simpler view of the features of each OR, summary tables organized by two different sections will be shown.

5.1 Hospital Clínic

As the project has been carried out with the supervision of the infrastructures and biomedical engineering department form the HC, the first Operating Room visited for the study was from this hospital. This allowed the author to take first contact with an Operating Room and familiarize himself with its characteristics. Thanks to this visit the list of predefined variables was changed by removing, redescribing, or adding new variables. Pictures of the different elements of the OR taken during the visit can be found in *Annex 1*.

The OR that was visited at HC is a recently constructed facility situated on the ground floor in the hospital's main surgical area and completed in the current year of 2023. Specifically designed for the field of neurosurgery, this OR is classified as a hybrid Operating Room. Therefore, it is important to acknowledge that certain characteristics of the OR are contingent upon its neurosurgical and hybrid nature i.e., the presence of specific imaging equipment. However, the selection of this OR was based on criteria focused on choosing the most recent ORs from each hospital, rather than solely on its neurosurgical and hybrid designation. Furthermore, most of the variables studied in relation to ORs do not depend on the specialty or its associated equipment as commented in the scopes section. In *Figure 11*, it can be seen a general picture of the OR visited.

Figure 11 Studied Operating Room from Hospital Clínic de Barcelona

The visit took place in the afternoon, a time when the level of activity in the surgery block is much lower than in the morning. This scheduled choice facilitated an ample amount of time to explore the OR without disruptions from the medical staff. It is important to keep in mind that due to the critical nature of these facilities, an emergency could have arisen at any time that would have forced us to stop the visit. During this visit all the variables were acquired as outlined in the methodology section. Furthermore, the attending professional provided detailed explanations, enabling a comprehensive understanding of the fundamental aspects of the OR's installations and infrastructure. This facilitated a deeper insight into the operational aspects and functionalities of the OR.

5.2 Hospital Sant Joan de Déu

HSJD was the last hospital visited. The entire hospital exhibited a contemporary architectural design, with a particular emphasis on creating a child-friendly atmosphere throughout its decoration. The OR analyzed is one of the eight newly ORs constructed in a new surgical block in 2019. This particular OR, located on the first floor, is primarily designated for general surgery procedures. Notably, it features an additional window which communicates to a separate room intended for lectures or hosting external visitors during the surgeries. The eight ORs present in this surgical mainly share the same. Additionally, three of the operating rooms feature windows that provide a captivating view of Barcelona city, fostering a sense of openness and connection to the surrounding environment.

The visit was guided by the head of the Bioengineering Group in HSJD, who provided relevant information about the variables studied and other aspects redacted to the field of the study. In *Figure 12* it can be seen a general picture of the OR analyzed. Furthermore, pictures depicting the different components of the operating room captured during the visit can be accessed in *Annex 2*.

Figure 12 Studied Operating Room from Hospital Sant Joan de Déu

5.3 Hospital Universitari Bellvitge

This section presents the results obtained from the analysis conducted on one of the new ORs at the HUB. Due to limitations in the accessibility to the Surgical area of the hospital, a physical visit to the ORs was not feasible within the time framework of the project. However, a meeting was arranged with the head of the Electromedicine and Biomedical Engineering Department, who supplied the necessary information and documentation for the analysis.

The OR under analysis is part of a complex of multiple ORs, which were completed in 2019 as part of the expansion project for the techno-surgical building at the hospital. This documentation includes the state of dimensions and characteristics of the executed work, with its associated documents: memory and annexes of the project, blueprints and quality and environmental documentation. To focus solely on the new ORs, an extraction process was performed to extract the pertinent information and blueprints from the overall building expansion project documentation.

As previously mentioned, due to the unavailability of physical access to the OR complex, the key variables were extracted from the blueprints of one of the new operating rooms., These blueprint details can be found in *Annex 3*. Moreover, other additional information not available in the blueprints was extracted from the memory. Finally, some observational variables such as color schemes, were assessed from pictures of the Operating Room extracted from the HUB's web site [67].

5.4 Hospital Germans Trias i Pujol

In the visit at the HGTP, we analyzed its most recent and advanced Operating Room, which corresponds to a hybrid OR specialized in cardiology. The OR started operating in 2019 and was built on the first floor of the hospital, at the main surgical area, using the space of two old operating rooms. As happened with HC, this OR was not a conventional OR, but it was chosen following the criteria of year of construction, being this the newest OR in the hospital. Like all the previous visits,

Figure 13 Studied Operating Room from Hospital Germans Trias i Pujol

this visit took place at the afternoon. The visit was carried out together with a biomedical engineer from the Hospital who provided a detailed explanation in the different characteristics of the OR. In *Figure 13* we can see picture of the chosen OR for the study. Additionally, in *Annex 5*ANNEX 5: PICTURES OF THE HOSPITAL GERMANS TRIAS I PUJOL OR. we can see more photographs of the OR.

5.5 Comparative

After having all the tables with the homogenized data from each one of the hospitals, the comparative study has been carried out. Within the comparative study, we have mainly looked for differences and similarities, as well as relation between different variables. To provide a better and easier comprehension, two different tables have been created; one for the infrastructure analysis (*Table 2)* and a second one for the installation and equipment (*Table 3*). The tables contain five columns: Variable, H. Clínic, H. GTiP, H. Bellvitge and H. SJD. The Variable column represents the specific aspect being compared, while the other columns provide data for each hospital's Operating Room. Consequently, the rows of the table stand for the OR features being compared. Note that some of the information, such as name of some variables, has been abbreviated due to limitations in the space. In *Annex 6* and *Annex 7*, complete tables with all the information and complete names can be found.

Table 2 Infrastructure variables of the ORs from the four different hospitals.

Variable	H. Clínic	H. GTiP	H. Bellvitge	H. SJD
Width	588	731	673	666
Length	829	881	875	699
Height	271	289	300	299
Corridor size	205	223	NaN	234
W Material	Corian & glass	Pladur	Vinyl	Glass
W Color	White	White	Beige	White
W Cont.	Yes	Yes	Yes	Yes
W Print Pan	Yes*	No	No	Yes**
W Int Monitor	2	0	1	2
F Material	PVC Tarkett	PVC Tarkett	PVC Tarkett	PVC Tarkett
F Color/s	D. Grey & L. Grey	Blue	Grey	Grey & Blue
F Cont.	Yes	Yes	Yes	Yes
F/W joint	Yes	Yes	Yes	Yes
C Material	Pladur & PTFE	Pladur & PTFE	Pladur & PTFE	Pladur & PTFE
C Color	White	Light Grey	White	White
C Cont.	Yes	No	Yes	Yes
Num Doors	2	2	2	2
Door Op Sys	Sensor	Push button	Push button	Sensor & Button
Door Size	1,093x212	NaN	160x220	160x220
Door material/s	St Steel & HPL	St Steel & HPL	St Steel & HPL	St Steel & HPL
Win num	0	0	1	3
Num Pass Box	0	0	0	0
Num Pendants	4	4	4	4

After analyzing the previous table (*Table 2*) we can observe some patterns that are repeated in all four hospitals and some other aspects that are different. Firstly, we can see that all ORs present continuous walls, ceilings, and floorings, with also a uniformity in their colors. In here we could highlight the presence of a printed panel in one of the walls of the HC's OR and the presence of printed births in the ceiling and walls of the HSJD.

Although the floors and wall coverings appear to be made of slightly different materials, in all four ORs the ceilings are made of the same material, Pladur painted with PTFE and fungistatic paints. This material has also been used to cover the walls in the HGTP. With contrast, the Clínic and Sant Joan de Déu's OR walls are made of glass, while the walls of the Bellvitge OR are covered with vinyl. Finally, conductive Polyvinyl Chloride (PVC) Tarkett has been employed in all hospitals for covering the floor.

With respect to the doors and windows, all ORs have 2 doors, one for the clean way and the other for the unclean way. Same doors have been employed in all hospitals, however, different door opening systems have been found. Furthermore, HSJD and HUB are the only hospitals that have exterior windows inside their OR. At last, none of the hospitals present pass boxes and the number of pendants in all the ORs is the same, which stands for four.

On the other hand, as commented before, in *Table 3* we can find the variables related to the OR installations and equipment analyzed.

Table 3 Installation and equipment variables of the ORs from the four different hospitals.

