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Final Degree Project

Biomedical Engineering Degree

" Analysis and Redesign Proposal for the Integration Systems and Technical Panels of Operating Room "

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Abstract

The increasing number of surgical procedures emphasizes the importance of operating rooms in hospitals. They are currently experiencing a digital revolution, reflecting the future direction of this field. The correct configuration of all systems of operating rooms is essential for enhancing surgical efficiency and reducing costs. Technical panels, also known as control panels, play a vital role in configuring operating rooms. These panels have evolved from basic modular systems to more interactive and user-friendly devices. During this study, the technical control panels in operating rooms and the existing solutions in the market are evaluated. From a theoretical perspective, the systems that need to be integrated and how they are integrated through a central integration server are being studied. On the other hand, a semi-functional mockup of the graphical user interface has been created using the Figma tool. The project includes the new way of interacting with the users and the Functional Plan of the user interface. Additionally, a demonstration video has been included to assess the user experience.

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Glossary of Abbreviations

OR	Operating Room
TCP	Theatre Control Panel
UPS	Uninterruptible Power Supplies
SAI	*Sistema d' Alimentació Ininterrompuda*
HEPA	High Efficiency Particular Air
HVAC	Heating, Ventilating and Air Conditioning

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1. Introduction

The operating room (OR) is a critical environment where healthcare providers conduct complex procedures that require precision, accuracy, and safety. The technological advancements within the surgical theater play a crucial role in ensuring the best possible outcomes for patients. The importance of ORs lies in the fact that they are where complex procedures are carried out, requiring a high level of technical expertise and advanced equipment. The efficient performance of ORs is crucial for patient safety, as well as for the success of surgical interventions. In recent years, there has been a growing trend towards digital integration in ORs, which is aimed at improving their efficiency and reducing the risk of errors.

One of the key components of ORs are the technical panels, which are used to control the various equipment and systems in the operating theatre. These panels have evolved over the years and have become increasingly sophisticated, incorporating advanced features such as touchscreens and video displays. However, there is still room for improvement in terms of their design and functionality, particularly in relation to digital integration with the OR.

1.1. Motivation and Aim of the Project

The motivation for this project is rooted in the importance of ORs and the need to ensure that they are equipped with the latest technology and equipment to provide the best possible care for patients. The aim of the project is to study the technical panels of ORs and propose a redesign for the digital integration of the operating room technical panels.

The trend towards digital integration in ORs has been driven by the need to improve efficiency, reduce errors, and enhance patient safety. One example of this is the use of electronic medical records, which allows healthcare professionals to access patient data in real-time during surgical procedures. Another example is the use of digital imaging systems, which allow surgeons to view high-quality images of the patient's anatomy during the procedure.

Despite the many benefits of digital integration in ORs, there are still challenges that need to be addressed. For example, the design and functionality of the technical panels can affect the efficiency and safety of the ORs. In addition, there is a need to ensure that the systems used in ORs are secure and reliable.

1.2. Objective

The objectives of this project are as follows:

- To understand the functioning of the technical panels in ORs.
- To analyze the different solutions and control systems used in ORs.
- To propose a redesign for the digital integration of the technical panels in ORs.
- To make a semi-functional mockup of the graphic user interface of the technical panel redesigned

To achieve these objectives, the project will be divided into three stages. The first stage will involve an analysis of the market and a deep understanding of the functioning of the technical panels. The second stage will involve a theoretical study of the current solutions and control systems used in ORs. Finally, in the third stage, a new solution will be proposed, taking into account the findings from the previous stages and incorporating digitalization into the design of the technical panels.

1.3. Structure and Methodology

The project will be divided into three stages, as described above. The first stage will involve an analysis of the market and an understanding of the functioning of the technical panels. This stage will include a review of the literature on ORs and technical panels, as well as an analysis of the market for OR equipment and systems. The second stage will involve a theoretical study of the current solutions and control systems used in ORs. This stage will include a review of the literature on OR control systems and an analysis of the systems used in the Hospital Clinic de Barcelona. Finally, in the third stage, a new solution will be proposed, considering the findings from the previous stages and incorporating digital integration into the design of the technical panels.

The methodology for the project will be based on a combination of cooperation with healthcare professionals and experts in the field of OR design and technology, as part of the project it will be carried out with Infrastructure Department colleagues. This will involve a detailed analysis of the functionality and design of the technical panels, as well as an assessment of their effectiveness in supporting surgical procedures.

The proposed solution for the digital integration of the technical panels will be based on the findings from the previous stages of the project. The solution will consider the needs of healthcare professionals, patients, and the technical requirements of the OR environment. The proposed solution will also be assessed for its feasibility and potential impact on the efficiency and safety of the ORs.

1.4. Limitations

One of the main limitations of this project is the lack of available information on OR technology and design. There is still a significant knowledge gap in this field, which makes it difficult to develop a comprehensive understanding of the technical panels used in ORs. This limitation may affect the accuracy and completeness of the findings and proposals in this project.

Another limitation is the difficulty of conducting a fully functional proof of concept for the proposed solution. ORs are complex and high-risk environments, which makes it challenging to implement new solutions without thorough testing and validation. Therefore, the proposed solution may need to be refined and validated through further research and testing before it can be implemented in real-world settings.

2. Background

The following section describes an operating room and its evolution and technologically disruptive changes over the years. It will talk about the definition of the concept of hospital and surgical areas, and its subsequent technical evolution. Moreover, it is also discussed all the digital integration surrounding the operating rooms and what is the correct concept when defining a technical panel of an operating room. It also discusses the state of the art of these, while pointing out what are the main needs that consumers have.

2.1. Design Evolution in Hospital Surgical Areas

The years go by, and hospitals evolve, and they evolve as much as technologies grow. Technology is advancing at the speed of light, just look at it in terms of communication. Forty years ago, the first cell phone was born at a very high cost for its customers. However, nowadays everyone can have one of them, as they are accessible and affordable for most people. This is the key point; technologies must advance to improve the current solutions but at the same time must be accessible to everyone.

To get into the situation, let's define the concept of a hospital and specifically a surgical area. Bearing in mind that a hospital is a space of care and healing, where science, technology and the art of medicine are combined, the most important of them is the objective of providing comprehensive care to patients and their families. In addition, hospitals are centers for research, education, and training of healthcare providers.

Hospitals include surgical areas made up of ORs, which are spaces designed for the performance of surgical interventions and other invasive procedures. These areas are usually equipped with state-of-the-art technology and staffed by highly trained professionals to ensure the safety and success of surgical interventions. Surgical areas also include recovery rooms and ICUs to care for patients after surgery.

Figure 1. Old Operating Room in the old Hospital Saint Thomas in London. [1]

It is true that hospitals have evolved, but probably no other hospital space has changed as much as the operating rooms have. If we go back in history, we can see that it was in the 18th century when the term Operation Theaters was first used, where surgeries were performed without anesthesia or antiseptics. At that time, surgeons showed their skills to the audience in the first surgical facilities that were like an amphitheater. The surgical intervention was shown as if it was a show for the audience. See Figure 1.

Surgical procedures began to gain a scientific basis when anesthesia was invented in 1840 and later in 1867 with the research on asepsis and sterilization principles thanks to Joseph Lister. Gradually, the evidence begins to give importance to the preparation and cleanliness of the material, space, and people involved directly in the intervention. Post-operative survival rates improved notably and pain during surgery was eradicated. [2]

After a few years, Paul Nelson in 1931 developed the first modern operating room at the Lille Hospital, where he was concerned with proper lighting, protection of the surgical space, and where the separation of clean-dirty flows was implemented for the first time. He changed the form of operating rooms, which become ovoid, using glass floors and walls. [3] Over the years, airlocks were added to this model to control air pressure and sterile environment. In addition, separate air conditioning units are incorporated. Many of these references mentioned are the ones we have most in mind and imagine when we want to refer to an operating room. See Figure 2.

Figure 2. Operating room where Christiaan Barnard and his team performed the first heart transplant in 1967. [4]

Modern operating rooms (Figure 3) have mainly focused on separating clean-dirty circuits to avoid contamination and ensure the sterility of surgical equipment. ORs are designed following the principle of a single direction of flow, from clean to dirty, and sterilization before returning to the clean circuit. Moreover, the design of the clean area of the operating room should be well limited, considering a surgical washing area located next to the operating room. It is certainly true that the implementation of infection control practices in hospitals is one of the most important issues in modern medical practice. Bearing in mind that it is focused on the principles of workflow from clean to dirty, not only depending on the proper design of surgical units, but it also focuses on the movement of surgical staff. [5] When we refer to the design of operating rooms, many types of cleaning circuits can be implemented, some with double corridors or others that prefer to optimize the areas and not use corridors. There are no written criteria as to which method is the correct one; in the end, it is the method that best suits the hospital, its staff, and its surgical activity.

Dimensions are a crucial issue for the correct design of an operating room. For its construction, a minimum usable area of 40 m² with a clear height of at least 3 meters from the floor to the false ceiling is considered. The walls should ideally form circles facilitating disinfection, avoiding corners that form a 90-degree angle. Corners contribute to the proliferation of bacteria inside the room. However, space is limited in hospitals and a formula is sought to optimize the space by forming rectangles where the corners should be as rounded as possible. When designing these spaces, it is considered that the walls must be hard, non-porous, impermeable, and washable. The most used materials are a double coating of Corian and glass for walls and vinyl for floor. In addition, the floor must be conductive and connected to the ground.

Figure 3. A modern Operating Room nowadays in Hospital Clinic.

In an operating room, the doors are closely related to the possible entry of pathogens into the room. The tendency is to reduce the number of accesses to the OR, always respecting the flow of clean-dirty areas. The type of door used in operating rooms should be automatic sliding. The use of slamming doors should be avoided as they can cause air currents and an increased risk of possible contamination. [6]

It has an immediate impact on the need to maintain air quality inside the OR. The OR typically maintains the high air pressure to ensure that air is displaced from the ORs to adjacent areas, thus minimizing air entry into the room. Even when the door is opened, the pressure differential does not allow the entry of any pathogens that could cause infection. [7] The lights installed in the operating rooms must be adequate, focusing mainly on the use of LEDs.

In addition, it must have excellent hyperconnectivity in case of emergency. This includes installation of telephones, intercoms, buzzers, emergency lights and the IT part of the room.
The trend in new operating rooms is focused on integrating minimally invasive surgery and overcoming the limitations of traditional setups. Ergonomic factors play a crucial role in the perceptual, cognitive, and motor skills of the surgical team. Communication protocols and strategies are being implemented to improve communication clarity, reduce distractions, and enhance workflow and safety. The integrated operating room aims to minimize sources of stress, fatigue, and interruptions, promoting harmony among the team. [8]

In the future, the use of advanced imaging technologies will be essential in surgical procedures. These technologies overcome limitations in visualization, improve surgical navigation, and enable real-time imaging. By integrating pre-operative data and intra-operative techniques, surgeons can enhance precision, decision-making, and patient outcomes. Image-guided technologies enable less invasive tumor ablation methods like radiofrequency ablation and focused radiation, reducing the need for extensive resection. Access techniques such as image-guided vascular access further facilitate minimally invasive interventions.

When it comes to robotic surgery, it is crucial to bear in mind that technology has evolved to become more compact and efficient, occupying less space in the operating room. It offers enhanced haptic sensation, tissue recognition, and real-time diagnostics. The main goal was to replicate the surgeon's hand motions with increased precision and visualization using 3D video images. While the da Vinci Surgical System is the most well-known and widely used robotic surgery solution, there are also several alternative systems available such as Medtronic's Hugo Surgical System and CMR Surgical's portable Versius Surgical System. [9]

2.2. State of the art

State of the art involves studying and understanding the latest developments relevant to the project. It helps identify cutting-edge technologies and practices to incorporate, ensuring that the project stays up-to-date and maximizes its potential for success.

2.2.1. Smart Operating Rooms

In the surgical field of healthcare, digitalization has had a significant impact, especially with the introduction of "digital surgery" also known as "surgery 4.0". This new way of surgery represents the ultimate expression of the consequences of digitalization in this field.

The accessibility of information is a key point for smart operating rooms, which allow the sharing and availability of the patient's clinical history at any time. This fact is closely linked to the fact of having a good connectivity and being able to access all patient data, as surgeries are becoming more complex and require a multidisciplinary staff, then reviewing this information is essential to make a good performance. [9]

This new phase of surgery is based on digitization and has been developed in parallel with the consolidation of video-assisted surgery. The growth of these techniques has allowed the incorporation of advanced audiovisual technologies in operating rooms, improving visualization and communication during surgical procedures. Real-time visualization systems have been implemented, such as endoscopy, and interventional radiology, which allow surgeons to have a detailed view of the anatomy, thus facilitating decision making and the precise performance of procedures. One of the distinctive features of these smart operating rooms is that they offer high quality images on various mobile and fixed screens accessible to all those present during the operation. This allows for better orientation and navigation within the patient's body. It has also contributed to the acquisition of high-definition three-dimensional visualization systems. These systems allow a more immersive and detailed view of the surgical site. The content projected on the operating room screens comes from a whole set of cameras installed in the operating rooms that allow viewing the surgery from different points of view. There are typically a minimum of two cameras: an ambient camera, and a camera hidden inside one of the surgical lights. In addition, depending on the surgical specialty there will also be the internal camera. [10]

In modern operating rooms, the surgeon has full control over the surgery. He can view images of the surgical field, medical reports, and vital signs on separate monitors, as mentioned above. He also monitors parameters such as lighting, camera position and image quality. In addition, environmental conditions such as temperature, humidity and general illumination are monitored. The operating tables can be mobile or fixed, some controlled with wireless remotes. Modern operating rooms have technical panels integrated into the wall to control variables and provide additional functions.

These large spaces are designed to have a minimal presence of cables on the floor. Instead, they have a rack located outside the operating room, in an area designated as the "dirty zone". Cables run to the rack from inside the walls of the operating room. Digital surgery is characterized by the integration of digital technologies and intelligent systems at all stages of the surgical process. From diagnosis to preoperative planning, procedure execution, and postoperative follow-up, digital tools are used to optimize and improve surgical outcomes. [11]

Surgery 4.0 uses technologies such as augmented reality, virtual reality, surgical robotics, artificial intelligence, and real-time data analysis. These tools give surgeons a more accurate and detailed view of the area to be treated, facilitating decision-making, and improving the precision of procedures. In addition, digital surgery promotes collaboration and communication among members of the medical team. Integrated communication systems enable the transmission of images and data in real-time, facilitating the participation of remote experts and the exchange of knowledge.

Another important aspect of digital surgery is data collection and analysis. During surgery, biometric and monitoring data can be collected, as well as images and videos of the procedure. This data can then be analyzed to evaluate the surgeon's performance, identify areas for improvement, and contribute to the research and development of new techniques and treatments.

2.2.2. Main actors and necessities

It is worth noting that the main locations where operating rooms can be found are predominantly in second and third-level hospitals. The operating rooms in these hospitals will be the main actors, as they all have the need to have operating room technical panels to control systems and features involved in the operating theatre.

According to data from the World Health Organization (WHO), approximately 312,9 million surgeries were performed worldwide in 2012. [12] Nevertheless, if we narrow our focus to our country, Hospital Clinic stands out by performing over 28.000 surgeries in its 31 operating rooms, making it one of the hospitals with the highest surgical activity in Catalonia. [13] Additionally, Hospital Vall Hebron conducted more than 34.000 operations last year, witnessing a 16,9% increase compared to the previous year activity. [14] Similarly, Hospital de Bellvitge recorded similar figures, with around 20.000 operations being performed each year in its 33 operating rooms.

This information is of great importance as it highlights the pivotal role that operating rooms play in the lives of numerous individuals. It emphasizes the need for operating rooms to be adequately prepared and optimized to ensure optimal surgical activity, considering the fact that the lives of millions of people are at stake each year. Technological advances in operating rooms are essential to meet these demands and to facilitate the work of the surgical team, thus underscoring the significance of staying up to date with evolving technologies.