Variables	H. Clínic	H. GTiP	H. Bellvitge	H. SJD
Num. Surg Lamp	2	2	2	2
Surg Lamp Type	Getinge	Steris Xled	Trumpf Medical	Trumpf Medical
Central Illum	RGB & White	White	White	White
Per. Ceil Illum	RGB	No presence	No presence	RGB
Per. Floor Illum	RGB	No presence	No presence	RGB
Medical Air	4	4	2	3
Oxygen	5	4	4	3
Carbon Dioxide	1	0	2	2
Nitrogen	0	0	2	0
Nitrous Oxide	0	0	4	3
Vacuum	5	4	4	6
AGGS or EGA	2	2	4	2
Air supply	Laminar Flux	Laminar Flux	Laminar Flux	Laminar Flux
Air return	8	8	8	8
Laminar Flux	1	1	1	1
Num. Power Plug	24	50	24	29
Num. Monitors	4	3	3	4
Num. Audio Out	4	0	0	2
Num. Video Out	3	4	2	9
Num. Net Conn	12	8	6	9
Num. Cameras	1	2	1	1
Surgical Table	Fixed	Fixed	Mobile	Mobile
Speakers	4	2	1	4

After analyzing *Table 3* we can extract relevant information about the installations and characteristics of the studied ORs.

Across all the variables it's clear that the four hospitals share several common characteristics. In terms of Ventilation and Climatization all ORs have a Laminar Airflow System (LAS), as well as all of them present a similar structure with the same amount of air return grids, located in the corners of the OR. Additionally, all ORs have a comparable number of cameras and monitors. However, HGTP is the only facility that does not feature a wall integrated monitor. In contrast HC and HSJD have two wall-integrated monitors in their respective ORs.

On the other side, notable differences have also been found between the ORs. Concerning the illumination, Hospital Clinic and Hospital Sant Joan de Déu, boast a RGB LED environmental illumination that the other two hospitals do not present. Moreover, although the number of surgical lamps is the same in all ORs, the brand and models, and consequently its characteristics differ between the four hospitals. Then, there are some differences with respect to the surgical table type, the number of power plugs, the audiovisual connections, and the gas outlets.

Overall, in this section we have seen the main differences and similarities between the ORs, as well as we have identified some patters and trends concerning the design and construction of the most recent constructed OR from Hospital Clinic, Hospital Germans Trias, Hospital Sant Joan de Déu and Hospital Bellvitge. Then, having all this different traits, and similar aspects from each hospital we have proceeded with the discussion, which will be executed in the following section.

6 DISCUSSION

In this section, all the differences and similarities found in the RESULTS part have been analyzed to, considering the context of the hospitals, extract a meaningful argument. Thus, the author has applied his background knowledge obtained from the degree, the previous research, and the set of visits to the hospitals, combined with his personal criticism and objective view of the question addressed, to extract meaningful conclusions about the architectural, infrastructural, and engineering approach of the ORs nowadays in Catalonia. After reviewing the results obtained, some significant differences have been found, most of them related to the nature and context of the hospital such as budgetary constraints, complexity, or spatial and structural limitations. Therefore, all these items will be discussed below.

To begin we want to take insight in a specific pattern that emerged from the results. After analyzing all the differences, it has been found that some variables divide the four hospitals into two groups. On one hand, we have HSJD and HC, while on the other hand, HUB and HGTP belong to the second group. The main variables that contribute to this differentiation are the materials and colors of the walls and floors, the environmental lighting systems, and the door opening systems.

HSJD and HC covered the OR walls with glass, while HUB and HGTP did it with Pladur and Vinyl. Although all these three materials accomplish with the recommendations established by the standards - having similar properties like continuousness, hardness, non-porousness, waterproofness, or easiness to clean and disinfect - glass surfaces present some differential characteristics, that can increase the value of the OR facilities. As commented before, despite Vinyl and Pladur have the basic and essential properties for the flooring and wall materials, glass offers a higher resistance to scratching, chemical, UV radiation, and heat. It also offers a higher design flexibility allowing for customized etching, frosting, or decorative patterns such as printed panels, enabling aesthetic enhancements in the OR. In contrast, due to the high economic costs of glass and its complex installation, Vinyl and Pladur tend to be more cost effective than glass, making them a popular choice in healthcare facilities where budget considerations are crucial. Regarding flooring colors, HSJD and HC have utilized two different colors to distinguish the surgical field. Conversely, the other two hospitals have opted for a single color, which leads to lower installation costs.

Concerning the environmental illumination, Clínic and Sant Joan de Déu, have used RGB LED lighting located around the laminar flux and on the ceiling and flooring perimeters (*Figure 14*). Besides, HGTP and Bellvitge opted for a simpler lighting system, using also LED technology but with only white light. First, we can see that all hospitals use LED systems for their surgical lights (SL), as a difference from the incandescent or halogen light sources used in the past. This shows a clear trend towards LED lighting, which can be explained by its high energy efficiency, long life, lower heat generation, greater control and precision, and greater safety and sterility. On the other hand, only two hospitals use RGB systems, so we can deduce that they are not yet essential for surgical practice. Nevertheless, this technology allows the creation of very diverse and dynamic lighting environments that can favor both the patient and the medical staff. An example is the use of this technology to simulate environments such as sunset or dusk that can improve the patient's experience during the surgery or anesthesia. Apart from providing higher comfort, the use of RGB light has other practical functionalities, as it can be used for increasing the contrast between tissues, or for specifying different states of the OR; clean, dirty, operating, or empty.

Figure 14 Floor perimetral, ceiling perimetral and ceiling central RGB LED systems in Hospital Clínic (from left to right)

Finally, different opening door systems has also been found between these two groups. The first group, HSJD and HC, has used touchless sensors, while the second group has employed push buttons. Moreover, HSJD has implemented a dual system to the doors connecting with the clean area. This double system, shown in *Figure 15* allows the door to be opened totally or partially. If the push button is used, the door will open in its entirety, which is associated with the entry of patients with stretchers. On the other hand, if the touchless opening system is used, which is dedicated to medical personnel, the door only opens partially. This dual system provides two main improvements by avoiding unnecessary door openings [70]. Firstly, it reduces the perturbation of the positive differential pressure and the laminar flow system which are crucial for the sterility of the clean area. Secondly, it contributes to the reduction of energy used for HVAC, due to the changes in temperature, humidity or pressure caused by the door openings. To sum up, we can say that, although their increased initial inversion, the double system can provide better outcomes and long-term savings lowering the HVAC energy consumption.

Figure 15 Dual door opening system from Hospital Sant Joan de Déu

We can translate all above-mentioned to our study observing that HC and HSJD are not totally public institutions, or they are founded by other private foundations, which allows them to invert more money in the construction of new ORs. By the other side, HB and HGTP, are members of the Institut Català de la Salut (ICS), a public company, attached to the Catalan Health Department. The totally public character of these institutions leads, thus, to greater budgetary limitations. This budget differences between the two groups of hospitals, explain the differences between hospitals in the variables mentioned before. Whereas HC and HSJD have opted for designs that include more expensive items which, apart from complying with the standards, provide extra value to the

OR, HGTP and HUB have decided to opt for simpler materials and systems that merely meet the needed functions of the surgical environment. Apart from the budgetary restrictions, other attributes such as the nature or specialty of the hospital may be contributed to these differential traits. For instance, HSJD is a pediatric hospital, therefore, all its ORs have been adapted to meet the needs of children, adding familiar or infantile decorative items. The printed birds shown in *Figure 16*, as well as the presence of devices to project images in the glass walls exemplify this approach.

Figure 16 Decorative elements in HSJD OR

But is it necessary and worthwhile to invest in these non-essential details such as RGB lighting or use of glass and printed panels? This is one of the key questions for this study. Nevertheless, there have not been found a correct answer. Following the example mentioned before about the environmental illumination, hospitals would need to weigh the costs associated with investing in RGB LED systems against the potential benefits. This would entail considering the costs of initial installation, ongoing maintenance, energy efficiency, and the expected lifespan of the systems as well as the potential benefits, such as increased visibility, energy savings, or enhanced ambiance. Therefore, it can be concluded that the hospital's approach to the design and construction of its ORs is closely related with the budgetary constraints and priorities of each institution. Institutions such as HC and HSJD can afford to spend large amounts of money on gadgets or decorative elements while other hospitals will just invest in the necessary and essential installations, materials, and equipment required for the proper functionality of the OR. Additionally, it is obvious to mention that hospitals must ensure that any material, equipment, or system used in the construction and installation of their ORs comply with the actual regulatory standards and guidelines.

Upon completion of the comparative analysis and discussion between the above-mentioned groups, we shall proceed to explore additional intriguing variables. Thus, the ensuing paragraphs will discuss other differences or similarities found in, i.e., the OR dimensions, SLs, type of operating tables or other general installations and infrastructures, such as gases used or doors and windows.

Firstly, we will examine those variables that have shown similar values across the four different hospitals. Into this group of variables, we include gas outlets, number of plugs, number of audiovisual connections, number of pendants, presence of laminar airflow and presence of flooring-wall joints. The uniformity between this group of variables can be explained by the actual standards on installations, as well as on the current trends of ORs. With respect to gas installations each OR contains similar number of oxygen, vacuum, AGSS and nitrous oxide outlets as their presence and minimum quantity are regulated by the standards [71]. An exception is, the carbon dioxide (CO_2) outlets, which are only present in SJD and HUB, since they are general surgery ORs, and they need CO_2 to perform laparoscopic procedures [27]. Other installations such as electrical and HVAC installations are also restricted to what is indicated in the standards. By the other side, the presence of pendants, audiovisual connections or flooring-wall joints is consistent in all ORs because they all follow a series of recommendations and actual trends.

Next, we will delve into the OR dimensions. Despite the fact that there is a diversity specially in the width and length sizes having ORs bigger than others, all dimensions are within a relatively confined range. These results appear to be logical as OR's dimensions are subject to both minimum bounds dictated by specifications and regulations, as well as maximum bounds primarily constrained by spatial considerations within hospitals. It is imperative for ORs to ensure the utilization of space in a purposeful and efficient manner, thus avoiding unnecessary and redundant occupation. Upon closer analysis of subtle differences, it becomes evident that the HC's OR dimensions are relatively smaller than those of other hospitals. This could be explained due to the spatial and structural constraints present in the HC building, due to its antiquated structure and its location in the middle of the Example district. On the contrary, we can see that the HGTP's OR demonstrates significantly larger dimensions, which can be attributed to the ample space available to the hospital due to its location on the outskirts of the city of Badalona. However, it is noteworthy to comment that an excessive space may not necessarily be beneficial for the OR since more energy is needed to maintain the established ventilation and climatic conditions and, on the other hand, space that could be used for another function is being.

Continuing with the infrastructures, operating rooms are generally windowless, though windows are becoming more prevalent in newly built theaters to provide clinical teams with natural light and feature controlled temperature and humidity. We can see this in some of the studied ORs, specifically in HSJD and HUB, which also present annex rooms dedicated to lecturing or external visits. The lack of windows and this annex spaces in HC may be due to space limitations mentioned before. By the other hand, although HGTP have enough space, the actual installations of this hospitals are generally outdated, which explain the absence of this type of areas or items. The professional commented that a project to expand the surgical block was underway.

On the other side, OR doors appear to be similar, as all of them are manufactured by the same company, Manusa [9]. These doors share common characteristics, being made of aluminum, featuring small windows, and operating on a sliding mechanism. This uniformity indicates that there is a current trend of OR doors, which is defined by the mentioned-above doors. This seems to be logic due to the high efficiency of sliding doors reported by some studies [72]. As it has been discussed in previous paragraphs some studies show that the door opening and closing process leads to air entering the OR from the adjacent areas. However, sliding doors are seen to reduce the amount of air entering from the adjacent area in different scenarios tested. Sliding doors are, thus, considered the preferred option in operating rooms.

Subsequently, regarding the surgical lights (SL), different models have been used: Getinge Maquet Volista [73], Steris Xled 3 [74], Trumpf Medical iLED™ 7 [75], and Trumpf Medical TruLight™ 3300 [76], in HC, HGTP, HUB and HSJD, respectively. By analyzing the technical sheet of each model, it has been found that all SLs have relatively similar features. All lamps, except from the ones in HSJD, have a maximum illumination level of 160 000 lux with a light patch diameter going from 16 to 25 cm in different SLs. Another important parameter is the color temperature provided by the light, which is similar in all models, being around 4500K. Finally, some other characteristics such as LED lifetime or Color rendering index (Ra) have also consistent values across all lamps and range from 55 000 to 65 000 hours and 93 to 97, respectively. Overall, it can be concluded that, although the four hospitals have selected different SL models, there are no significant differences in terms of its technical characteristics. Nevertheless, despite all the surgical lamps have similar technical characteristics, there are differences in their designs that may alter the Laminar Air Flow (LAF). Nowadays, most of the ORs - and all the ORs studied in the project - are equipped with a LAF system that provides a sterile, laminar air flow to the surgical table to reduce the risk of contamination of the wound. As SLs and their suspension system are located between the LAF exit and the surgical table, they can distort the laminar flow, introducing turbulence and therefore affecting the sterility of the surgical field. This has been demonstrated by both experiments and simulations where an increased particle count was assessed at the location of the wound [77]. Therefore, the design of the surgical light head should be into consideration, apart from the technical features of the SL. Some companies offer light head shapes with designs that aim for the compatibility with the laminar air flow, by intending to maximize the aerodynamics of the light head and minimize the obstruction of the flow. In *Figure 17* we can see the design used by Steris, which tries to reduce the flow disturbance by incorporating an open-sheet configuration that allows the air to pass between the sheets.

Figure 17 Surgical light Steris Xled3 in Hospital Germans Trias I Pujol

Lastly, we will discuss the operating table by considering whether it is fixed or mobile. We can find a fixed operating table in HC and HGTP. Fixed operating tables are firmly anchored to the floor making it simple to transport and position any extra required medical equipment. These devices include, for example, x-ray equipment, which can easily be slid under the tabletop. For medical staff, this type of operating tables offer improved leg space since disruptive foot geometry is no longer present, as a difference from the mobile ones. The fixed operating tables present in HC and HGTP ORs, which are a neurosurgery OR and a cardiovascular OR, respectively. Both specialties often need the presence of a C-arm X-Ray, which explains the need for fixed tables that facilitate the coupling of this medical imaging devices. On the other hand, HSJD and HUB have opted for mobile operating tables. The advantage of these tables mainly lies in their dynamic nature, as the position of the table can be changed within the operating room. In essence, the selection of the operating table type is not crucial and may vary depending on the priorities and preferences of the surgical team, as well as the intended use and medical specialty performed in the OR.

In conclusion, our study provides valuable insights into the different approaches in the design and construction followed by four different Hospitals in Catalonia. Through rigorous analysis and interpretation of the data we have identified several key findings. First, some of the variables demonstrated that economy of the hospitals and, therefore, the private or public character of this hospitals influence the selection of some materials, systems, or installations in the OR. All these selections have been found not to be essential for the proper functioning of the OR, but some of them increase the value and the efficiency of the OR and surgical procedures. Second, we observed other differences caused by structural or spatial constraints, as well as other differences, probably, driven by the hospital personnel and its values and purposes. Finally, many other aspects of the ORs exhibit similarities, which can be explained due to the minimum requirements given by the standards.

Overall, this study elucidates that despite apparent similarities in approaches, each of the observed ORs exhibits differential traits which depend on the inherent hospital and its socioeconomic and geographical context. The findings underscore the idea that ORs have nuanced traits, thereby highlighting the influence of contextual factors on their design and functioning.

7 EXECUTION SCHEDULE

In the execution chronogram we find all the relevant information related to the temporal and economic organization aspects of the project management. In this section we find the Work Breakdown Structure (WBS), the PERT diagram, and the GANTT diagram.

7.1 Work Breakdown Structure (WBS)

The Work Breakdown Structure (WBS) is the structure in charge of hierarchically breaking down the tasks to be carried out to complete the project. The WBS scheme can be designed with different levels. For this project, two levels have been used: one for a more general distribution of the project, and a second level to divide it into specific sub-brands. The first level is primarily responsible for dividing the project into four main branches, which are essential for its execution. Once at the second level, each branch is further divided into different work packages. Each of these work packages are small processes that must be completed to achieve a goal, which corresponds to its corresponding first level.

In the WBS dictionary, we can see how each work package has associated tasks, some of which also include an associated deliverable. These tables also indicate the planned temporal and economic cost.