When it comes to the need of doing a comprehensive study and redesigning technical panels in operating rooms, it is important to acknowledge that while most operating rooms currently have technical control panels, the evolution of surgical equipment and the digitization of operating rooms needs an immediate update, and this implies an adaptation of these panels to meet the specific requirements of the medical team. [8]

Furthermore, bringing together all the control of the technological elements of the operating room in a single point and standardizing the technical panels of all operating rooms is crucial to increase patient safety, improve process efficiency or guarantee the performance of the surgical team.

In conclusion, when discussing operating rooms, it is essentially addressed to the well-being and life of a patient. By streamlining the preoperative processes for the surgical team and optimizing the preparation of the operating room, we can significantly enhance their ability to perform their duties effectively. The technical panels serve as the key instruments for controlling the various integrated systems within an operating room. Therefore, proposing a new redesign that standardizes these panels and makes them more user-friendly for the staff will greatly facilitate their implementation. This, in turn, enables a smoother workflow, reduces the risk of errors, and enhances overall patient care.

2.2.3. Operating Room Technical Panels

The primary goal of state-of-the-art operating room (OR) technical panels, also known as theatre or surgeon control panels (TCP), is to centralize and optimize the control and visualization systems within the OR. These advanced devices are specifically designed to ensure a comfortable environment for both the patient and the surgical team, while also providing the optimal working conditions required for successful surgical procedures. One of the key features of these operating theatre control panels is their ability to regulate the environment within the theatre. They combine the controls for lighting, temperature, humidity, ventilation, and critical alarms into a single interface panel. In fact, there can be included any technology involved in the OR. [15]

Traditionally, control panels in operating rooms have been fragmented, with separate units dedicated to controlling different aspects of the room. These units were recessed into the wall and featured buttons and keypads for control. Initially introduced with stainless steel fronts in the 1990s, technical panels now offer various options such as fiber alloy, aluminum alloys, glass alloys, and Corian. This fragment set up serious challenges for surgical teams, as they had to navigate through multiple panels to manage different elements. [16]

To address this issue, integrated control panels have been developed, consolidating the management of various functions into a single interface in a touch screen surface. This intuitive and user-friendly interface empowers the clinical team to easily manage and adjust the entire operating theatre environment with just a touch. However, the lack of standardization in operating room control panels hinders usability, emphasizing the need for a consistent and intuitive design.

Figure 4. Old generation TCP with modular control systems with buttons (left) and control panel in a touchscreen device, (right). [16, 17].

Bearing in mind that technical panels provide a wide range of functionalities, in addition to their control and display features, some of these panels are also equipped with electrical outlets, gas outlets, and even an X-ray viewer. This integration facilitates efficient and convenient access to essential resources during surgical procedures. However, for the purpose of our redesign, we will focus only on the control and visualization functions of the panel, as the other physical components may have limited influence on the redesign process.

Nevertheless, despite the advancements, the Hospital Clinic of Barcelona, known as one of the most technologically developed hospitals in Europe, still employs the old generation technical panels in some of their OR's. Even so, they have started to implement integrated solutions, but they have not yet met the expected standards of user-friendliness, thus not facilitating the work of the medical team.

In operating rooms, it's important to prevent infections by choosing the optimal material for maintaining cleanliness. The control panels are designed to be easily cleaned and disinfected, with a special anti-microbial finish that reduces the risk of contamination and the spread of bacteria. The advanced operating room control panels provide a centralized, easy-to-use, and customizable solution for managing the theatre environment. They improve workflow efficiency, reduce the chance of mistakes, and prioritize infection prevention. [18]

3. Market Analysis

In this third section, the market analysis will be presented, which includes the current state of the situation, that is, the level of digitization in surgical areas; the main manufacturers of operating room technical panels; and the most innovative proposals available in the market regarding theatre control panels.

3.1. State of the situation: Digitalization of surgical areas

In recent years, there has been significant growth in the field of video-assisted surgery, driven by the integration of surgical robots and minimally invasive surgery. [19] However, it is important to view these advancements as components of an integrated environment that is the operating room, which can be controlled from the operating room technical panel. [9]

The role of video technology in surgery has been able to improve hospital care and empower it over the years. Medical image control systems have been developed, providing hospitals with a certain level of independence from thirds. The implementation of these systems allows surgical areas to be autonomous in managing the audiovisual material generated before and after the procedure. [19]

Digital twins are a clear representation of the transformation in the surgical world. Digital clones serve as virtual representations of patients, systems, or procedures. Digital twins can be achieved through extensive data collection that will be used to predict situations and complications, diagnose diseases and customize treatments. [20] The implementation of the Internet of Things in hospitals has been crucial in storing all this data and, thus, building intelligent hospitals that allow us to improve the quality of ambient surroundings of surgical areas. [21]

3.2. Main manufacturers of surgical technical panels

In Table 1, a comparative study is carried out on the possible solutions that can be found in the market. The following are the main companies that have been producing technical operating room panels for years: Carburos Medica [22], Electrolumen [23], Karl Storz [24], Schönn [25], Starckstrom [26], Tedisel [27], and Transforma [28].

Table 1. Comparative study of the possible market solutions.

	Carburos Medica	*Electrolumen*	*Karl Storz*	*Schönn*	*Starckstrom*	*Tedisel*	*Transforma*
Modular o or with button	Yes	Yes	Yes	No	Yes	Yes	No
Digital	No	No	Yes	Yes	Yes	Yes	Yes
Keyboard	Membrane keyboards mounted on a fold-down drawer.	Membrane keyboards mounted on a fold-down drawer.	Membrane keyboards mounted on a fold-down drawer.	No	No	Membrane keyboards mounted on a fold-down drawer.	No
Dimensions	1,95 x 1,5 m	2 x 1,5 m	Not found	21,5" touch screen	Modular version: 0,93 x 0,63 m Digital model: 21,5" touch screen.	1,25 x 1,05 m with 15" touch screen.	21,5" touch screen
Model	Modular	Modular	Mixed	Digital	Modular or Digital	Mixed	Digital
Clock	Yes	Yes	Yes, modular	Yes	Yes, both models	Yes, modular	Yes
Stopwatch	Yes	Yes	Yes, modular	Yes	Yes, both models	Yes, modular	Yes
Gas Alert System	Yes	Yes	Yes, modular	Yes	Yes, both models	Yes, digital	Yes
OR status	Yes	Yes	Yes, modular	Yes	Yes, both models	Yes, digital	Yes
Perimeter Lighting	Yes	Yes	Yes, digital	Yes, not RGB	Yes, in digital model	Yes, digital	Yes
Operating Lights	Yes	Yes	Yes, digital	Yes	Yes, both models	Yes, digital	Yes
HVAC Control	Yes	Yes	Yes, modular	Yes	Yes, both models	Yes, digital	Yes
UPS Alarm	Yes	Yes	Yes, modular	Yes	Yes, both models	Yes, modular	Yes
Show UPS charge status and available time	No	No	No	No	No	No	No
***Phone /* Communication**	Yes	Yes	Yes, digital	Yes	No	Yes, modular	No
Internet access	No	No	Yes, digital	No	No	No	Yes
Operating table position	No	No	No	No	No	No	No
AV System Control	No	No	No, independent system	No	No	Yes, digital	No
Data Recording	No	No	No	No	No	No	No
Music	No	No	No	Yes, by USB	Yes, by Bluetooth	No	Yes
Negatoscope	Yes	Yes	No	No	Yes, in modular model	Yes, modular	No
Gas Outlets	Yes	Yes	Yes, modular	No	Yes, in modular model	Yes, modular	No
Power Socket	Yes	Yes	Yes, modular	No	Yes, in modular model	Yes, modular	No

Currently, more companies that manufacture surgical materials and equipment have also developed different control systems. Tedisel's proposal is one of the most implemented in Spain, as it combines digital model with modular model. As we can see in Figure 5, three types of models have been defined based on whether they provide a completely digital, modular, or mixed version.

Figure 5. From left to right: Mixed Model (Tedisel), Digital Model (Transforma) and Modular Model (Starckstrom). [27, 28, 26].

3.3. Innovation projects on surgical technical panels

In the following section, we present two innovative proposals that have been developed in recent years to control operating room systems.

3.3.1. TedCube

TedCube is an innovative system developed by Spanish company TedCas that enables simultaneous touch-free control of multiple medical devices in the operating room using simple voice commands and/or natural gestures. It was designed to give surgeons access to and control of digital information without interrupting or asking for help. The main advantages is the easy access to vital data during surgery, to have less distraction and greater concentration on the surgery and make the surgery more efficient. [29]

TedCube software is not classified as a medical device, as the technology itself does not perform any action on patient data and does not add any new data processing or analysis functionality. There's no software download required. When it comes to using TedCube, it can be connected via a USB port to your medical workstation as a simple plug-and-play technology. In addition, it is supplied with a standard wireless receiver, and additional receivers can be provided to control multiple devices simultaneously.

Bearing in mind its multifunctionality, it is important to highlight that allows us to control multiple facilities in the OR, such as the neuronavigator, microscope, DICOM viewer, robot, integrated operating room and endoscopy suite. TedCube is designed to work seamlessly with all the popular sensors available in the market, as they have taken customer feedback into account while developing the product. Although the standard package of TedCube includes a Plantronics microphone and a gesture sensor, they are open to collaborating with customers who prefer a different type of sensor. The main sensors used are Myo bracelet, Leap Motion controller, BlasterX Senz3D and the Plantronics Voyager Legend UC.

3.3.2. Optimus Integrated Surgical Environment

The Optimus Integrated Surgical Environment (ISE) stands as a global pioneer, integrating advanced technologies like big data and intelligent lighting. It was built within the renowned Hospital Clinic de Barcelona in 2017. This remarkable technological integration leads to remarkable outcomes, including a significant decrease in infections, enhanced care efficiency, reduced surgical expenses, and improved treatment outcomes. It was a project that was implemented once in Barcelona but for several reasons the company went bankrupt, and does it only exist one in the world, yet it is considered one of the most cutting-edge operating rooms worldwide. [30]

The Optimus Operating Room offers a multitude of benefits that revolutionize operating theatres and improve patient care. Firstly, it addresses the critical issue of hospital-acquired infections, also known as nosocomial infections, by incorporating innovative solutions. The Ozone Sterility System allows the operating room to become fully sterilizable, reducing the risk of infections. By integrating nanoparticle photo-active titanium dioxide (TiO2), which is a disinfectant agent, into the composition of the solid surface material, the Optimus ISE has achieved a wall cladding system that possesses self-sanitizing properties under full-spectrum lighting that inhibits the growth of bacteria. It also uses UV lighting diodes to mitigate potential sources of infection. The Integrated Air Plenum structure enables a flawless laminar flow within the operating room ensuring optimal air circulation. It achieves this by replacing the air volume within the operating room 30 times per hour, employing low velocities to minimize the presence of potential pathogens.

The logical design approach is creating a well-designed and risk-free environment in operating rooms, promoting the well-being of both patients and staff. By simplifying the operating room infrastructure, tripping hazards are minimized, and accidental disconnection is reduced by eliminating wires and implementing floor pods. The implementation of pass-through supply cabinets and larger room sizes minimizes the entry of outside staff, reducing the risk of bringing infectious materials and disrupting surgical activities. Furthermore, all quadrants of the room have radiused corners.

Bearing in mind stressful and tense situations experienced in the Operating Room, creating an environment of calm and confidence is a key aspect. The integration of variable ambient solid-state lighting and improved ergonomics promotes a sense of calm for patients and surgical staff. In the wall cladding system, we can appreciate that all color spectra can be shown using RGB LED's. The Ambiwall lighting system creates a room-within-a-room delimiting the sterile zone. RGB LED backlighting produces a calming glow effect, positively impacting patients and surgical staff. Hue, saturation, and luminosity can be adjusted using the ISE software control interface from an iPad.

Furthermore, it is the pioneer in the maintenance of the circadian rhythm by using modified full-spectrum lighting. By aligning the lighting with the natural patterns of daylight, the OR promotes a healthier sleep-wake cycle, ultimately improving the overall quality of vision for medical professionals. Intelligent and robotic lighting systems, also known as Celestial System, play a crucial role in creating an environment that provides shadow-free, variable intensity, and modifying color temperature, as well as variable focus and spot size. The Plenum structure seamlessly incorporates the hospital's Heating, Ventilating, and Air Conditioning (HVAC) system ducting, encompassing essential components such as surgical lights and sensors (Celestial System), webcams, surgical cameras, microphones, and speakers. [31]

The Optimus ISE sets a new standard for operating rooms, prioritizing patient safety, staff well-being, and optimal surgical performance.

Figure 6. Optimus ISE Operating Room. [31].

4. Concept Engineering

This section includes a description of the different solutions that were considered for user interaction and includes an analysis of the different technological elements that are integrated into our control panel and how they are integrated. From time to time, it is discussed what technical specifications are necessary to implement this integration. Finally, it is determined which is the best environment to make a semi-functional mockup of the new design.

4.1. Interaction with individuals

When it comes to designing a proposal for an operating room control panel is very important which will be the interaction of the users with the solution. In this section, there's a little brainstorming about several alternative solutions studied that are different from the old wall panel with buttons and modular organization.

Firstly, an alternative proposal is to use Augmented Reality (AR) glasses that should be designed to be lightweight. These glasses would eliminate the need for the surgeon to have a physical interaction with the technical panel. This solution would be based on designing a graphical interface that would be superposed in the reality of the OR, without interrupting the surgical vision. In this virtual interface, the surgeon would be able to configure the operating room setup with gestures recognized by augmented reality. The main advantage of this solution is that the surgeon can have access to this data when it raises his head out of his field of vision. Nevertheless, it also has some drawbacks to consider as this technology hasn't extended use in the surgical world as it can limit your field of view due to the AR glasses use. Moreover, surgeons would also need a learning period to become an expert using it. [32]

As a second proposal, it would be interesting to implement sensors in the gloves of surgeons and in a bracelet to manage the operating room control panel. The sensors would detect and translate the gestures into corresponding commands. Surgeons would use predefined hand gestures to perform actions such as adjusting lights, changing the camera on the monitor, etc. This proposal is highly beneficial for the surgery outcomes because it allows to keep the sterile environment during the whole operation. It plays a key role to be natural and ergonomic for the surgeon to use it. Nevertheless, the hand sensors proposal obligates surgeons to memorize different specific gestures, as well as it will be difficult for the recognition system to identify some of the gestures. [33]

In the third place, probably the simplest idea but at the same time the most efficient way, an iPad. iPad is portable, easy to manage, lightweight, and trendy. It could be interesting to design an attractive, intuitive, and user-friendly interface that could be implemented in an iPad to control all systems selected from the operating room. The intuitiveness of the interface and using an iPad helps surgeons not to be expertise, as most of them are used with these devices. It can be fixed to one place but also be mobile when needed, which gives flexibility and convenience. In this way, it is accessible from anywhere in the operating room. However, the size of the screens is one of the main limitations. It requires the use of different servers to integrate all systems to be controlled.

In conclusion, the option where the advantages outweigh most of the drawbacks is the use of an iPad stands out as the most adequate tool for interaction to integrate different control systems of the OR. Its portable ergonomics offer the freedom to create a familiar and easy-to-use interface where medical staff can set up the OR. It is a key point that is the only solution proposed that can be used by more than one person, as it can be shared between people during the surgery. Moreover, in terms of economic viability, it is the most affordable solution when it comes to technology and hardware infrastructure cost.

4.2. Technological elements involved

In this section, we will discuss the technological elements that we aim to integrate into our operating room's technical panel. It will describe what they are and explain why they are important for the surgeon and why are to be all these elements seamlessly integrated into the theater control panel. Additionally, we will explore the methods through which we can make this integration possible.