Below, we define the WBS scheme, with the various tasks that comprise the creation and implementation of the project in question. (*Figure* 18*)*

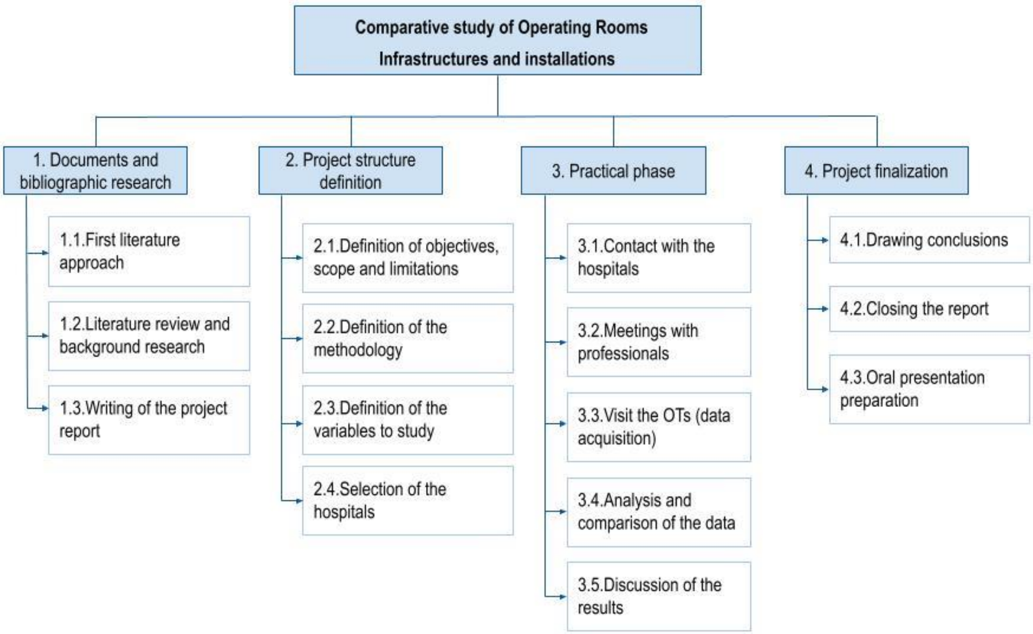

Figure 18 Working Breakdown Scheme

As it is depicted in *Figure 18*, the project is divided into 4 distinct work packages. Each of them comprises multiple tasks that must be completed to ensure that the work package is successfully completed. To understand more specifically what each task consists in, a WBS dictionary has been elaborated.

1. **Documents and bibliographic research**

TASK	DESCRIPTION
1.1. First literature approach	Research of similar past study and first approach to OTs and its main characteristics
1.2. Literature review and background research	Extensive research of the characteristics of OTs infrastructures, installations, and equipment and research of the current market and state of the art, analyzing the current trends, future perspectives, and the actual stablished companies in Catalonia that work designing and building healthcare facilities.
1.3. Writing of the project report	Development of the project written report.

2. **Project structure definition**

TASK	DESCRIPTION
2.1. Definition of objectives, scope, and limitations	Definition of a real and feasible objectives, as well as the scopes of the project and its main limitations considering the situation of the author, the time and the resources needed.
2.2. Definition of the methodology	Definition of a proper work structure to develop the different stages of the project, from the research to the final discussion of the results
2.3. Definition of the variables to study	Definition of the proper variables that will be obtained and studied. The definition will include both infrastructure, installation and equipment related variables.
2.4. Selection of the hospitals	Selection of the hospitals that will participate in the study considering the context of the project and its goals, scopes, and limitations.

3. **Practical phase**

TASK	DESCRIPTION
3.1. Contact with the hospitals	Establishing contact with the hospitals and obtaining permissions and approvals to have access to their surgical areas.
3.2. Meetings with professionals	Meet the personnel in charge of the infrastructure, electromedicine, surgical area or other similar departments and explain them the purpose of the project.
3.3. Visit the OTs (data acquisition)	Visit the OTs from each hospital and gather all the needed data.
3.4. Analysis and comparison of the data	Homogenization of the different data gathered and a further analysis and comparison of the results.
3.5. Discussion of the results	Discussion of the results by establishing different relations, patrons or differences between

	hospitals and justifying them applying the background theory.

4. Project finalization

TASK	DESCRIPTION
4.1. Drawing conclusions	Extraction of main conclusions according to the objectives defined.
4.2. Closing the report	Finishing all the report format, pictures, tables, references, and appends to submit it.
4.3. Oral presentation preparation	Realization of the power point presentation and preparation of the explanation to be done during the oral exposition.

7.2 PERT diagram

To ensure efficient coordination and timely completion of the project, a PERT-CPM diagram has been created. This diagram provides a visual representation of the tasks involved, their respective durations, and their interdependencies. It establishes the sequential order in which tasks should be executed, indicating the predecessors and successors of each task. By calculating the "early" and "last" start and finish times for each task, the critical path can be identified. The critical path determines the duration of the project, as it represents the sequence of tasks that must be completed without delay to avoid project delays. In the upcoming section, these concepts will be further elaborated for a better understanding. *Table 4* shows the relation between the different tasks or activities and its duration. The table depicts the name of the task, its associated ID in the PERT diagram, its precedent activities, and its estimated duration in terms of weeks.

ID WSB	**ID PERT**	**Precedent Activities**	**Duration (Weeks)**
1.1 First approach	A	-	2
1.2 Background Research	B	D	3
1.3 Report writing	C	-	15
2.1 Objectives, scope, and limitations	D	A	1
2.2 Methodology	E	D	1
2.3 Variables Definition	F	B, E	1
2.4 Hospital Selection	G	E	1
3.1 Contact to Hospitals	H	G	3
3.2 Meetings with professionals	I	F, H	2
3.3 OTs visiting	J	F, H	4
3.4 Data analysis and comparison	K	I, J	1
3.5 Discussion	L	K	2
4.1 Conclusions	M	L	1
4.2 Finishing Report	N	C, M	1
4.3 Presentation preparation	O	N	1

Table 4 Tasks with its associated precedent activities and duration

After defining the relation between the different activities and its estimated time, the PERT diagram has been created.

It can be seen in *Figure 19* that the critical path from our project is formed by most of the activities of the project. Key activities such as the objectives definition or the visit to the hospitals are critical activities as the following stages of the project depend exclusively in those activities.

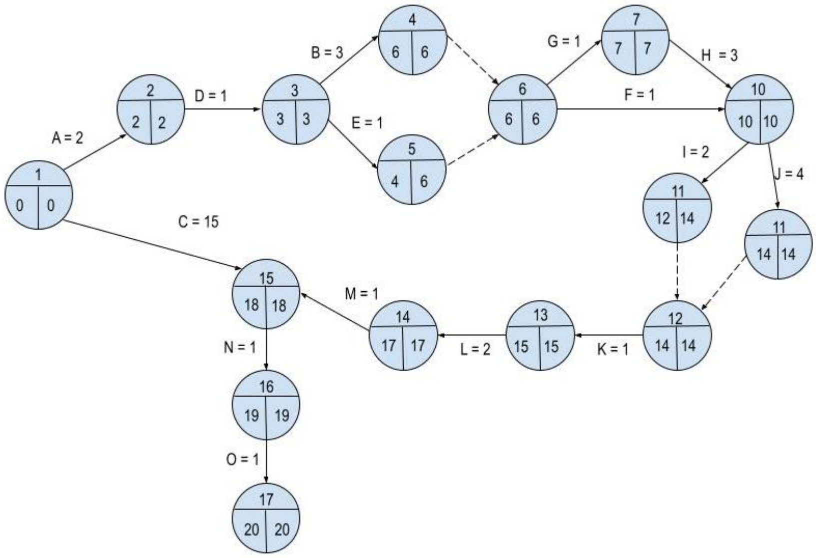

Figure 19 PERT diagram

7.3 GANTT diagram

Apart from analyzing the duration of each task and the critical path it is also important to establish a calendar to execute the different activities of the project. The GANTT chart is a graphical method of project management in which the different task deadlines for completing a project are scheduled. This method facilitates the tracking of the progress of the activities to be performed within the timeframe in which the project must be completed. In this case, it has been decided to opt for a daily GANTT schedule, which shows the tasks that must be completed each day. The project started on January 15th and its delivery deadline is on June 12th. Therefore, considering the mentioned workdays, the project had been completed in 5 months. In *Figure 20* the GANTT diagram is displayed. All tasks are classified as critical activities; thus, it is important not to delay in any activity, otherwise the project would not be finished in the defined deadline. It can also be seen that the total duration of the project is around

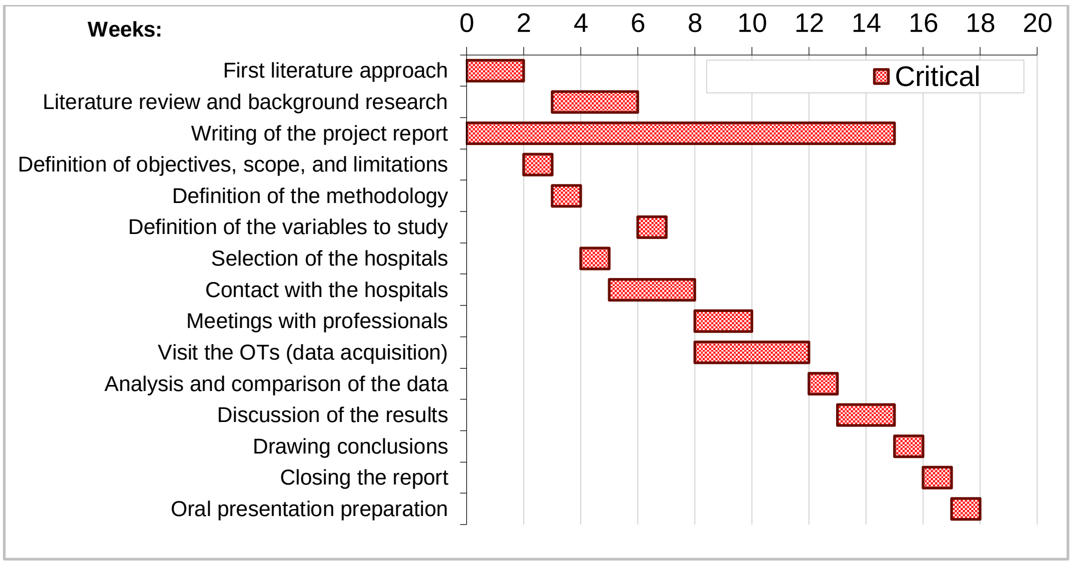

Figure 20 GANTT Diagram

8 LEGISLATION AND REGULATION

In this section we will comment the principal regulations and standards regarding the design, construction, and installation requirements for an OR.

8.1 General standards

The current standard UNE-EN ISO 14644-1:2000, Clean rooms, and annexed premises, defines the concept of clean room: "A room in which the concentration of airborne particles is specifically managed, and which has been constructed and is used to minimize the introduction, production and retention of particles in its interior, and in which other relevant parameters, such as temperature, humidity and pressure, are adequately managed".

The part 4 of this current standard, UNE-EN ISO 14644-4:2001, Design, construction and start-up specifies requirements for the design and construction of cleanroom facilities but does not indicate specific technology or contractual means for meeting these requirements. It is intended for use by purchasers, suppliers and cleanroom designers and includes a listing of important operating parameters. Guidance for construction and design is included, including requirements for start-up and qualifications.

The UNE 100713:2005 standard classifies operating rooms as Class I areas, indicating that they have high requirements regarding the presence of germs.

The UNE-EN ISO 14644-1:2000 standard on cleanrooms aligns with the air quality requirements needed in the operating room. According to this standard, operating rooms are classified as follows: Type A operating rooms, which have the highest level of asepsis; Type B operating rooms, which correspond to an intermediate level of asepsis requirement; and Type C operating rooms, which have the lowest level of asepsis requirement. *Figure 21* specifies the different classifications of operating rooms according to various standards.

Tipo quirófano	UNE 100713:2005	UNE-EN ISO 14644-1:2000	Denominación quirófano	Tipo de intervención
A	Clase I	ISO clase 5	Quirófanos de alta tecnología. Cirugía especial.	Transplantes de órganos, cirugía cardíaca, cirugía vascular, cirugía ortopédica con implantes, neurocirugía,...
B	Clase I	ISO clase 7	Quirófanos convencionales	Cirugía convencional y de urgencias. Resto de operaciones quirúrgicas.
C	Clase I	ISO clase 8	Quirófano de cirugía ambulatoria	Cirugía ambulatoria. Salas de partos.

Figure 21 Types and classification of Operating Rooms according to the UNE 100713:2005 and UNE-EN ISO 14644-1:2000

8.2 Gas installation standards

The UNE-EN ISO 7396-1. Medical gas pipeline systems: Pipeline systems for compressed medical gases and vacuum, specifies the requirements for the design, installation, operation, and start-up of the piping systems for compressed medical gases and vacuum. This standard includes requirements for supply systems, ducted distribution systems, control systems, monitoring and alarm systems, and devices that prevent interchangeability of connections between components of different gas/vacuum systems. The standard includes the supply of oxygen, breathing medical compressed air, high-pressure compressed air or nitrogen gas, nitrous oxide, vacuum, and anesthetic gas extraction. In relation to the provision of a centralized CO_2 facility, the cost-benefit ratio should be evaluated in relation to the laparoscopic activity.

The supply of medical gases and vacuum gases to the operating room must be independent from other supplies to the hospital, i.e., direct from the gas plants and with double supply line to guarantee supply even in case of failure or maintenance of one line. At the entrance to each operating room or at the connection to the pendants there must be cut-off valves to make an operating room or pendant independent in case of failure.

Optical and acoustic alarms are necessary to immediately know if there has been a drop in pressure in each gas or vacuum outlet, which can be located in the control panel of each OR or centralized in a specific control area.

8.3 Illumination standards

Lighting installations in operating room areas should be designed in accordance with the Technical Building Code (CTE). The sections dealing with the different aspects of lighting are:

- Section SU4: safety against the risk of inadequate lighting.
- Section HE3: energy efficiency in lighting installations.

For the rest of the parameters, it refers to the UNE-EN 12464-1:2022 standard: Light and lighting - Lighting of work places - Part 1: Indoor work places. This standard specifies the lighting requirements for human beings in indoor workplaces, which meet the comfort and visual performance needs of people with normal vision. This standard also classifies the different indoor areas and establishes the lighting requirements for each of them, indicating the minimum values of parameters such as maintained illumination (Em), unified glare index (UGR) and color rendering index (Ra). It also considers the relationship between the illumination in the area where the task is performed and the surrounding area to avoid fatigue due to excessive contrast and to facilitate accommodation. In the operating room, 10,000 to 100,000 lux are required in the operating area and a minimum illumination of surrounding areas of 500 lux.

8.4 Electrical installation standards

The UNE - HD 60364 – 710: 2014, Low-voltage electrical installations - Part 7-710: Requirements for special installations or locations - Medical locations, define the characteristics and requirements of the electrical installations in medical premises to ensure the safety of patients and medical personnel. In Spain the specific requirements for the electrical installations in Operating Rooms are defined in the ITC-BT-38, which has been explained in the theoretical background in the section 2.3.4.Electrical installation.

8.5 Ventilation standards

The UNE-EN ISO 14644-1:1999, Cleanrooms and associated controlled environments. Part 1: Classification of air cleanliness, contains the classification of air purity in clean rooms and adjoining premises, referring to the concentration of particles contained in the air. Based exclusively on groups of particles whose distribution is distribution is between the critical particle sizes (lower limit) 0.1 µm and 5 µm. Regarding to the air conditioning systems in this type of facilities the current standard is the UNE-100713:2005, Air conditioning in hospitals. This standard contains the requirements to be met by air conditioning installations in hospitals or other buildings with similar activities and the classification of different areas within the hospitals and its respective requirements. Finally, the UNE-EN 1822-1:2020, High efficiency air filters (EPA, HEPA and ULPA), define and classify the filters used in the ventilation of Operating Rooms. These filters must be H13 with an efficiency of 99,95%.

More information about the classification of the OR and its specific regulation about ventilation and climatization can be found in the ventilation subsection from the theoretical background section.

9 CONCLUSIONS

As surgical procedures become increasingly central in healthcare systems, and thus the need of new ORs, it is crucial to understand how different hospitals manage their resources to provide new ORs that fulfill the necessities of the surgical team but also accomplish the current recommendations, and standards. By comparing four tertiary hospitals in Catalonia, this study established the main differences and similitudes found in the architectural and engineering approach taken by each hospital when designing and constructing their ORs.