4.2.1. Illumination and Lighting System

Effective lighting in hospitals and healthcare facilities plays a crucial role in ensuring optimal conditions for carrying out specific tasks and creating a comfortable atmosphere for patients. It is also crucial to prioritize energy efficiency to reduce costs and contribute to environmental preservation. Hospital areas can be categorized based on how much visual attention is needed. Operating rooms can be classified as a space with high visual activity. In recent years, the field of surgical lighting has witnessed significant advancements, primarily driven by the emergence of LED (Light Emitting Diode) technology. This trend has revolutionized the illumination of surgical rooms, replacing traditional incandescent and gas discharge lamps with more efficient and versatile LED lamps. [34]

LED lamps offer several advantages for surgical lighting applications. Firstly, they provide a high-intensity white light that closely resembles natural daylight, ensuring optimal visibility for surgeons. This white light is achieved by combining the primary colors of light: red, green, and blue (RGB). By varying the intensity of each color, a wide range of color temperatures, hues, and intensities can be produced.

By controlling the intensity of red, green, and blue light, it is possible to generate a broad spectrum of colors, including shades of white. This capability allows surgical lighting systems to adapt to specific procedural requirements and enhance visualization during different surgical procedures. For example, certain procedures may benefit from a cooler, bluish light, while others may require a warmer, reddish light. For instance, photodynamic diagnosis administers photosensitive substances and specific wavelength light, like violet light, to detect and diagnose cancerous tissue by fluorescence imaging. This technique enhances visualization and facilitates precise identification and targeting of specific tissues during surgical procedures. [35] See Figure 7. Within modern operating rooms, various types of lighting fixtures are commonly used to optimize illumination. These include:

1. **Operating Light or Surgical Lighthead:** This is the primary light source used in surgical procedures, providing focused illumination on the operation. LED-based surgical lights offer high-intensity white, exceptional color rendering and manual precise positioning capabilities. Surgeons can adjust the intensity and focus of the light to achieve optimal visualization during procedures. Most operating lights use advanced DC dimming technology to control illumination without flickering at high thus avoiding eye damage to the surgeon. [36]
2. **Laminar Ligh**t: Laminar lighting systems utilize LED technology and are typically mounted on the ceiling directly above the surgical table. These systems provide uniform, shadow-free illumination, ensuring consistent illumination across the entire surgical field. Laminar lights can be configured to emit either white light or RGB light, allowing for greater flexibility and customization in the operating room environment.
3. **Perimeter Ceiling Light:** Perimeter LED ceiling lights are installed along the edges of the operating room ceiling. These lights can emit RGB light, allowing creation of dynamic lighting scenarios. They can be used to define a specific environment, to visualize anatomical structures, or even provide visual cues during surgical procedures.
4. **Perimeter Floor Light:** Like perimeter ceiling lights, LED-based perimeter floor lights are installed along the lower edges of the operating room walls or on the floor. These lights also offer RGB functionality, adding an additional layer of lighting control and customization to the surgical environment. They can contribute to an attractive visual framework while ensuring optimal lighting conditions for the team.

They are also very important for cleaning, as they provide a bright contrast to identify dirt and dust on the floor, as well as to appreciate when it is wet.

After delving into specific types of lighting, let's conduct a brief literature search on the quality and design criteria that determine the lighting systems in an operating room. [37]

- Illuminance, measured in lux, refers to the amount of light emitted by a source that reaches a surface vertically or horizontally, if then is divided by surface value, it will be indicating the level of luminous flux (lumens) present. The Operating Light or Surgical Lighthead can provide illuminance levels of up to 100.000 lux. Moreover, it is recommended to establish two levels of illumination: one of minimum 2.000 lux for Laminar Light and other of 1.000 lux for Perimeter Light (both ceiling and floor). This parameter can be controlled from the theatre control panel for all lights in the OR, including perimeter lights, laminar lights, and surgical lamps.

- Blinding can occur either directly from lamps or through reflection from highly reflective surfaces. The CIE (Comisión Internacional de Iluminación) criterion is employed to assess this phenomenon by categorizing activities into five groups and defining corresponding quality classes. Each class is assigned a blinding index based on subjective evaluations. Class "A" represents activities with very high visual demand, having a blinding index of 1.15, while class "B" represents activities with high visual demand, having a blinding index of 1.50.

- The color of an illuminated space will depend on a parameter associated with the lamp, such as the Color Rendering Index (CRI), which in the case of surgical areas should be excellent, with values greater than 90. Additionally, according to the CIE, it will belong to the 1A Color Performance Group.

- The color temperature of a light source is determined by comparing its color to that of light emitted by a black body at a specific temperature, expressed in Kelvin. Lower numbers indicate warmer light, while higher numbers indicate cooler light. The color temperature of Operating Light should be between 4.000 and 5.000 K. This parameter can be controlled from the theatre control panel just for operating lights.

- The focus of the light is key, and it can vary depending on which surgery is performed. For instance, in high precision surgeries, the focus will be smaller and concentrated to illuminate specific areas with higher clarity.

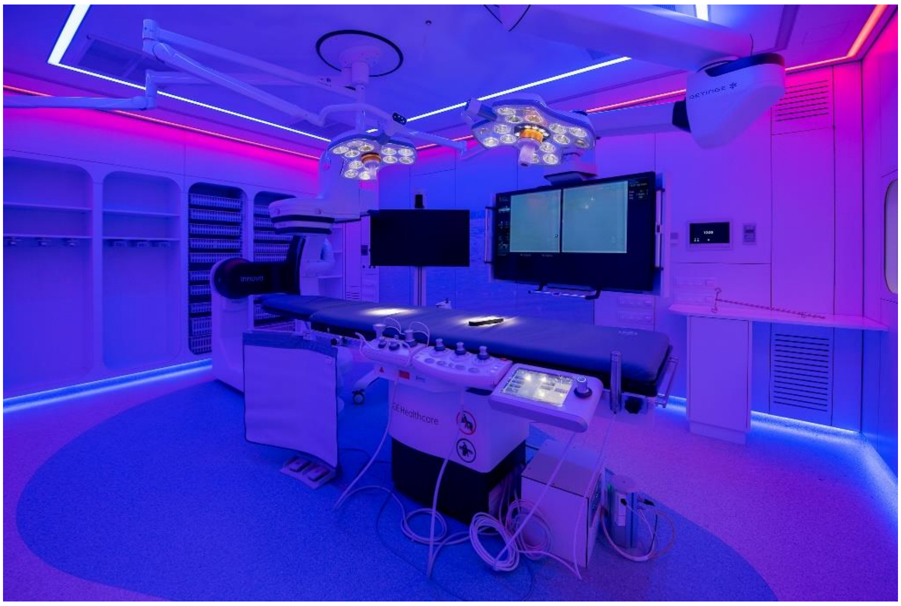

Figure 7. Hemodynamics Operating Room where two Operating Lights, a Laminar Light, and a Perimeter Light, both ceiling and floor, can be clearly observed. Own source.

Proper lighting is a crucial aspect of operating theaters as it allows surgeons to see detailed structures during open surgeries and not to get glare to see screens when it comes to video-assisted surgery. Additionally, well-designed lighting configurations can reduce stress and fatigue among the surgical team with colors configure by RGB LEDs, creating also a more comfortable environment for the patient. Integrating illumination elements into the theatre control panel holds significant value for several reasons.

By integrating lighting controls into the panel, it allows for pre-configured settings to be easily accessed from a central location within the OR. This enables surgeons to optimize lighting conditions for better visibility and precision during procedures, ultimately enhancing surgical outcomes. Furthermore, having lighting controls conveniently located on the control panel saves time and effort, as surgeons and staff no longer need to manually adjust lighting settings by separate switches. It also enhances overall safety in the OR with easy access to lighting controls, adjustments can be made promptly in case of unexpected events or emergencies, ensuring adequate lighting for critical situations, and preventing potential accidents.

Integrating lighting controls into the theatre control panel can be achieved through a combination of technological and design considerations allowing surgeons and staff to access and adjust the lighting settings easily. The control panel should provide intuitive and user-friendly interfaces, with clear labeling and visual indicators for different lighting modes to enable quick adjustments.

To enable integration, the lighting system should be compatible with the control panel through appropriate communication protocols. This can involve the use of centralized lighting control systems, such as DMX (Digital Multiplex), which allow for seamless integration and synchronization of multiple lighting systems. [38]

In the context of an operation room, it is crucial to point out that control of all systems requires servers. Each server must be connected to the central integration server, working as a hub to connect all other systems. Servers are computer systems that facilitate the sharing and exchange of data with other computers to carry out a specific action.

The lighting system server communicates with the central integration server as follows. Firstly, each LED has its three units Red, Green, and Blue, which are integrated into a single chip. The lighting system achieves the desired color by controlling the intensity of each RGB unit in the LED. Each chip usually includes drivers that control the operation of LED units. These drivers interpret signals from the lighting system server and adjust the RGB units accordingly. The lighting system can be controlled through connection protocols, such as RS-232, KNX or DMX, that define the communication approach to send control signals from the servers to LED drivers.

The central integration server acts as a central server where the servers of the other systems that must be controlled are integrated, including the lighting system. The operating room lighting system server could be, for example, the aforementioned DMX, which is a lighting management system. The DMX server could be connected to the central integration server through an RJ45 connector that will allow the main server to communicate with the server in charge of controlling the operating room lighting system. Finally, an intuitive interface connected to the central integration server will allow the control of the lighting in the Theatre Control Panel (TCP).

Thinking out of the box, it could be viable in the future installing occupancy sensors that could detect the presence of individuals in the room and automatically adjust the lighting levels, accordingly, optimizing energy efficiency and ensuring proper illumination when needed. Furthermore, surgeons and staff can use pre-configured lighting scenes, allowing for quick recall of optimal lighting settings without the need for manual adjustments.

4.2.2. Audiovisual System

The implementation of integrated audiovisual (AV) systems in operating rooms has been accelerated by the impact of video-assisted surgery. The main objective of these audiovisual systems is to provide surgeons with high-quality visual and auditory support, enabling a clear and detailed view of the operating area.

In addition, the AV system may incorporate functionality that recording and storage of images and videos, are useful for educational purposes, and reviews. Moreover, preoperative images of the patient can be on these systems to serve as a guide for the surgeon. An adequate audio-visual system in the operating room should allow the transmission in real time of the surgery of other health professionals. This facilitates collaboration, medical education, and joint decision-making.

The operating rooms must have certain features that are essential for the proper integration of a surgical audiovisual system. The video signal must be captured with ambient cameras and lamp cameras. At the same time, it is necessary to capture the audio signal with a ceiling microphone, a wireless microphone, or a headset.

Beyond signal capture, audio must be reproduced on speakers integrated into the ceiling or on headphones. At the same time, it must be possible to reproduce piped music inside the operating room through these loudspeakers. For the correct visualization of images and videos, there must be a high luminosity 4K wall monitor and two 4K medical-grade monitors. In some types of video-assisted surgery, as in the case of laparoscopy, medical-grade monitors are incorporated that can be seen in 3D through 3D glasses. The main reason is to be able to visualize the laparoscopic image in three dimensions and better visualize the internal anatomy of the patient. See Figure 8.

In addition, a multiview system should be included in the wall screen for switching video signals. It would also be interesting to incorporate hospital-centralized recording systems to store a signal from inside the operating room. This audiovisual signal can be stored on portable storage device or ingested through a server for storage and cataloguing on a disk array with redundancy. Finally, it should include different input connections to the integration system, some for medical equipment or others for external inputs. In addition, it should include outputs for the integration system, some for-wall monitors, others for medical grade monitors, and others for external outputs. [39]

Figure 8. Audiovisual integration of an operating room powered by Olympus. Several components can be identified: 1. Wall monitor; 2. Medical-grade monitor; 3. Ambient camera (PTZ); 4. Lamp camera; 5. Audiovisual column; and 6. Operating Room Technical Panel. Source: 40.

These audio and video signals are sent to and from the rack in the technical control room through cabling where it takes place the integrations of all signals in the operating room. For the signals to be managed, it is necessary to have devices that capture and convert the signals into compatible formats for processing, which can be done by encoders/decoders systems that can be found in the rack. Additionally, fiber optic cabling can be employed to transmit the signals, ensuring high image quality.

When it comes to video over ethernet, there is an initial signal captured and encoded by encoders, converting them into a suitable format for network transmission. These encoded signals are then transmitted through an Ethernet network. On the receiving end, decoders are used to decode the signals, converting them back into a usable format for display on devices. In this scenario, the rack system works as the server for audiovisual control, which can be connected to the main integration server. The audiovisual control server plays a crucial role in enabling the central integration server to access and control the audiovisual system.

The Theatre Control Panel (TCP) grants the surgical team the capability to configure various switching and signal management options according to their specific requirements. It empowers them to manage audio, recording, streaming, and storage functionalities. With this control panel, they can select signal sources and adjust quality and resolution of image or video through an intuitive and user-friendly interface. It offers essential controls to efficiently manage and switch between different signals as and when necessary. In conclusion, the central integration server for the OR will be connected to a graphical interface.

4.2.3. Heating, Ventilating and Air Conditioning System

Heating, Ventilating and Air Conditioning (HVAC) systems from hospitals goes beyond simply heating or cooling an environment. It involves a comprehensive process of controlling the overall ambient conditions. [41]

Hospitals require measures to limit air movement between departments, and specific ventilation, and filtration systems to reduce the presence of contaminants such as odors, viruses, and airborne microorganisms. Additionally, different areas within hospitals have varying temperature and humidity requirements. To prevent the spread of infectious diseases through the air, hospitals also need sophisticated designs that allow precise control over environmental conditions.

Thermal comfort is essential in maintaining the internal parameters of the human body within certain limits. The body continuously generates heat through metabolic processes, and it needs effective mechanisms to regulate thermal exchange with the environment and keep the interior temperature constant at around 37ºC. In hospital settings, it is crucial to ensure a comfortable thermal environment for patients and medical staff. Bearing in mind the situation for operating rooms, it is important to maintain optimal pressurization levels and temperature ranges. Moreover, it plays a key role in controlling humidity levels and managing air movement to contribute to enhancing thermal comfort and promoting well-being.

There are two types of HVAC systems: air-based and water-based. Air-based systems include heating equipment such as boilers and cooling equipment. They also utilize direct expansion cooling/heating equipment, such as heat pumps, which deliver treated air to the desired conditioned environment. Centralized systems involve a single unit that serves multiple areas through ducts, while unitary systems consist of independent units installed in specific locations. Water-based HVAC systems are commonly used in hospitals. They utilize various distribution systems, such as single-pipe, double-pipe, three-pipe, and four-pipe systems. The four-pipe system is particularly popular in hospitals due to its ability to provide simultaneous cooling and heating. This system consists of four pipes: two supply pipes (cold and hot) and two return pipes (cold and hot). Although it is more expensive to install and operate, the four-pipe system offers flexibility for hospitals with varying cooling and heating demands. [42]

Maintaining optimal humidity levels prevents respiratory issues and condensation. Controlling air velocity enhances heat dissipation, providing comfort and freshness. Ventilation is crucial for aerobiological control. Aerobiological control aims to maintain air purity in indoor environments, reducing the risk of infection in hospitals. Bioaerosols, airborne particles carrying microorganisms, can be controlled through various techniques to prevent contamination and disease transmission through ventilation systems. [43]

For high-tech operating rooms or conventional operating rooms (type A and type B, according to UNE 100713:2005), the designations Class I and Class II, respectively, also known as ISO Class 5 or ISO Class 7, are used. The minimum airflow required is 2400 m^3/hour or 1200 m^3/hour if outside air is used. Class A operating rooms require at least 30 air changes per hour, while Class B operating rooms require a minimum of 20 changes. The air temperature can range from 18 to 22ºC in summer, and from 23 to 27ºC in winter. A relative humidity of 50% is recommended. Regulations require that Class I and Class II operating rooms go through different levels of filtration, using F5 filters (with an efficiency between 40% and 60%) and F9 filters (with an efficiency above 95%). In addition, Class I operating rooms must also filter the air using an H13 filter with an efficiency of 99,95%. H3, also known as HEPA Filters, captures submicron particles, preventing the spread of bacteria and viruses, ensuring high-level protection against airborne diseases.