Returning to the main issue set out in the project objectives, it is worth noting that hospitals do follow different approaches in the construction of their ORs, as had been questioned. Even so, although these approaches differ among hospitals, many common characteristics and patterns have been found that can be explained due to trends and the established regulations. Common elements observed include specialized ventilation systems, surgical lighting, gas, electrical, and audiovisual installations, doors, and ceilings.

As commented before, despite these similarities, the study has uncovered notable differences in the approach and implementation of OR installations. These dissimilarities primarily stem from the specific context and nature of each hospital. Factors such as hospital size, specialization, budget constraints, and historical infrastructure have a significant impact on the design and construction decision made by the institutions.

One key aspect influencing the differences is the budget constraints. Hospitals with limited financial resources may prioritize essential infrastructure elements while making compromises on more advanced features. Such limitation can affect the incorporation of state-of-the-art technologies, equipment redundancy, or additional space for future expansions. Consequently, hospitals with higher budgets may demonstrate more extensive and advanced OR installations. The findings of the study indicate that all four hospitals examined reflect this approach. Hospital Clinic and Hospital Sant Joan de Déu are renowned institutions funded by private foundations, enabling them to incorporate specialized features in their ORs. In contrast, Hospital Germans Trias i Pujol and Hospital Bellvitge are entirely public hospitals, operating within the constraints and limitations associated with public healthcare institutions.

The specialization of hospitals also plays a crucial role in shaping their OR installations. Hospitals with a specific focus may have specialized equipment and infrastructure tailored to their unique requirements. Hospital Sant Joan de Déu exemplifies this approach as a pediatric hospital, wherein all of its Operating Rooms (ORs) have been tailored to meet the unique needs of children. These ORs are adorned with decorations and equipped with projectors for displaying drawings or decorative elements on the walls.

Furthermore, hospital's historical infrastructure and space also play a role in the variations observed. Older hospitals, such as Clinic, may face challenges in retrofitting existing spaces to meet modern OR requirements, leading to compromises in layout, equipment placement, or infrastructure upgrades. In contrast, newer hospitals have the advantage of purpose-built spaces that can be tailored to meet the specific needs of ORs, resulting in more efficient and contemporary designs.

Concerning the future of ORs, integration of digital systems and smart technologies, such as artificial intelligence, is expected to revolutionize OR operations. Additionally, there will be a greater emphasis on infection control measures, including the integration of antimicrobial materials and advanced air filtration systems. Moreover, sustainable practices and energy-efficient solutions will be prioritized to reduce environmental impact and optimize resource utilization. As the healthcare landscape continues to evolve, it is imperative to remain vigilant of emerging trends and technological advancements that shape the future of OR design. By staying abreast of these developments and innovative solutions, hospitals can stay at the forefront of delivering high-quality surgical services that prioritize patient safety, comfort, and optimal outcomes.

To end up with, it could be said that understanding the differences found in this study can provide valuable insights for future OR projects, enabling hospitals to optimize their resources and enhance patient care within their unique contexts.

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11 ANNEXES

ANNEX 1: PICTURES OF THE HOSPITAL CLÍNIC OR


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ANNEX 2: PICTURES OF THE HOSPITAL SANT JOAN DE DÉU OR


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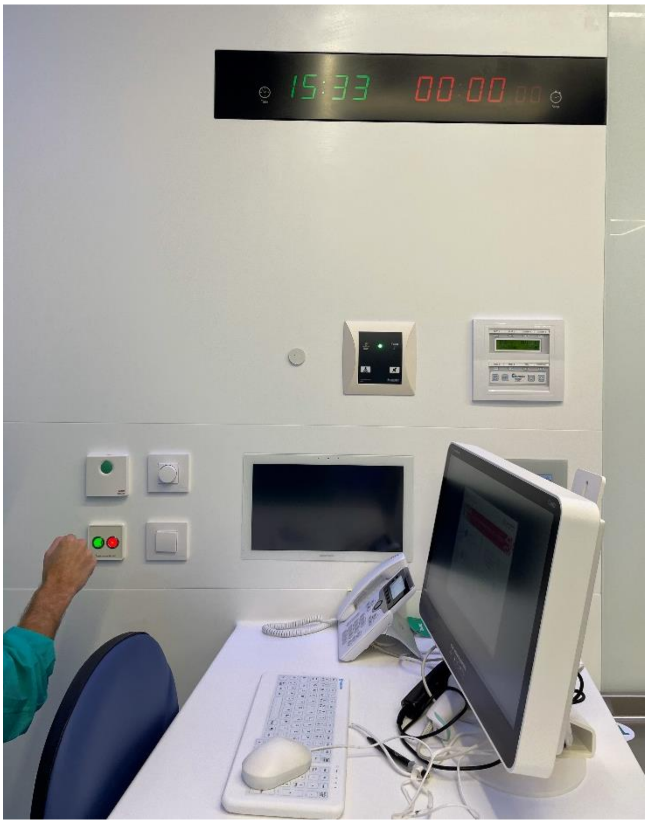
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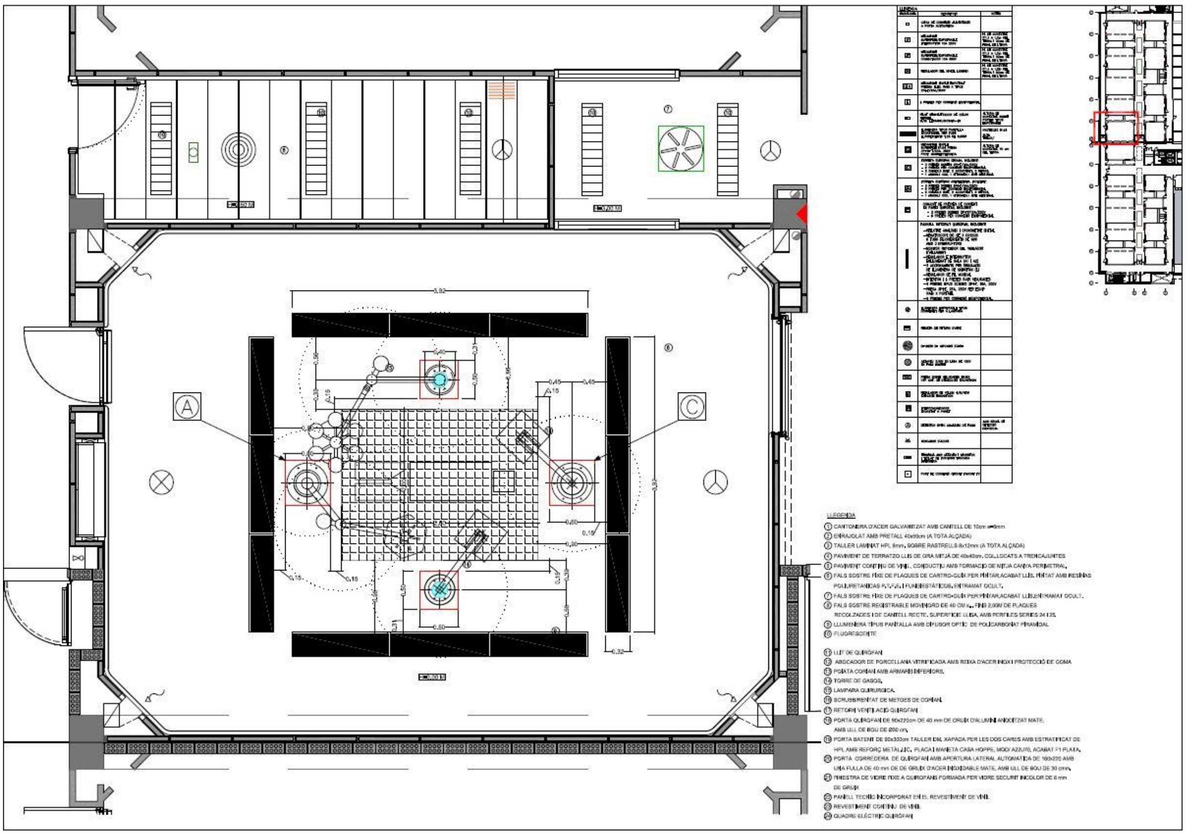
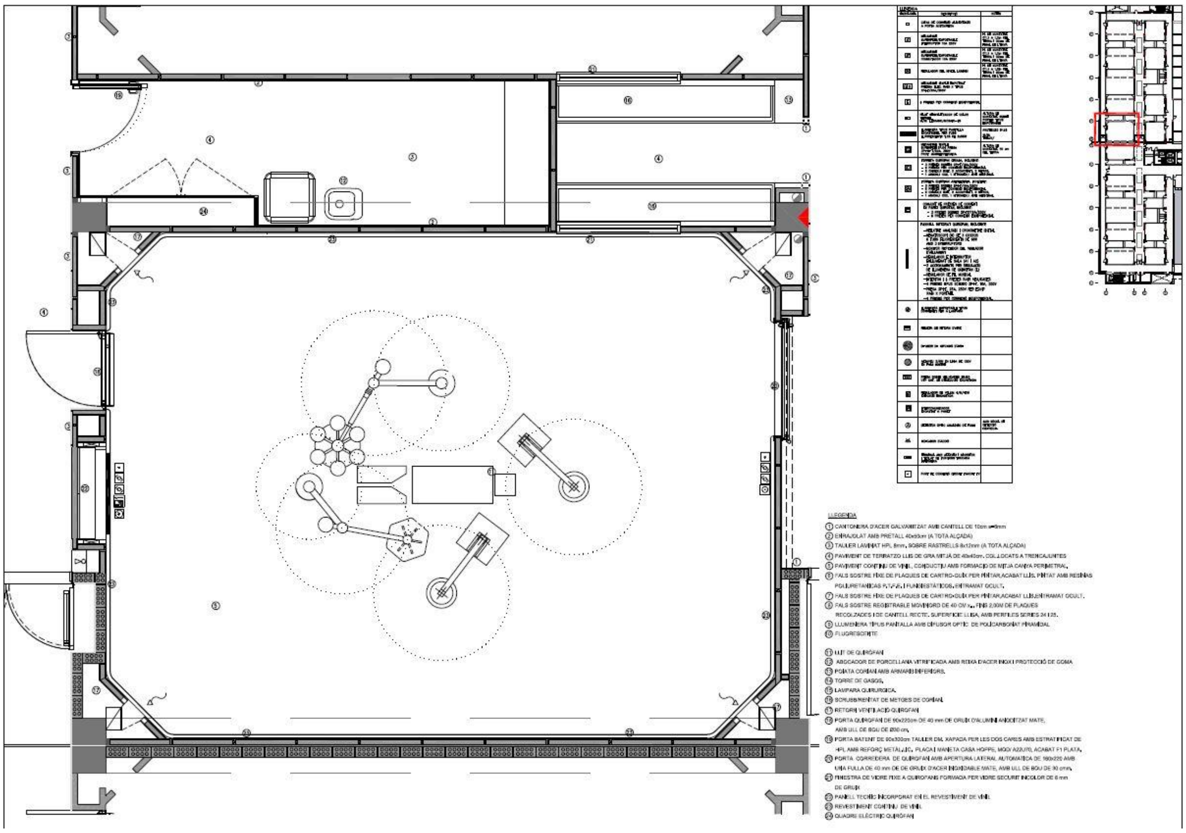
ANNEX 3: BLUEPRINTS OF THE HOSPITAL UNIVERSITARI BELLVITGE OR AND SURGICAL BLOCK


LLEGENDA
1 CANTONERA D'ACER GALVANITZAT AMB CANTELL DE 10cm e=6mm
2 ENRAJOLAT AMB PRETALL 40x90cm (A TOTA ALÇADA)
3 TAULER LAMINAT HPL 8mm, SOBRE RASTRELLS 8x12mm (A TOTA ALÇADA)
4 PAVIMENT DE TERRATZO LLIS DE GRA MITJÀ DE 40x40cm, COL.LOCATS A TRENCAJUNTES
5 PAVIMENT CONTINU DE VINIL, CONDUCTIU AMB FORMACIO DE MITJA CANYA PERIMETRAL,
6 FALS SOSTRE FIXE DE PLAQUES DE CARTRO-GUIX PER PINTAR,ACABAT LLIS, PINTAT AMB RESINAS POLIURETANICAS P.T.F.E. I FUNGIESTÁTICOS, ENTRAMAT OCULT.
7 FALS SOSTRE FIXE DE PLAQUES DE CARTRO-GUIX PER PINTAR,ACABAT LLIS,ENTRAMAT OCULT.
8 FALS SOSTRE REGISTRABLE MOVINORD DE 40 CM x.. FINS 2,00M DE PLAQUES RECOLZADES I DE CANTELL RECTE. SUPERFICIE LLISA, AMB PERFILES SERIES 24 I 25.
9 LLUMENERA TIPUS PANTALLA AMB DIFUSOR OPTIC DE POLICARBONAT PIRAMIDAL
10 FLUORESCENTE
11 LLIT DE QUIRÒFAN
ABOCADOR DE PORCELLANA VITRIFICADA AMB REIXA D'ACER INOX I PROTECCIÓ DE GOMA
13 POIATA CORIAN AMB ARMARIS INFERIORS.
14 TORRE DE GASOS.
15 LAMPARA QUIRURGICA.
16 SCRUBB/RENTAT DE METGES DE CORIAN.
17 RETORN VENTILACIO QUIROFAN
18 PORTA QUIROFAN DE 90x220cm DE 40 mm DE GRUIX D'ALUMINI ANODITZAT MATE, AMB ULL DE BOU DE ⌀30 cm,
19 PORTA BATENT DE 90x300cm TAULER DM. XAPADA PER LES DOS CARES AMB ESTRATIFICAT DE HPL AMB REFORÇ METÀL.LIC. PLACA I MANETA CASA HOPPE, MOD/ AZZURO, ACABAT F1 PLATA.
20 PORTA CORREDERA DE QUIROFAN AMB APERTURA LATERAL AUTOMATICA DE 180x220 AMB UNA FULLA DE 40 mm DE DE GRUIX D'ACER INOXIDABLE MATE, AMB ULL DE BOU DE 30 cm.
21 FINESTRA DE VIDRE FIXE A QUIROFANS FORMADA PER VIDRE SECURIT INCOLOR DE 6 mm DE GRUIX
22 PANELL TECNIC INCORPORAT EN EL REVESTIMENT DE VINIL
23 REVESTIMENT CONTINU DE VINIL
24 QUADRE ELÈCTRIC QUIRÒFAN


LLEGENDA
1 CANTONERA D'ACER GALVANITZAT AMB CANTELL DE 10cm e=6mm
2 ENRAJOLAT AMB PRETALL 40x90cm (A TOTA ALÇADA)
3 TAULER LAMINAT HPL 8mm, SOBRE RASTRELLS 8x12mm (A TOTA ALÇADA)
4 PAVIMENT DE TERRATZO LLIS DE GRA MITJÀ DE 40x40cm, COL.LOCATS A TRENCAJUNTES
5 PAVIMENT CONTINU DE VINIL, CONDUCTIU AMB FORMACIO DE MITJA CANYA PERIMETRAL,
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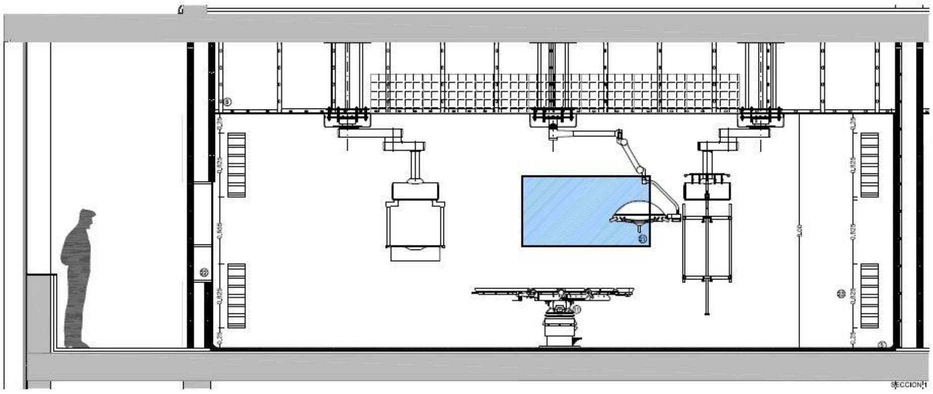