Ultraviolet Germicidal Irradiation (UVGI) can be another aerobiological control tool that uses UV light in ventilation ducts to kill or inactivate airborne microorganisms, preventing the spread of infectious diseases caused by bacteria, viruses, and fungi. Furthermore, another tool is implemented in operating rooms, Environmental Pressure Differential Control is used to establish pressure differences between different environments in the surgical area. For example, the pressure inside the operating rooms must be positive to generate a pressure difference with adjacent rooms and prevent the entry of pathogens or microorganisms. Thanks to the positive pressure in the operating room, air tends to escape, creating an outflow of air that prevents this entry.

As we can see, the HVAC system of an operating room is highly complex, therefore, it is important to understand it. All these factors are relevant for this system to be integrated into a technical panel from an informative perspective, as many of these parameters are controlled by the hospital's Maintenance Department. All these environmental conditions have a direct impact on the operation, so it is essential that the surgeon is always informed.

When it comes to integration of HVAC system in our TCP proposal, we have to bear in mind that in hospitals, Building Management Systems (BMS) are utilized for HVAC systems to achieve efficient and centralized control. The BMS allows for real-time monitoring and adjustment of environmental parameters such as temperature, humidity, and air quality in different areas, including operating rooms. This task is usually done by the Maintenance Department of the Hospital. [44]

Nevertheless, Guest Room Management Systems (GRMS) are particularly useful in operating rooms as they provide specialized control and monitoring of the air conditioning system. This allows for quick and easy modification of the air conditioning settings to maintain optimal conditions during surgical procedures. That's the main reason why the only tool that can be controlled from the HVAC system in OR is temperature. The Maintenance Department fixed a value for the temperature and surgical staff can modify with a margin of two degrees above or below, as a preventive measure to avoid extreme temperatures and damage to the HVAC system. However, it is important for the medical team to be informed at all times of the relative humidity of the operating room and the operating room pressurization.

In the case of the integration of the HVAC system to the central integration server, we see a very large server that oversees regulating the HVAC system of the entire hospital, which is the BMS system. This is divided into different subservers, such as the GRMS system, which oversees managing the HVAC system of smaller areas of the hospital to adapt it to the comfort of those who are in the room at that precise moment. This subserver would be the one that through a USB or RJ45 connection would connect to the central integration server to manage the temperature of the operating room. The central integration server for the operating room will be connected to a graphical interface of the Theatre Control Panel (TCP) proposal, enabling surgeons to access other servers through an intuitive and user-friendly interface.

4.2.4. Medical Gas Alert System

Medical gases are pharmaceutical preparations used for the prevention, diagnosis, treatment, and cure of diseases. These gases act within the human body through diverse mechanisms, including pharmacological, immunological, and metabolic effects. Bearing in mind that are classified as medical gases, they must meet specific characteristics. These products are composed of one or more gaseous components and are intended for direct contact with the human body.

There is a wide range of medical gases, of which we highlight the main that can be found in the Operating Room as oxygen, medical air, vacuum, carbon dioxide, and nitrous oxide. Oxygen, a colorless, odorless gas, is used in a variety of medical applications, such as oxygen therapy, cardiopulmonary resuscitation, and intensive care, among others. Medical air, a mixture of 21% medical oxygen and 79% medical nitrogen, is a compressed gas used primarily in the administration of medication by nebulization or inhalation, as well as in inhalation therapy, and ventilation. In the Operating Room both gases are respectively coded in white and black color. See Figure 9.

Figure 9. Medical gas outlet in an operating room with its corresponding color code.

Medical vacuum, generated by a central plant and delivered through yellow vacuum pipes, is not a gas but a negative pressure system used for patient suction and anesthetic gas. Furthermore, carbon dioxide is commonly used as a seed for insufflations purpose in open heart surgery and laparoscopy procedure. Carbon dioxide is usually coded with grey color. Nitrous oxide is a slightly narcotic, non-toxic oxidant used as an analgesic, sedative and in cryosurgery. Nitrous oxide pipes are coded with blue color. [45]

The medical gas supply system operates using various components, including compressed gas cylinders (liquefied and non-liquefied), thermal and cryogenic tanks, and On-Site units (PSA - Compressor) for compressed gases. The process begins at these supply sources, then proceeds to the high-pressure cylinder station, the operating alarm panel, and the section valve, ultimately reaching the main network. Within this network, a portion of the supply is directed to a backup system, while the remaining gas is distributed to secondary mains passing for a control system. This control system plays a crucial role in communicating any malfunctions, leaks, or concentration-related issues in the operating room. As a result, the operating rooms are equipped with different gas intakes, distinguished by the color coding mentioned earlier.

Medical gas alarms are technological systems that monitor the flow and pressure of medical gases in healthcare facilities. They detect problems such as low pressure, leaks or variations in flow, in addition to indicating the need for revision or maintenance. These alarms are essential to ensure the proper functioning of gas lines in areas such as operating rooms. These alarms accurately detect gas line pressures, alerting them to low/high pressures and leaks. They can be interconnected with other alarm systems. Additionally, they provide a visual display of pressure in medical gas networks. By promptly detecting and alerting to low or high gas pressures and leaks, they help prevent potential risks and complications during surgery. Malfunctioning or inaccurate alarms can compromise patient safety and lead to critical situations. Therefore, the proper working of medical gas alarms is essential for maintaining a secure surgical environment and optimizing surgical outcomes. [46]

The way in which the gas alarm could be integrated into our Theatre Control Panel proposal would be to use current digital alarm solutions that use integrated devices and advanced microprocessors to control the flow of medical gases. They can detect irregularities in low or high pressure according to set parameters. The readings are displayed on a monitor, and the alarm status is visually indicated by a LED-lit luminous scale. Typically color-coded as red, yellow, or green, these signals represent a severe emergency, a mild alert, or normal operation, respectively. The central gas system is controlled by microprocessors that analyze the flow of medical gases and send an alarm if detected. In this case we will not have an external server that will connect to the central integration server, but the microprocessors will act as an information gateway. The microprocessor will receive information that will be translated so that the central integration server can read it and project it on the graphical interface in the form of an alarm.

The gas alarm system can detect several key issues in the gas lines, including high pressure, low pressure, pressure leaks, and pressure interferences. These alarms provide crucial notifications to ensure prompt corrective action and maintenance, safeguarding the integrity and functionality of the gas supply system. By monitoring and detecting these faults, the alarm system helps maintain a safe and reliable environment for medical procedures and patient care. [47]

4.2.5. UPS Alarm Control

The electrical system of a hospital is essential for the safety of people, the critical care of patients and the effective operation of the health center. Emergency power is divided into two main branches: the critical branch, which supplies power to areas such as intensive care and operating rooms, and the safety branch, which provides power for evacuation routes, alarm systems and communications.

The power supply in medical centers is crucial to carry out their activities. The correct electrical infrastructure influences the actions carried out in these places. The regulations for electrical installations in medical centers establish that operating rooms belong to Group 2 due to their application in surgical procedures. A maximum interruption level of Class 0.5 is required in case of failure, with an auxiliary connection in less than 0.5 seconds. Continuity of power supply is vital in hospitals, and the main objective of the electrical infrastructure is to ensure availability and eliminate electrical risks in critical areas. Different design criteria are established for general infrastructure and risk areas, since in risk areas safety and reliability must be increased to reduce possible electrical risks.

According to the *Reglamento Electrotécnico para Baja Tensión* (REBT), hospitals, as buildings open to the public, must have both a regular electrical supply and a complementary backup supply. The regulations state that at least 25% of the total contracted power must be covered by this complementary supply. Typically, this backup is achieved using generator sets, which consist of an alternator connected to a Diesel engine. In summary, hospitals must have a backup electrical supply to ensure their operation in case of failures in the normal power supply, and this is commonly achieved using generator sets. [48]

In addition, in situations where a power outage occurs, certain installations require continuous power supply without experiencing a complete loss of power. This is because the time it takes for generator sets (gensets) to start operating may result in a temporary interruption. To address this issue, uninterruptible power supply systems (UPS), known as SAI (*Sistema de Alimentación Ininterrumpida*) in Spain, have become a widely adopted solution. These systems ensure uninterrupted power supply by offering various options for power sources and installation. A UPS works by converting mains power into a direct electrical current that is used to charge an internal battery. When a mains power outage occurs, the UPS uses the energy stored in the battery to supply power to the devices connected to it. The amount of time the UPS can supply power to the devices depends on the capacity of the battery and the amount of power being consumed by the devices. [49]

It is important to integrate in our OR technical panel proposal that the UPS (Uninterruptible Power Supply) has a limited capacity and cannot maintain power indefinitely. Therefore, it is crucial to take steps to restore power to the hospital promptly. If power is not restored before the UPS battery is depleted, the devices and equipment in the operating room will shut down. Consequently, it is essential that both surgical and maintenance staff are alerted if an alarm is triggered during a procedure, considering the timing of the operation to make an informed decision about its continuation. Moreover, it is relevant to say that UPS that is powering permanently ORs has an autonomy of 2 hours approximately.

Typically, UPSs have a circuit that monitors the electrical current that is reaching the equipment. If there is an interruption in the electrical current, the UPS circuit detects the fault and triggers the alarm. With future trends in mind, the UPS is closely linked to other parameters such as temperature and humidity that can affect its performance. Therefore, sensors could be implemented to monitor these variables and if any anomaly is detected in these parameters, the UPS can activate the alarm. [50]

In some cases, the UPS may use a dry contact relay to trigger the alarm. When an alarm condition occurs, the dry contact closes, which can generate an electrical signal that is sent to the OR control panel via a cable. The central integration server is equipped with various input connectors, including USB and RJ45, to establish connections with the servers responsible for controlling some of the operating room systems. In addition, the central integration server has power socket inputs. If any of these is connected to the dry contact of the UPS system, it can detect electric current and interpret it as an alarm signal from the UPS system every time the dry contact closes.

This signal is interpreted by the Theatre Control Panel and displayed as a notification or alarm indicator for surgeons and medical staff to see. The OR control panel notification includes UPS battery charge level and the estimated battery backup time, to monitor the status of the UPS and ensure continuity of power in the OR.

4.2.6. Operating Table Position

The positioning of the surgical table (Figure 10) is key to perform highly complex surgeries, since the first step of a surgery is always the positioning of the patient. For instance, positioning on the surgical table is one of the most important steps in any spinal surgical procedure. [51]

The operating tables are structures in stainless steel a hydraulic column which can be fixed or mobile. Its width and load capacity vary depending on model and surgical needs. The boards are fragmented and removable to adapt to the size of the patient. Standard tables consist of consist of central, back, head and leg modules, with remote control for height, flexion, and angle adjustments. Surgical tables allow great freedom of movement and should ideally be radiolucent. In addition, they are modular since they can fix different to obtain unnatural positions of the human body to better perform the surgical procedures. [53]

Figure 10. Standard Surgical Table.

In the technical panel of the operating room, it will be possible to remotely control the position of the surgical table through the following movements:

- **Up:** Raise the height of the surgical table.
- **Down:** The surgical table height is lowered.
- **Lateral Displacement:** Lateral displacement of the operating table to the left (towards the patient's head) or to the right (towards the patient's feet).
- **Trendelenburg:** Position in which the body is leaning backwards, with the head lower than the feet.
- **Antitrendelenburg:** Position in which the body is tilted upwards, with the head elevated while the legs remain lower.
- **Lateral Tilt:** Laterally tilts the operating table to the left side and right side.
- **Flex:** The table moves from the patient's hip, tilting downward.
- **Reflex:** The table moves from the patient's hip, tilting upward.
- **Legs Movement:** Raise or lower the patient's foot.
- **Back Movement:** Raise or lower the patient's head, chest, and abdomen.

When integrating control functionality with the operating table, a microcontroller installed on the is responsible for transmitting movement commands. This microcontroller is connected to the manufacturer surgical table server, which will be connected via USB to the central integration server. This main server is connected to the graphical user interface. The actual commands will however be initiated from the central integration server interface, which will be interconnected with the surgical table responsible for sending the microcontroller movement commands. [52]

4.2.7. Stopwatch

In the field of operating rooms, many parameters must be taken into consideration to ensure functionality and facilitate the flawless execution of surgical procedures. When we talk about surgery, we are referring to time, because one of the main goals of 4.0 has been the minimization of the duration of along with the reduction of invasiveness. Therefore, monitoring time appears to be crucial in the context of an operating room.

For the main purpose indicated, the incorporation of two-time measurement features is suggested for the proposed operating room technical panel. The objective is to display the surgery's real-time progress, allowing the surgeon to have a direct awareness of the elapsed time and keep updated of the current time. This is especially crucial during long-time operating room sessions when the surgeon may not have the opportunity to leave the OR, thereby emphasizing the significance of maintaining a sense of time. The proposed concept entails the availability of real-time on the control panel at any given moment. In addition, as usual practice, analog clocks are typically installed in the operating rooms to ensure easy access to this information.

However, many surgeons require the use of a stopwatch to calculate the duration of surgical procedures, particularly in cases such as cardiovascular or orthopedic surgeries where patients may be subjected to ischemia. In the context of orthopedic surgeries, the exact duration of ischemia is not entirely predictable, but it is advisable to minimize it as much as possible. Nonetheless, it should never exceed one hour and a half. By utilizing a stopwatch, the surgeon can accurately measure the amount of time the patient has been in ischemia.

All these parameters would be incorporated into the proposed Theatre Control Panel (TCP) interface, wherein the stopwatch could be activated through the utilization of the touch screen interface. Nonetheless, the time would consistently be displayed on the graphical interface of this control panel. [54]

4.2.8. Communication

In the operating room, numerous emergency episodes require immediate and decisive action. Recognizing the need for efficient communication, a dedicated section has been established carefully evaluating critical incidents. Its primary objective is to facilitate the alerting of various departments within the hospital during emergency situations. Extensive analysis of significant episodes has been carried out to identify the key services that frequently require direct communication with the operating room due to clinical episodes, staff requirements, or equipment needs. [55]

The main services most frequently requested from the operating room are the following:

- **Cardiac Arrest:** Communication regarding cardiac arrest in the OR is crucial and must occur at a high velocity. The medical team needs to be alerted promptly, and communication should be efficient to ensure a swift response from the hospital. It is important to establish effective communication for issuing a warning in cases of intraoperative cardiac arrest. The designated individual responsible for activating the appropriate protocol should be promptly notified, considering the high mortality rate associated with such incidents. [56]
- **Anesthesiology:** During a surgical procedure can take place some potential failure that will require technical support from the anesthesia department. Potential anesthesia failures during surgery include airway management, hemodynamic stability, drug administration, allergic reactions, and inadequate monitoring. [57]

- **Emergencies:** Numerous situations can lead to emergencies. One such example is the transfer of a patient to another medical facility following surgery. Alternatively, it may involve seeking consultation from the emergency staff regarding the arrival of a critically ill patient who requires immediate surgery. In such cases, it is essential to obtain feedback on the patient's condition and the events surrounding their situation, making it advisable to engage in conversation with the emergency personnel.
- **Intraoperative Radiology:** Intraoperative radiology equipment is necessary for certain surgeries as it aids in guiding the specific procedure. It is particularly beneficial in orthopedic surgery. [58]
- **Clinical Laboratory:** In some surgeries, a part of an organ must be resected so that it can be analyzed clinically and give a result on the state of the organ. In many tumor cases, this type of intervention is known as biopsies. These samples must be collected by the laboratory staff in cold storage to keep the sample. This system would allow them to be notified through this system, moments before obtaining the sample.
- **Stretcher:** The person in charge of the stretcher must be notified once the surgery is finished to take the patient with the stretcher to the Post anesthesia Care and Recovery Unit.
- **Intensive Care Unit (ICU):** Many of the patients who undergo major surgery come from or will in the future pass through the ICU, so it would be ideal for the operating room staff to contact this unit before starting the surgery, to be aware of the state of the patients, or after the surgery is finished, to inform how it was the surgery.
- **Post anesthesia Care and Recovery Unit (URPA):** It would have a function very similar to that of the ICU, as it is where patients who have undergone minor surgeries recover from anesthesia. The main objective would be to communicate to the staff how the operation went.
- **Ictus:** In the event of a stroke occurring during surgery, it is imperative to activate the Stroke Code and subsequently follow all the established steps for stroke management. As part of this process, the responsible individual will be sooner notified about the activation of the stroke code.
- **Blood Transfusion:** The purpose of this communication is to urgently request an immediate blood transfusion for a specific blood group.
- **Pharmacy:** It is important to communicate with the pharmacy for various reasons. They can provide us with urgent and innovative medication options, while also offering information about potential allergens or complications.
- **Maintenance Department:** It is essential to contact them regarding any equipment failure, such as gas connections, cameras, microphones, loudspeakers, electricity, computers, audiovisual system, control system, lighting, etc.