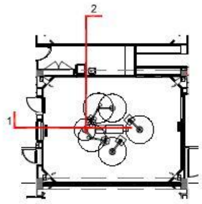

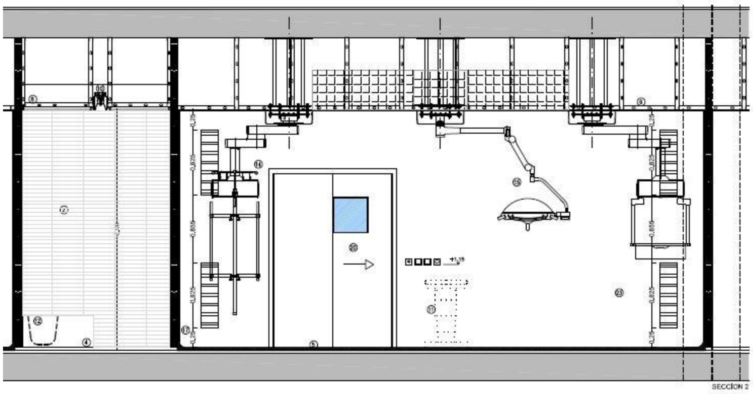

LLEGENDA

1. CANTONERA D'ACER GALVANITZAT AMB CANTELL DE 10cm e=6mm
2. ENRAJOLAT AMB PRETALL 40x90cm (A TOTA ALÇADA)
3. TAULER LAMINAT HPL 8mm, SOBRE RASTRELLS 8x12mm (A TOTA ALÇADA)
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5. PAVIMENT CONTINU DE VINIL, CONDUCTIU AMB FORMACIÓ DE MITJA CANYA PERIMETRAL.
6. FALS SOSTRE FIXE DE PLAQUES DE CARTRO-GUIX PER PINTAR,ACABAT LLIS, PINTAT AMB RESINAS POLIURETANICAS P.T.F.E. I FUNGIESTÀTICOS, ENTRAMAT OCULT.
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21. FINESTRA DE VIDRE FIXE A QUIROFANS FORMADA PER VIDRE SECURIT INCOLOR DE 8 mm DE GRUIX
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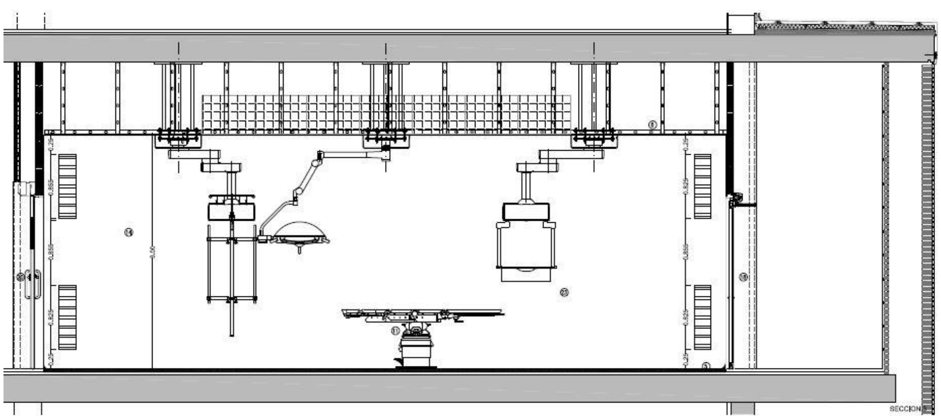

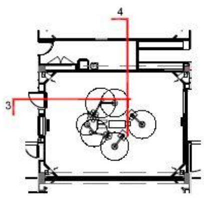

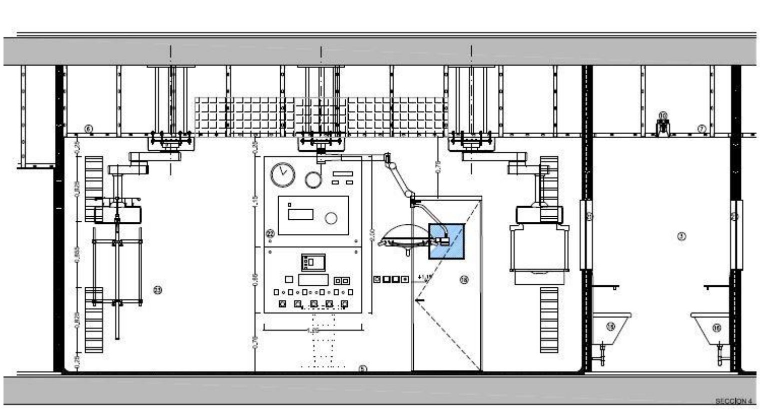

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23. REVESTIMENT CONTINU DE VINIL
24. QUADRE ELÈCTRIC QUIRÒFAN

ANNEX 4: PICTURES OF THE HOSPITAL UNIVERSITARI BELLVITGE OR

ANNEX 5: PICTURES OF THE HOSPITAL GERMANS TRIAS I PUJOL OR.


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D-458

ANNEX 6: COMPLETE TABLE INFRASTRUCTURE VARIABLES

VARIABLES	HOSPITAL CLÍNIC	GERMANS TRIAS I PUJOL	HOSPITAL BELLVITGE	HOSPITAL SANT JOAN DE DÉU
Width (cm)	588	731	673	666
Length (cm)	829	881	875	699
Height (cm)	271	289	300	299
Wall Material/s	Corian covered by glass	Gypsum board & PTFE	Vinyl	Glass
Wall Color/s	White	White	Beige	White
Wall Continuousness	Yes	Yes	Yes	Yes
Wall printed panels	Yes (beach motives wall)	No	No	Yes (birds in walls and ceilings)
Wall Integrated Monitors	2	0	1	2
Flooring Material/s	PVC Tarkett Conductive	PVC Tarkett Conductive	PVC Tarkett Conductive	PVC Tarkett Conductive
Flooring Color/s	Dark Grey & Light Grey	Blue	Grey	Grey & Blue
Flooring Continuousnes	Yes	Yes	Yes	Yes
Corner Continuousnes	Yes	Yes	Yes	Yes
Ceiling Material/s	Gypsum board & PTFE	Gypsum board & PTFE	Gypsum board & PTFE	Gypsum board & PTFE
Ceiling Color/s	White	Light Grey	White	White
Ceiling Continuousness	Yes	No	Yes	Yes
Number Doors	2	2	2	2
Door Opening System	Touchless System	Push button	Push Button	Touchless System & Push Button
Door Size (cm)	160x220	NaN	160x220	160x220
Door material/s	Stainless Steel & HPL	Stainless Steel & HPL	Stainless Steel & HPL	Stainless Steel & HPL
Number Windows	0	0	1	3
Number Pass Boxes	0	0	0	0
Number Pendants	4	4	4	4

ANNEX 7: COMPLETE TABLE INSTALLATION AND EQUIPMENT VARIABLES

VARIABLES	HOSPITAL CLÍNIC	GERMANS TRIAS I PUJOL	HOSPITAL BELLVITGE	HOSPITAL SANT JOAN DE DÉU
Number Surgical Lamps	2	2	1	2
Surgical Lamp Type	Getinge Maquet Volista	Steris Xled 3	Trumpf Medical Iled7	Trumpf Medical TruLight 3300
Central Illumination	RGB LED & White Light LED	White Light LED	White Light LED	White Light LED
Perimetral Ceiling Illumination	RGB LED	No presence	No presence	RGB LED
Perimetral Flooring Illumination	RGB LED	No presence	No presence	RGB LED
Num. Medical Air Outlets	4	4	2	3
Num. Oxygen Outlets	5	4	4	3
Num. Carbon Dioxide Outlets	1	0	2	2
Num. Nitrogen Outlets	0	0	2	0
Num. Nitrous Oxide Outlets	0	0	4	3
Num. Vacuum Outlets	5	4	4	6
Num. AGGS Outlets	2	2	4	2
Num. Air supply	Laminar flux	Laminar flux	Laminar flux	Laminar flux
Num. Air return	8	8	8	8
Laminar Flux	1	1	1	1
Num. Power plugs	24	50	24	29
Num. Monitors	2 pendant & 2 wall integrated	3 pendant	2 pendant & 1 wall integrated	2 pendant & 2 wall integrated
Num. Audio Outputs	4	NaN	0	2
Num. Video Outputs	3	4	2	9
Num. Network Connections	12	8	6	9
Num. Cameras	1	2	1	1
Surgical Table Type	Fixed	Fixed	Mobile	Mobile
Num. Speakers	4	2	2	4
Corridor size	205	223	NaN	234