Regarding the iPad model, it should be chosen the version with cellular capability, so it is essential to have a SIM card slot. However, it also exists a type of SIM card adapter that enables the insertion of mobile data into devices like computers or other compatible devices. These adapters can function normally when an interface and digital infrastructure are in place to facilitate calls.

4.2.9. Browser

Surgical procedures are highly individualized, with each patient and surgery being a unique case. While there are guidelines that provide a general framework, many steps in the process may vary depending on the patient's specific anatomy and characteristics. Granting access to the Internet from the technical panel can bring additional value by allowing the consultation of information relevant to the setup of the operating room and its adaptation to the specific needs of the procedure and the patient. It is important to note that the technical panel serves as a control system for the technological elements involved.

Above all, access to the Internet allows real-time communication and information. The control panels of the operating room are connected to the Internet, and they can receive automatic updates on the status and availability of medical equipment. This facilitates more efficient management of resources and empowers medical professionals to make well-informed decisions. Secondly, healthcare professionals can access current information on operating room setup, procedures, surgical techniques, medications, and treatments from reliable sources. For instance, one can look up information regarding the most appropriate perimeter light color for a surgical procedure that is to be performed.

Moreover, in challenging situations during surgery, surgeons can seek advice or consultation from other specialists through videoconferencing or online data exchange. This allows for immediate collaboration and the potential for obtaining valuable insights from experienced professionals. [59]

Connectivity can be easily established through the hospital's Wi-Fi, which offers excellent connectivity. If a hospital center has a low efficient wireless system, implementing an Ethernet adapter or multiple signal repeaters in the surgical area can ensure uninterrupted connectivity. This is crucial as many medical equipment and computers rely on this connection. In summary, regardless of the method used to interact with the user, connectivity-related issues should not arise.

4.2.10. Music

According to the cited sources, music is played in between 53% and 72% of surgical operations performed. The evolution of music reproduction technologies, as in the past with the appearance of MP3 or iPod, to the current free digital platforms with unlimited access to music, such as Spotify or YouTube. In addition, television series have influenced the presence of piped music in operating rooms, where it began to be seen as a common practice, for example, in series such as The Good Doctor or Scrubs.

Bearing in mind all the evolution in this field, music has become an additional feature to manage in the operating room. It is a feature that is closely related to audiovisual systems as this piped music is reproduced from the loudspeakers integrated in the ceiling. Surgeons playing music often report doing so to relieve stress, reduce white noise and enhance performance and concentration during surgical procedures. Since it serves as a tool for enhancing surgical outcomes, it is crucial to offer it as an option. It is not a mandatory feature, so then if surgeons want to open it, they can do it freely. [60]

Furthermore, music can contribute to the well-being of patients in several ways. Firstly, it has been observed that listening to music can help reduce anxiety and promote relaxation, this can be particularly beneficial for patients who may experience fear or apprehension before undergoing surgery. Music can evoke positive emotions that can have a positive impact on the patient's overall experience and may even contribute to a faster recovery. [61]

In any case, it is important to listen to calm and relaxing music that creates a soothing environment for both the patient and the surgeon. This atmosphere enables the surgeon to concentrate more accurately while allowing the patient to relax and alleviate stress. To integrate this aspect, one simply needs to utilize the Internet, as in the browser section, to access these digital platforms that offer free music.

4.2.11. MySurg

The future is characterized by the integration of intelligent technologies that provide advice, predict events, and support decision-making in various medical activities. Artificial intelligence (AI) is increasingly being utilized in the field of surgery, where it plays a crucial role in live image processing methods, utilizing overhead cameras and trained algorithms, enabling the analysis of surgical procedures in real-time. These techniques can provide recommendations to surgeons, guiding them on the subsequent steps to be taken during the operation.

The proposed feature for integrating into the operating room control panel called *MySurg*, has the primary objective of recording, registering, and monitoring all activities within the technical panel of an operating room. Its purpose is to collect specific information about everything it is happening in the theatre control panel that can be highly useful in predicting and recommending optimal operating room configurations and also comparing surgeons' performance.

For a more accurate prediction model, we kindly request the manual input of certain information. This step is essential to develop a predictive model that encompasses relevant details not captured by the technical panel. The required manually entered data includes the name of the lead surgeon, surgical specialty, surgical technique, and the specific disease being treated. However, we aim to minimize the data entry burden, as extensive information input would deter medical staff from participating. For this reason, all information would be included in a drop down, except the surgeon's name which would be optional.

Automated data recording by MySurg comprises monitoring the status of lights, managing monitors and audiovisual signals, registering operating table positions, and tracking surgery duration. Additionally, the system will track the temperature and pressure of medical gases utilized during the procedure. It will also record any alarms triggered, whether from the UPS or the gas system. Lastly, the music played during the surgery will be captured as well.

After an initial phase of data collection, the model will be trained using numerous surgeries as a basis. Subsequently, the medical staff will be able to access the operating room and utilize a newly developed tool to manually input information regarding the surgical specialty, technique, and disease. The system would then automatically generate recommendations of the most optimal operating room setup, based on the clinical information given by the surgeon, before starting surgery. The recommendation system would consider factors based on previous surgeries such as surgery duration, surgeon expertise, and alarm frequency, among others.

4.2.12. Configuration

The configuration section in the operating room control panel allows customizing the device according to the user's preferences. It includes options such as changing the interface language, adjusting the screen brightness, selecting the wallpaper, and setting the time. These options allow you to adapt the panel to operating room conditions and provide a personalized user experience. The goal is to make the device easier to use and improve the overall experience in the operating room.

4.3. Technical specifications

In this section, we want to specify some technical aspects that should not be overlooked since we have already defined from a theoretical point of view how our proposed operating room technical panel will be. The user interaction will be through an iPad, and we have also defined all the technological elements of the operating room that we want to control from the control panel we propose.

First, the new technical panel should be easy to clean and should not contain buttons. The new iPad models do not incorporate buttons on their screen and consist of a single touch screen. In addition, the device must be protected with a minimum protection rating of IP65, making it dust-tight and protected against sprayed water.

As we have previously mentioned, it is necessary to have separate servers for each operating room system, which should be managed by the theater control panel. These servers will be connected to a central integration server. This main server must have different connector inputs to receive the information from the other subservers, they can be RJ45 connectors, power outlets, or even USB. Therefore, what the interactive graphic interface does is connect to this main server to receive all the inputs from the control systems of the operating room and to give orders to these. In the following Figure 11, it can be observed a diagram of the connection between the central integration server and with the control systems via other servers or simple inputs.

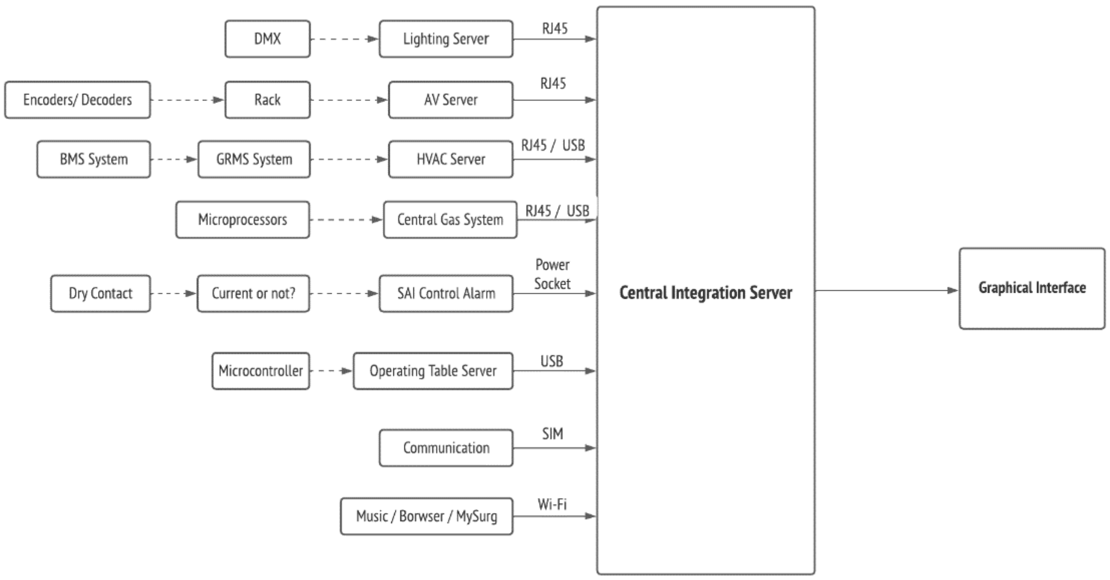

Figure 11. Diagram of the connection between the central integration server and with the control systems via other servers or simple inputs. Own source.

4.4. Analysis of environments for designing graphical interface

As one of the final objectives of the project is to redesign the technical panels from operating rooms, and as a secondary it is to design a semi-functional mockup graphical interface. This graphical interface, a semi-functional mockup, is a visual representation of a user interface design that shows the layout, components characteristics, and some of the interactions of the final software.

First, Figma is a powerful design tool. It offers a wide range of design features, including vector editing, and prototyping interactive components. It is commonly used for User Interface (UI) and User Experience (UX) design projects. It has several crucial aspects such as a robust set of design tools to create appealing UI designs. Moreover, it allows the creation of interactive prototypes to show the functionality and the user experience. It also allows us to work on collaborative projects in teams. Nevertheless, there might be a learning curve due to the large and professional set of tools available. It is a pay program, but it can be obtained a free license through the University of Barcelona.

On the other hand, the alternative solution is to use Canva, which is a graphic design tool used mainly for presentations and simple UI designs. It offers many templates, many components, and many page layouts. Moreover, it includes many graphic resources and a large number of fonts. It is very intuitive, user-friendly, and very easy to use, and can be used without previous learning. Furthermore, it offers a free plan and a premium one with access to extra resources. The main drawback of this program is that it doesn't offer the possibility to create interactive prototypes to show the functionalities of the solution.

In summary, the best environment to design the semi-functional mockup of the graphical interface is Figma, since it allows us to design with high-level graphical tools both the User Interface and the User Experience.

5. Detailed Engineering

In the following section it is detailed described the new proposal solution of technical panel, including a video tutorial of how the semi-functional mockup of the graphic user interface works. On the other hand, it refers to the design statement following and what would be the main changes in the daily work of the medical team opting to replace part of the functions of the technical panel with a digital solution.

5.1. Main proposal

According to the objectives defined, the final scope of the project does not include a fully functional prototype of this control panel, but a semi-functional mockup of the graphic user interface (GUI) has been developed. In addition, it includes the study of the operating room control elements to be incorporated, as well as the brief workflow required to achieve the full integration of these systems with the designed interface. This study, as well as the evaluation of the various user interaction proposals, is carried out from a more theoretical point of view, as described in the previous section (Concept Engineering), where these points are exactly defined.

As we have seen, the technical panels include a wide range of functionalities. On the one hand, they are responsible for managing the control of the operating room systems, allowing easy and quick operating room setup. On the other hand, some technical panels also include medical gas supply and power outlets, and other features that have nothing to do with the control of the systems integrated in the operating room. It should be remembered that in the solution we propose we only include the control functionalities, specifically we have chosen to control the following systems: Illumination and lighting, audiovisual, HVAC, medical gas alert system, UPS alarm control, operating table position, stopwatch, communication with other departments of the hospital, browser access, music access, and a new tool to register data of the control panel.

The solution we are proposing aims to integrate all operating room systems mentioned above into software with an intuitive and user-friendly graphical interface that can be controlled from an iPad. All systems integrated into the graphical interface would be previously integrated through a central integration unit as explained in the Concept Engineering section. The program will be created from specific design standards and according to the need of the operating rooms. This streamlined approach ensures an efficient workflow and minimizes disruptions during surgical interventions through centralized control unit.

In the following sections is included the functional plan for the solution designed, where it can be found all functional requirements of the graphical interface, specifying the user experience (UX) when it is using the solution.

In the following link, you can find a video with a functional demonstration of how it works and how the graphical user interface would be used for user experience. Watch it in this link: https://youtu.be/rZWSOPAvTag

5.1.1. Interaction with individuals

The program with graphic interface can be used and installed on the iPad, which can be mobile or fixed to the wall, according to the needs of the user. A magnetization and wireless charging system will be necessary to keep it always with battery and fixed in the wall, since most of the time it will occupy this position. The mobility of the iPad will be essential during preoperative period, for the start-up and configuration of all the elements integrated in the solution.

By default, iPads do not achieve an IP65 level of protection. Nevertheless, if they are protected by specific cases, they can achieve it. Furthermore, one of the requirements of the iPad is to have cellular capabilities, which includes a SIM card slot.

The iPad was chosen because Apple is the tech company leader in the health sector. Apple offers various applications and programs on its devices to facilitate the daily life of hospital staff, either by providing information on medicines or taking measurements from medical equipment via Bluetooth. In addition, it has implemented tools that promote telemedicine, so it would be ideal to implement a program for controlling operating room systems. Among all similar devices, the iPad is the most widely used by surgeons, many of whom already use it in their daily routine. Also, being such a popular brand, it is easier to find IP65-protected enclosures.

5.1.2. Functional plan for the technical panel

As is done in all projects carried out in a hospital by the Infrastructure Department, we have decided to make the Functional Plan of the proposed solution where the functionalities of the designed operating room control panel must be defined. It is also essential to evaluate if the proposal is the right one to offer correct attention according to the clinical needs. There are defined what must contain the semi functional mockup graphic user interface of the theatre control panel.

Develop an informative, intuitive, and easy-to-use graphical user interface containing:

- Lock screen where time and date are indicated.
- General menu screen with all the icons of the systems to be controlled available.
- Enlargement of the icons of the systems to be controlled in the OR available while hovering your finger above.

- Access to the desired operating room control system on tap on the respective icon.
- Each system must contain a color and icon associated.
- Dock system where in each frame of the interface by dragging from bottom to top you can return to the general menu and access the different applications again. [62]
- As the dock system cannot be implemented in all frames, an alternative is displayed as an arrow that allows also to move to a frame before or to the General menu.
- Thin gray bar to indicate where the Dock is located.
- Time and date, connectivity, and switch-off buttons must be displayed someplace in all frames of the interface, except for the stopwatch and the browser.
- The switch off button should always lead to the lock screen.

Control the Operating Room Illumination and Lighting System:

- Use preset light settings for cleaning, clean, and dirty situations by clicking on the icon that will change color when clicked.
- Use preset light settings for preoperative, operative, and postoperative situations by clicking on the icon that will change color when clicked.
- Customize the OR lighting.
- Customize the color of the lights freely or use the default ones for perimeter and laminar light (RGB LED's). It can be adjusted to the brightness with a horizontal scroll bar.
- Turn on and turn off operating lights. Switch on and off the camera if they have it. It can be adjusted the brightness and the focus with a horizontal scroll bar. Also, it is possible to switch between three different light temperatures of the lamps.

Control the Audiovisual System:

- Turn on and turn off the microphone.
- Turn on and turn off the ambient camera.
- Connect or disconnect with music application.
- Regulate operating room speakers' volume with a horizontal scroll bar.
- Switch from viewing mode to sources in the left column.
- Switch viewing mode, from single-signal viewing mode to multi-signal viewing mode and inversely.
- Selects a monitor for the output once you have chosen the viewing mode.
- Selects one of the available sources if the monitor is in single-signal viewing mode.

- Selects by sort multiple of the available sources if the monitor is in multi-signal viewing mode.
- Display always in the center of the screen which signals are being selected, both for the single-signal viewing mode and for the multi-signal viewing mode.
- When the camera is connected, the microphone is turned on, a viewing mode is selected, an output monitor is selected or a source is selected, the lower bar of the icons becomes colored.

Control of the Heating, Ventilating and Air Conditioning System:

- Raise or lower the temperature a maximum of two degrees above the indicated temperature.
- Indicate the humidity and pressure in the OR

Control of the Medical Gas Alert:

- Indicate the pressure of the medical gases in the operating room according to a scale of values and colors.
- Display in red the gas alarms after a gas pressure change.

Control of the UPS Alarm Control:

- Display an alarm in case the UPS System is activated.
- Display the UPS charge status and battery remaining time.
- Display the alarm, the UPS charging status and the available time in a visible way in the General Menu so that at any time you can keep track of the UPS status.

Control Operating Table:

- Move up or move down the operating table while pressing the icon.
- Move to the left or to the right the operating table while pressing the icon.
- Move to Trendelenburg or Antitrendelenburg position while pressing the icon.
- Tilt to the left or to the right of the operating table while pressing the icon.
- Flex or reflex the operating table while pressing the icon.
- Move the legs of the operation table up or down while pressing the icon.
- Move the back of the operation table up or down while pressing the icon.

Control the stopwatch:

- Start stopwatch.
- Reset the stopwatch.
- Stop the stopwatch.

Control communication system:

- Call suggested hospital departments by double-clicking.
- Call a personalized phone number.
- Hang up the call.
- Connect the call to the OR loudspeakers and microphones.

Control browser and music:

- Browse the Internet.
- Listen to music from Sportify.
- Listen to music from YouTube.
- Use a keyboard for searching.

Control MySurg and Configuration:

- Select the options for the three mandatory parameters in the dropdowns.
- Start registering control panel data.
- Save and stop registering control panel data.
- Configure features via dropdowns.

5.1.3. OR technical panel workflow

This section defines the user experience achieved through interactive prototypes in the semi-functional mockup graphical user interface. We will explain how it works each part of the platform that was developed.

Initially, there is a lock screen that is easily unlocked by dragging from the bottom up to access a general menu. In this general menu, it can be finding the dock system, that presents a horizontal bar in the lower central area. While users are hovering their finger over the icons on the dock, they enlarge, and clicking on these icons, users can access the different tools that will be all the systems of the operating room that are controlled from the technical panel proposal.

In the lighting system there are two different options: the first one is two kits with a preset lighting configuration and the second one is the customization of the operating room lighting. In Figure 12, we can see a flowchart of how the configuration of the lighting system works in our GUI. The preset light configuration icons open an overlay changing the color while they are pressed to indicate that the icon was selected. However, the two perimeter lights and the laminar lights formed by LEDs allow us to set the desired color and brightness. Meanwhile, the lamps can be turned on and off, as well as set brightness, and focus by horizontal scrolling bar. The focus temperature has three positions and is activated by clicking on the icon, increasing the temperature with each click. The lamp camera is switched on clicking on its icon that will change the color to green to see that is activated.

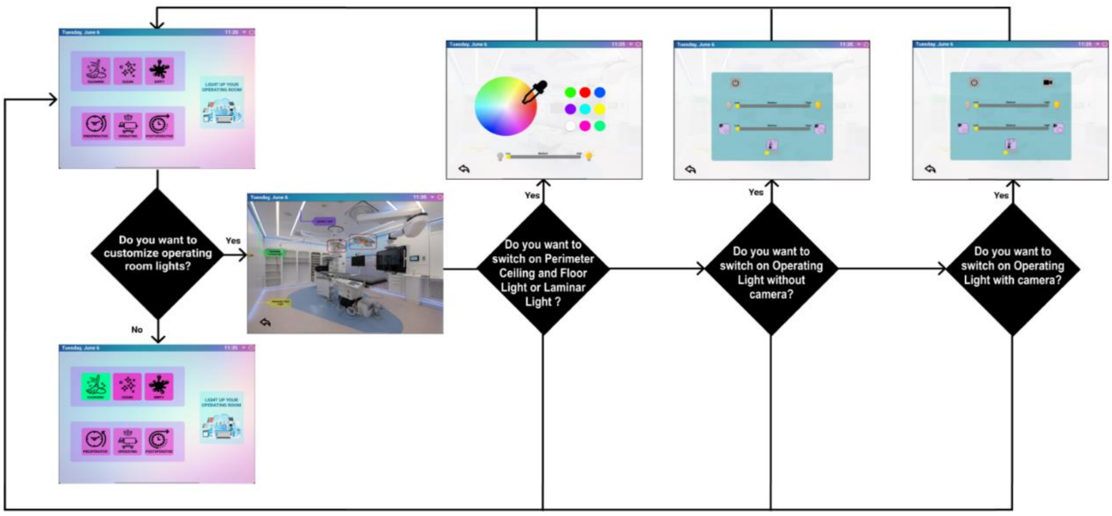

Figure 12. User experience workflow of the lighting system control in the graphical user interface. Own source.

For the audiovisual control screen, it can be observed in Figure 13 that it must be first selected the viewing mode, either multiple or individual. Next, it must be indicated which output monitor will be used to reproduce the sources. Finally, it can be chosen the desired sources. If it has been previously selected the single view mode, it will only be able to choose one signal, while if it has been selected multi signal viewing mode, can be selected up to 4 sources. In the multiview mode the signals will be selected in the order indicated on the screen with the first selected source occupying the space with the number 1 and so on. However, from any frame, you can activate the microphone of the operating room or connect to the music system, by clicking on its icon will change in color to indicate that is activated. Also, horizontal scrolling is incorporated to regulate the volume of the operating room speaker. Furthermore, the camera configuration can be opened by tapping on the icon. In it, we can move the direction of the ambient camera and zoom with it, while it supervised in real-time.

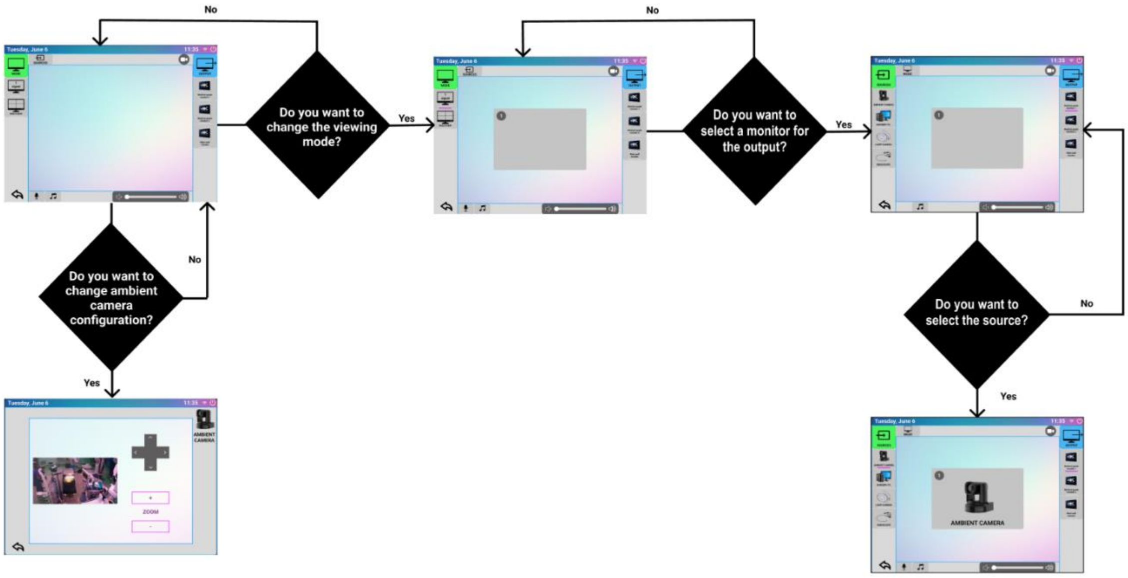

Figure 13. User experience workflow of the audiovisual system control in the graphical user interface. Own source.

In Figure 14, the temperature can be modified by raising or lowering two grades from the temperature established by the Maintenance Department. So, as you can see in Figure 14 as much as we increase temperature, the redder becomes the number until it reaches the maximum. It happens the same when it comes to lowering the temperature but with a blue color. Meanwhile, pressure and humidity values are displayed. On the other hand, the control for the operating table position works by opening an overlay that changes the color of the command icon while pressing it until it reaches the position selected. If you stop pressing before reaching the maximum, the surgical table will remain in that fixed position. It can be observed in Figure 15.

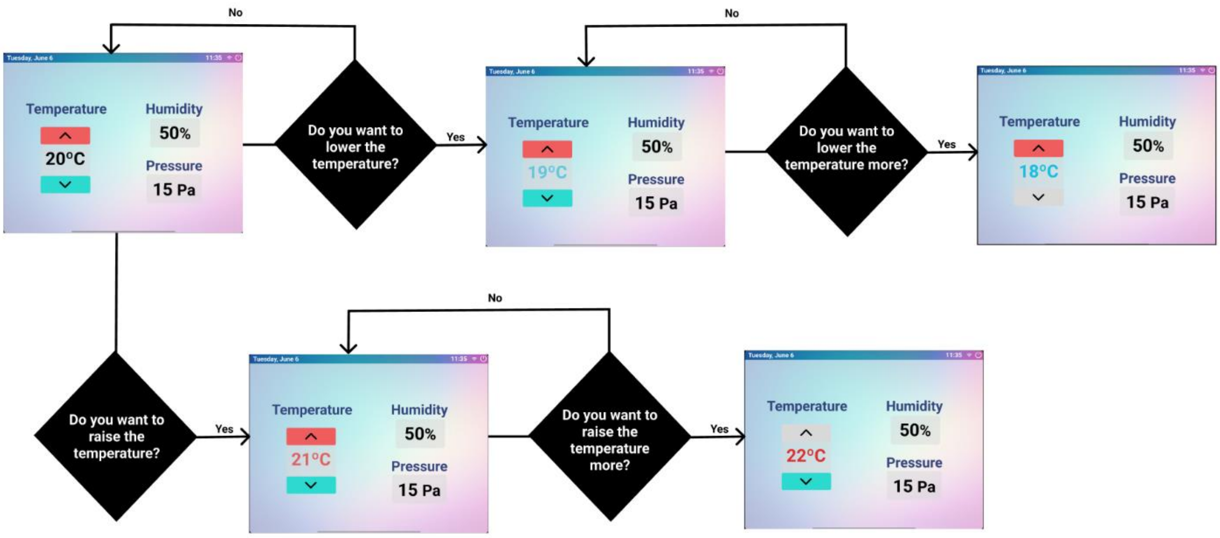

Figure 14. User experience workflow of temperature control in the graphical user interface. Own source.

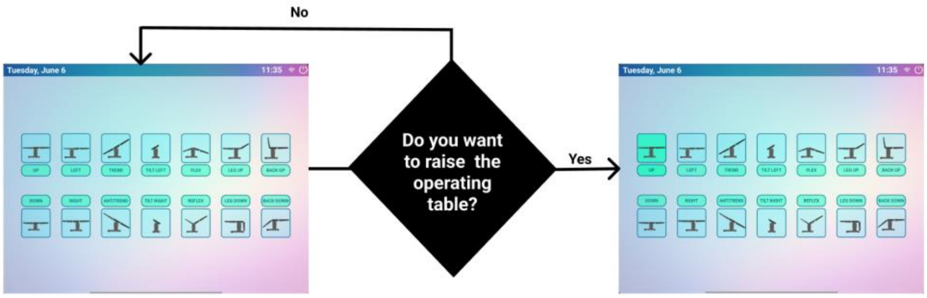

Figure 15. User experience workflow of the operating table position control in the graphical user interface. Own source.

In case the UPS system alarm is activated, an alarm will be displayed on the screen indicating the UPS charging status and available time. By using the dock system, it is possible to navigate to the general menu where the alarm should be closed. In the general menu it could be used the other functions, but it would always keep the warning with all the information in the upper central banner indicated in red. The sequence of these three frames can be observed in Figure 16.

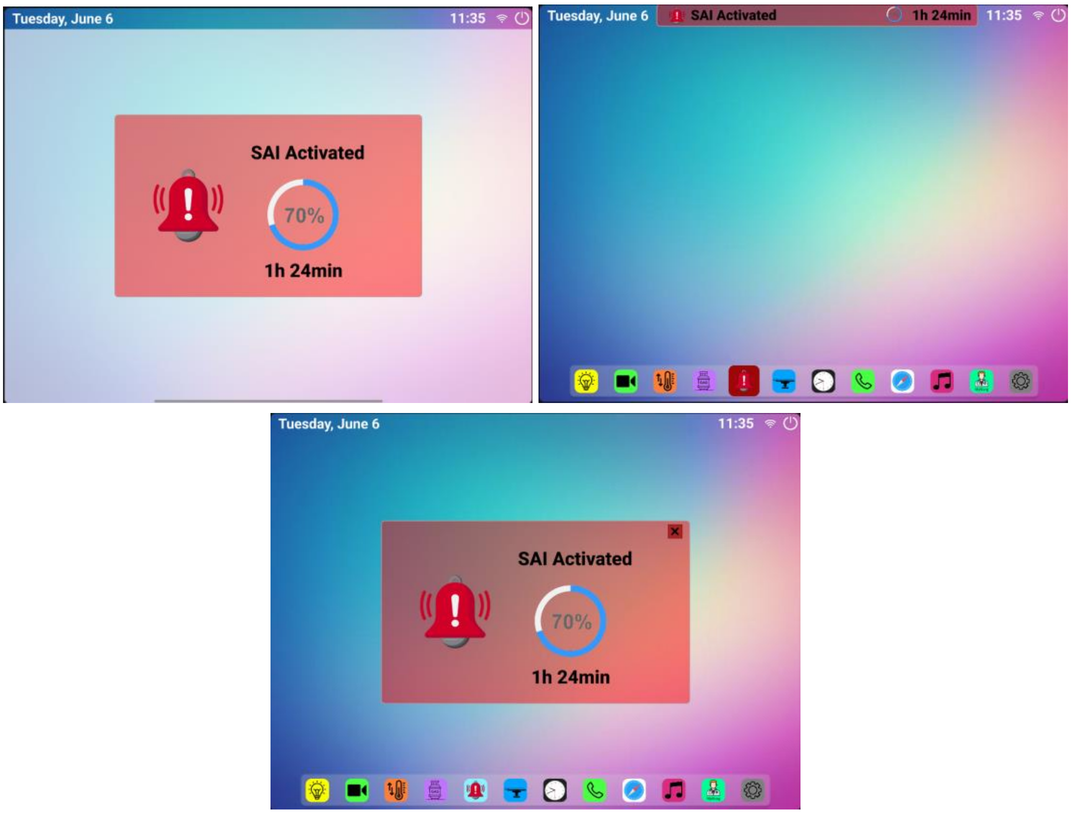

Figure 16. Graphical user interface of the UPS Alarm Control.

In Figure 17, it can be observed the case for a gas alert system that is very similar to the UPS alarm control. In this case, the pressure of all medical gases is displayed and represented by a color and value scale. Nevertheless, in case some gas has a pressure drop the alarm will be indicated in red.

Figure 17. Graphical user interface of the Medical Gas Alert System.

According to Figure 18, the stopwatch has distinct states: start, reset and stop. By clicking on the start icon, the stopwatch starts timing, and the start icon is then replaced by stop. If the reset icon is clicked, the stopwatch instantly returns to zero and starts again from there, while activating the stop button causes the reset at counter zero and stationary. After the stop action, the icon returns to the start icon.

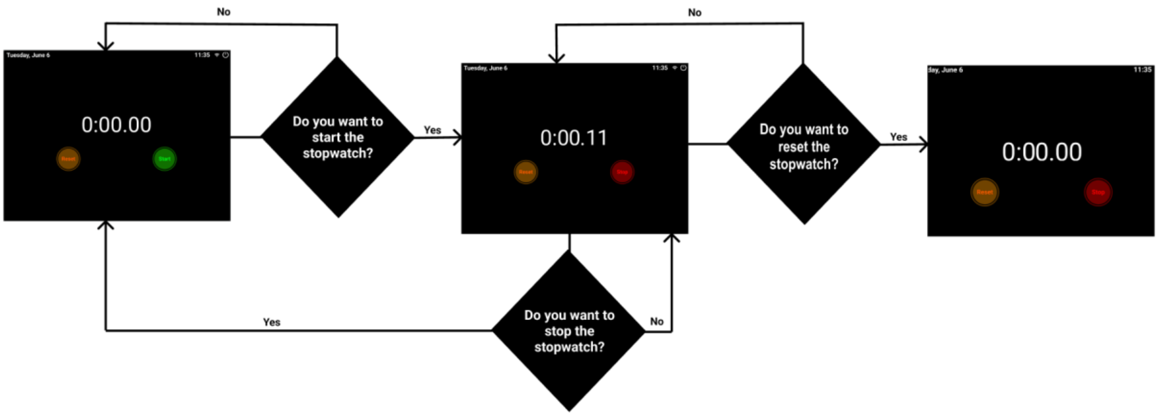

Figure 18. User experience workflow of the stopwatch in the graphical user interface. Own source.

In the case of the frames representing the Internet browser and access to unlimited music platforms, a common pattern can be observed. When a specific search is initiated that involves typing text into a searcher, the virtual keyboard overlays on the device to query whatever is necessary. It is shown in Figure 19.

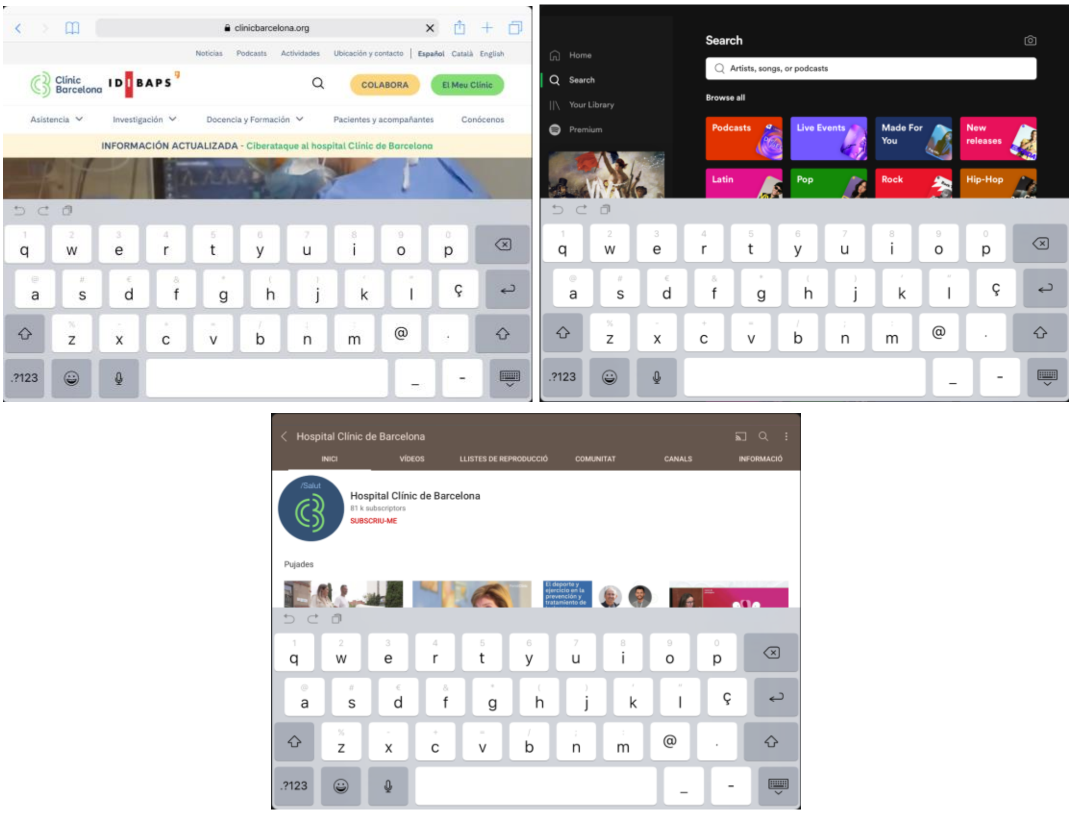

Figure 19. Graphical user interface of the Browser and Music System. Own source.

The communication system workflow diagram implemented can be observed in Figure 20. When attempting to contact any department within the hospital, the user must first select the user icon. Following this, we will notice a color change in the icon, turning it into a shade of green. Subsequently, to confirm the call, we click once more on the icon that has been highlighted in green, initiating the call. Finally, by clicking on the red hang-up icon, the call will end, and the user will return to the initial screen of the communication system. However, this calling feature can also be connected to the speaker and microphone in the Operating Room by selecting its corresponding icon. Furthermore, any phone number can be dialed using the customized keyboard to choose the desired number to call.

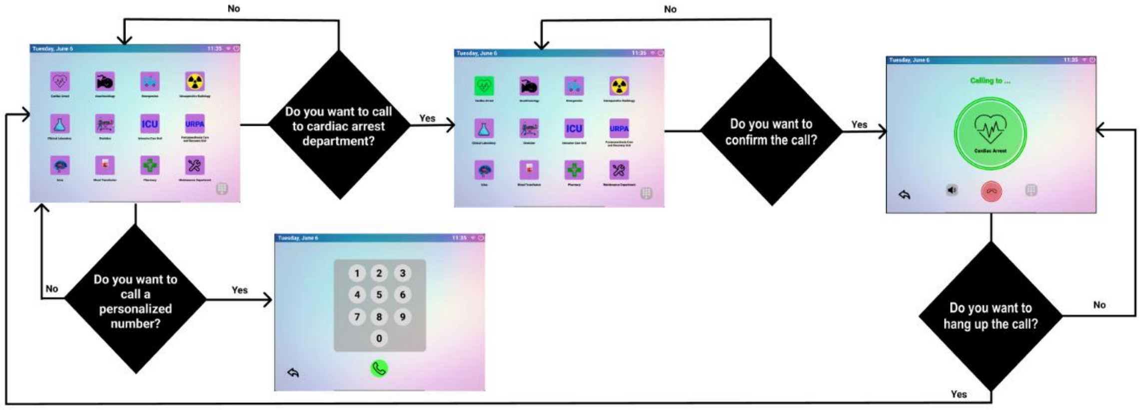

Figure 20. User experience workflow of the phone communication in the graphical user interface. Own source.

Bearing in mind *MySurg* section needs to be filled out using several dropdown menus, Figure 21 illustrates the flowchart that is followed by the control panel tool. First, the name of the surgeon can be entered by the keyboard, while the surgical specialty must be specified using a dropdown. Once this information is provided, the surgical technique employed and the disease treated must be indicated, also by a dropdown menu. Thereafter, data can be recorded and registered from the technical panel. After configuring the operating room and once surgery has ended the recording can be stopped, and the data will be automatically saved to the cloud.

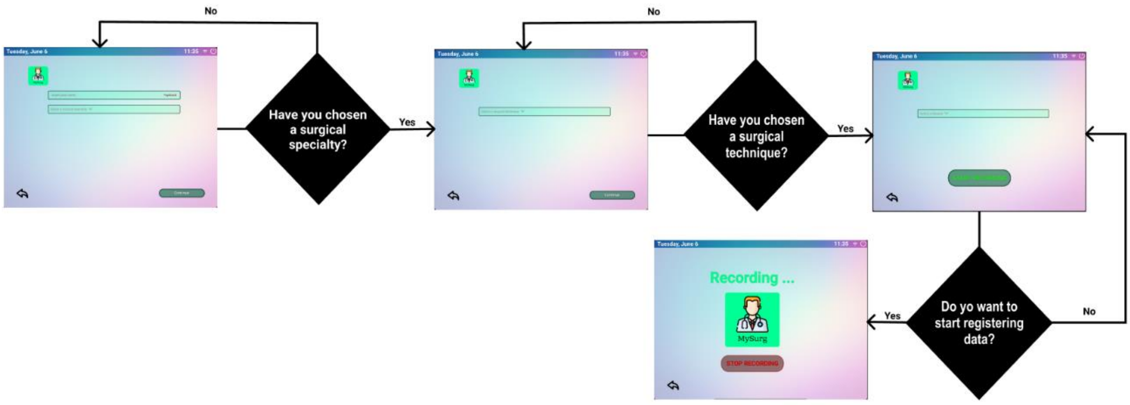

Figure 21. User experience workflow of the MySurg tool in the graphical user interface. Own source.

Finally, the last frame to be observed is the configuration tool of the control panel, where it can be modified the language, screen brightness, wallpaper, and date and time. It is shown in the Figure 22.

Figure 22. Graphical user interface of the Configuration tool. Own source.

5.2. Statement of the design of the graphic interface

The design of the graphical user interface (GUI) has a logical and well-thought-out purpose to ensure that the surgical team can easily understand and use the created graphical proposal. We have relied on our own criteria as well as social and scientific criteria that demonstrate how the elements thought and designed make the user experience more intuitive, without any required learning. [65]

When it comes to social criteria, it has been performed a deep analysis in which is the most used digital brand by medical staff in general. During the clinical internship, It has been observed that most part of the hospital staff use Apple devices, especially when we refer to iPhones and iPads. Bearing this in mind, we would like to implement San Francisco Font, which is a sans serif typeface family that is easily read and gives comfort to the reader. Nevertheless, for the mockup, it has been implemented Roboto Font, that is the most similar font available in Figma. We have implemented several Apple traits, and we also get inspired by the dock system in Mac, where when the cursor is hovering over the apps, those get enlarged. It is important that we mix the use of dock system from Mac with the returning to the general menu by sliding bottom to up from iOS. [63]

In the second place, many shapes and icons have been used to give intuitive and comfort to the interface. Most of the shapes have rounded corners mimicking the design of the Operating Room, where 90-degree corners don't exist. Rounded corners are not as aggressive and alarming as straight for the users' ones. Many icons have been used to indicate and define exactly what each system is, or it should do. In addition, pictures can help to see the reality of the surgical environment and configure it. Furthermore, it has implemented a pixel-perfect design feature that consists of aligning all elements precisely and consistently in order to seem symmetrical to the user. [64]

Finally, stress and fatigue are very common for surgeons that spend large days in the OR. There are many ways to face it, that could help to reduce anxiety, as color light configuration, in this case, the colors selected denote calm, smooth, fullness and spirit. The combination of cold colors, such as blue, green, purple, and pink palettes, helps surgeons to use the interface without being tired and set up the operating room properly.

5.3. Value proposals for the digitization of technical panels

All technological revolutions require human adaptation. In the case of this proposed solution, a paradigm shift is occurring in the design of operating room control panels. The transition is moving away from a fully manual, modular, and button-centric model towards a streamlined, centralized, digital, intuitive, and user-friendly model. Additionally, the appealing design of the new solution enhances its usability and comfort. The iPad gives us the flexibility to move around and set up the OR directly from the device, maintaining eye contact with each other in the OR.

However, in the end, we are incorporating a well-established solution in the daily lives of many individuals in a different environment, which will make it easier for responsible to use it. The intuitive design with icons and colors, and Apple-inspired functionalities makes the work easier. Additionally, we have integrated many operating room systems that previously could not be controlled from the technical panel, such as the surgical table control or audiovisual management of the operating room, which usually had to be performed separately.

6. Execution Schedule

In the execution schedule we find all the information related to the temporal and economic organization aspects of the project management. Therefore, in this section we attach the diagrams of the Work Breakdown Structure (WBS), PERT and GANTT.

6.1. Work Breakdown Structure

The WBS (Work Breakdown Structure) diagram developed for this project is included, and later on, the dictionary with a more detailed explanation of each work package is included.

As we can see in Figure 23, the project is divided into four basic levels, each of which is further divided into several simpler work packages. Next, each of these activities will be presented in the WBS dictionary with a brief explanation of activities description.

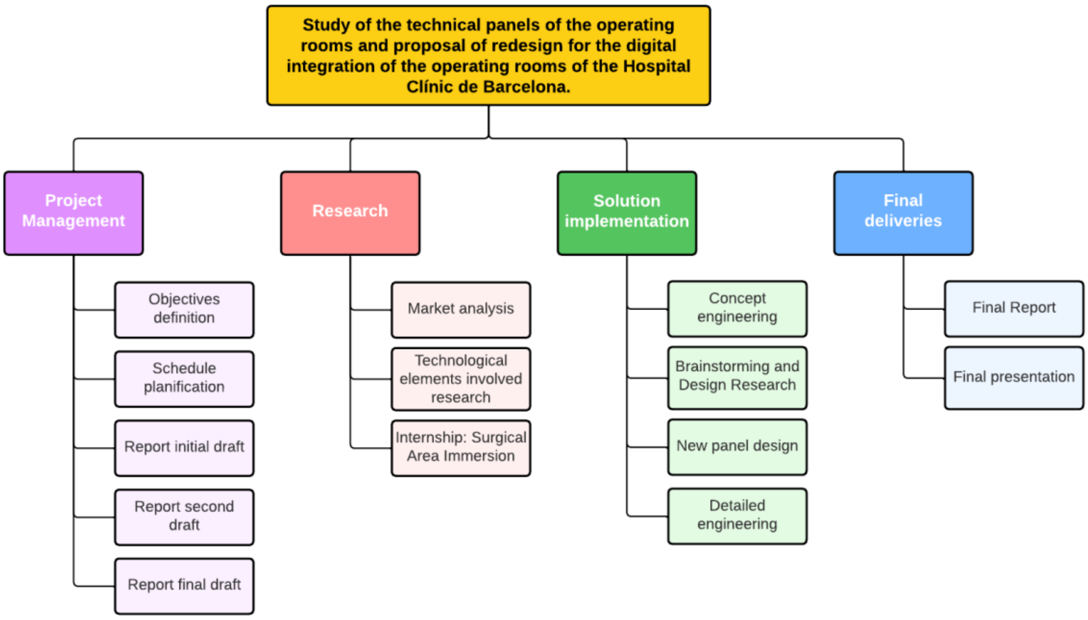

Figure 23. WBS Diagram of the Final Degree Project. Own source.

The following is the breakdown of the different work packages that make up the corresponding WBS representing the WBS dictionary.

1. Project Management

Table 2. Activities for Project Management work package.

WBS ID	*Activity Name*	*Activity Description*
1.1	Objectives Definition	Identify the objective of the project, its intended purpose, and the approach it will employ. Define the scope of the subject matter that will be addressed while acknowledging its constraints.
1.2	Schedule planification	Developing a comprehensive plan and organizing all the activities to be accomplished throughout the 20-week duration of the project. Within this planning, it is imperative to fulfill all the objectives established at the beginning of the project.
1.3	Report initial draft	Write the final documentation for the Introduction, Background, Market Analysis and Execution Schedule sections.
1.4	Report second draft	Write the final documentation for Concept Engineering, Technical Feasibility, and Regulation and Legal Aspects.
1.5	Report final draft	Write the final documentation for Detailed Engineering, Economic Feasibility and Conclusions.

2. Research

Table 3. Activities for Research work package.

WBS ID	*Activity Name*	*Activity Description*
2.1	Market Analysis	To analyze the state of the situation of digitalization in operating rooms. In addition, explore what are the existing solutions for operating room technical panels and what innovation projects exist related to the topic.
2.2	Technological elements involved research	A search of technological elements to integrate into our Theatre Control Panel proposal, selecting which of those that are integrated we should continue integrating and which of the new ones we should integrate.
2.3	Internship: Surgical Area Immersion	After taking the course in Medical Applications to Engineering (AME), we saw the need to transform the OR's. For this reason, during a few extra weeks, we dedicated some time to observing what we could improve in the OR to keep them up to date technologically.

3. Solution Implementation

Table 4. Activities for Solution Implementation work package.

WBS ID	***Activity Name***	***Activity Description***
3.1	Concept Engineering	Study of all integration possibilities, as well as tools with which to create a final solution to be presented. It is also important to define the selected technological elements involved, as well as why we integrate it and how.
3.2	Brainstorming and Design Research	Study, evaluation, and selection of graphic design trends that appeal to the intuitiveness, ease, and speed of the surgical team's work. As well as the definition of how should be the workflow of the interface that we will design.
3.3	New panel design	Design and elaboration of the final interface of the new operating room technical panel proposal.
3.4	Detailed Engineering	Elaboration of a thorough study of the interaction of the individuals, the technical requirements, and the integration of the elements in the new proposal. In addition, a critical analysis of the current solution should be made, and relevant conclusions should be drawn in comparison with the new proposal.

4. Final Deliveries

Table 5. Activities for Final Deliveries work package.

WBS ID	***Activity Name***	***Activity Description***
4.1	Final Report	Finish the details of the written project to be presented in the final TFG submission Thesis on June 7th.
4.2	Final Presentation	Creating the PowerPoint slideshow and structuring the presentation for the verbal delivery of the final project.

6.2. PERT Diagram

The PERT-CPM diagram is a graphical representation that illustrates the sequential and parallel activities of a project, along with their respective durations and dependencies. For the interpretation of the PERT diagram of the project, it is important to consider that each activity of the WBS corresponds to a specific identification in order to carry out the PERT diagram.

When it comes to creating the PERT diagram, we need to know which activities are the previous and posterior ones for each activity, indicating de chronologic dependance between them. This relationship between the different activities is detailed below in Table 6.

Table 6. Chronological dependencies of the activities.

WBS ID	PERT ID	ACTIVITY	Previous Activities	Posterior Activities
1.1	A	Objectives definition	B	**F**
1.2	B	Schedule planification	-	**C, A**
1.3	C	Report initial draft	B	**D**
1.4	D	Report second draft	C	**E**
1.5	E	Report final draft	D	**M**
2.1	F	Market analysis	A	**I**
2.2	G	Technological elements involved research	H	**J**
2.3	H	Internship: Surgical Area Immersion	-	**G**
3.1	I	Concept Engineering	F	**M**
3.2	J	Brainstorming and Design Research	G	**K**
3.3	K	New panel design	J	**L**
3.4	L	Detailed Engineering	K	**M**
4.1	M	Final Report	E, I, L	**N**
4.2	N	Final Presentation	M	-

Afterwards, the average, pessimistic, and optimistic times were associated with each activity in Table 7. Equation 1 shows the formula for the probabilistic calculation of PERT time, which has been used to estimate the time for each activity (last column). The time values are all expressed in weeks for simplifying calculations, and they have been rounded to obtain more coherent and reasonable values.

$$\mu_{PERT} = \frac{\mu_o + 4\mu_a + \mu_p}{6}$$

Equation 1. Probabilistic model to calculate PERT time.

Table 7. Times needed to calculate PERT time.

PERT ID	Optimistic Time (weeks)	Average Time (weeks)	Pessimistic Time (weeks)	PERT Time (weeks)
A	0,5	1	1,5	**1**
B	1	2	2,5	**2**
C	4	5	5,5	**5**
D	5	5	5,5	**5**
E	5	6	6,5	**6**
F	2,5	4	5	**4**
G	1,5	2	3	**2**
H	2,5	3	3,5	**3**
I	1	3	4	**3**
J	2	3	3,5	**3**
K	6	7	8	**7**
L	1,5	2	3	**2**
M	0,5	1	1,5	**1**
N	0,5	1	1	1

In this PERT-CPM diagram (Figure 24) we find that there are 14 activities, but we have had to create two fictitious activities to avoid the problems generated by activities I and L. The fictitious tasks have no effect on time or the critical path.

At the top of each node, we find the corresponding node number. In the lower left part, we find the early time which represents the minimum time needed to be able to carry out an activity. In the lower right part is the last time, the latest time in which an event can take place. This information allows us to know the critical path that will be the one that indicates the minimum time necessary to be able to carry out a project. The critical path is formed by the **B, C, D, E, M, and N** activities that are indicated in red.

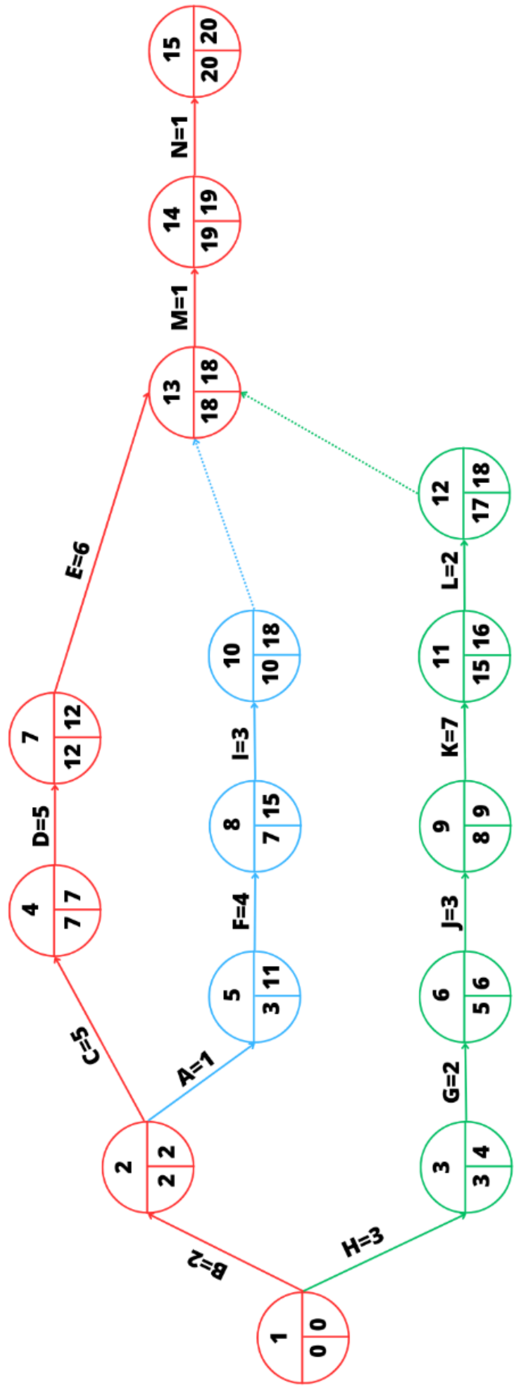

Figure 24. PERT Diagram of the Final Degree Project.

6.3. GANTT Diagram

The GANTT diagram is a project management method that supports the scheduling of agreed deadlines to carry out a project. In this way, it speeds up and facilitates the follow-up of the evolution of the activities to be developed during the project. In our case, we have chosen to establish a weekly planning GANTT chronogram, where the work packages to be completed each week are observed.

This diagram shows the elaboration of the project during several months, to be concrete from the last week of January 2023 to the third week of June 2023. A total period of 20 working weeks. Looking at Figure 25, the activities that make up the critical path are marked in red. The activities that have more flexibility are indicated in blue and green, where the margin is indicated in gray.

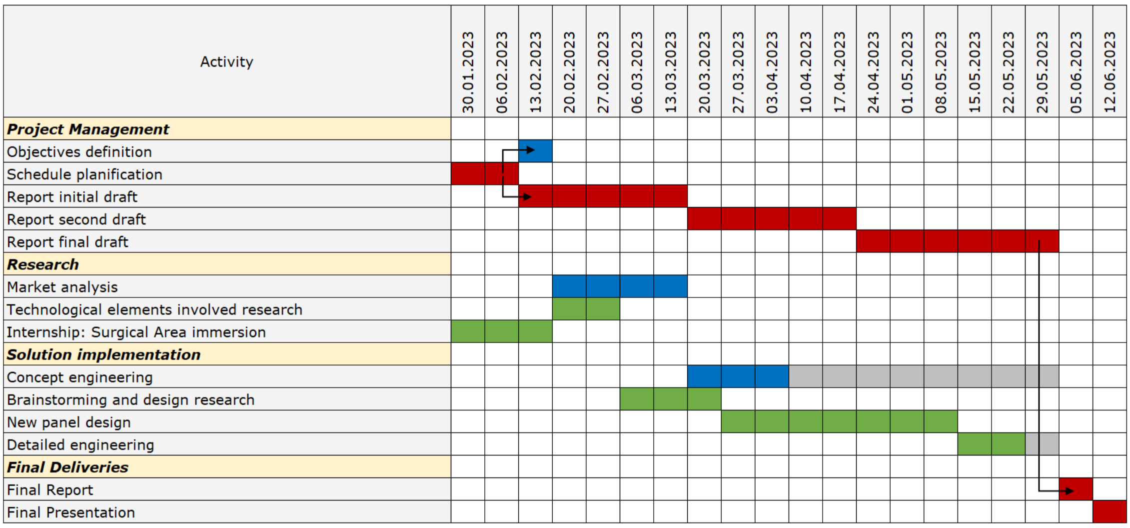

Figure 25. GANTT Diagram of the Final Degree Project.

7. Technical Feasibility

The technical feasibility of the project can be determined through a SWOT analysis, in other words, by conducting a detailed study of the external factors (opportunities and threats) and internal factors (strengths and weaknesses) that directly impact the project and are described promptly.

Table 8. SWOT Analysis of the project.

STRENGTHS	WEAKNESSSES
S1. Improvement of surgical outcomes through increased efficiency and precision. **S2.** Integration of operating table position control and Internet access. **S3.** Integration of audiovisual management tool into the operating room control panel. **S4.** Enhancement of surgeon's personal safety **S5.** Reduction of surgical time. **S6.** Recording of data generated by the operating room control panel. **S7.** iPad allows for free movements within the operating room, as it can be fixed in the wall or not.	**W1.** High costs of installation, programming, and regulation. **W2.** Customization of the graphical interface for each operating room. The control of the lighting system includes photos of the layout of the implemented operating room. **W3.** Technical challenges in integrating the graphical interface with the technical infrastructure of the servers.
THREATS	**OPPORTUNITIES**
T1. Established and direct competition in the market. **T2.** High expectations from users. **T3.** Stringent regulatory requirements. **T4.** Risk of errors or technical failures that could affect patient safety in the operating room.	**O1.** An AI-based recommendation system is utilized to optimize operating room configurations using data from recorded information. **O2.** Improve the graphic design of the user interface, making the user experience even more intuitive. **O3.** High demand for digital and innovative solutions in the surgical sector. **O4.** Possibility to collaborate with suppliers of surgical equipment to facilitate the integration.

As shown in Table 8, the implementation of the new operating room technical panel proposal presents a range of strengths and a set of new opportunities for operating rooms of the future. However, it can be also seen threats and weaknesses associated.

Focusing on the strengths of the new theatre control panel, it can be observed how surgeons gain greater personal confidence, as they can configure operating room systems and move freely within it. Furthermore, it is the first operating room control panel that integrated audiovisual management too, operating table position, and Internet access in the same device. Moreover, all data generated is registered to upload in a private cloud. The main strengths are evident, including reduced surgical time and greater surgical outcomes enhancing efficiency and precision.

There is also the opportunity to modify graphic design to enhance user interface and user experience for surgeons. It exists the possibility to collaborate with surgical equipment suppliers to facilitate the integration of their equipment. As can be seen during the development of the project, digitalization is playing a crucial role in surgery 4.0. Bearing in mind the data recorded by *MySurg* tool, it can be implemented a recommender system to suggest optimal operating room configurations.

On the other hand, surgical staff have high expectations that may not always be met as they hoped. Bearing in mind patient safety, it is important to consider that can exist risk of errors or technical failures. The current regulations are very strict and must pass several tough regulation and validation processes. It is important to be aware of those direct threats and keep informed accordingly.

Regarding installation, the integration of a graphical interface with the technical infrastructure of servers can be challenging and expensive. It is also important to consider the costs associated with programming and complying with regulations that must be implemented. In conclusion, the more you customize your device, the more work will be involved, as you will need to develop software according to each client's specific demands.

8. Economic Feasibility

This section aims to assess the economic viability of the project. Therefore, in this section, the cost of the analysis carried out and the production of a semi-functional mock-up of how the design of the graphic user interface of the new proposal will be determined and specified. However, this economic viability also includes the cost of the development of a fully functional program and the cost of installing it in an operating room, assuming that the proposed solution is already a market solution.

The economic viability has been divided into direct costs generated by material resources and human resources. Material resources costs include the cost of the materials needed to develop the project. However, the cost of human resources includes all costs related to the cost of working hours for individuals. In the end, indirect costs have been estimated, referring to expenses such as electricity, lighting, transport, etc. To do so, it has been estimated as 10% of the total direct costs obtained.

For the development of the project carried out, a Figma premium license obtained free of charge through the University of Barcelona has been needed. However, a personal laptop computer has also been required to carry out both the study and analysis of the technical panels in the operating room and the creation of a semi-functional mockup that shows the user interface and the user experience. This developed project has involved the work of a Biomedical Engineer for 450 hours. The salary considered for a biomedical engineer has been 18€/hour. The total cost of the project developed is attached to Table 9.

Table 9. Economic feasibility of the project developed.

			Quantity	***Cost (€)***
Direct Costs	Material Resources	Figma Premium License	1 u.	Free
		Personal Laptop	1 u.	800 €
	Human Resources	Biomedical Engineer	450 hours	6.750 €
Indirect Costs			10%	755 €
Total Cost of the Project Developed			**8.305 €**	

However, for the implementation in the real environment of the proposed solution, a software development cost should be included, as well as the digital integration of the operating room systems with the respective servers. In addition, an iPad with 12.9" cellular capacity and its respective casing that guarantees IP65 protection should be purchased. Finally, for the final construction of the fully functional interface, work will be needed for approximately 1000 hours, which will be in some moments (200 hours) advised by a designer.

Finally, a team made up of installers will work for 96 hours to carry out the total integration and prepare it for use it. The salary considered for a biomedical engineer, design consultant and installer has been 18€/hour, 15€/hour, and 15€/hour, respectively. The total cost of the project developed is attached to Table 10.

Table 10. Economic feasibility for implementation of the final solution.

			Quantity	***Cost (€)***
Direct Costs	Material Resources	Software Development	1 u.	40.000,00 €
		Digital Integration of the Systems of Operating Room	1 u.	100.000,00 €
		iPad Pro (2022 6ª gen., 256 GB, Plata, 12.9", WiFi+CELL)	1u.	1.689,00 €
		Case with IP65 protection	1u.	40,00 €
	Human Resources	Biomedical Engineer	1000 hours	18.000,00 €
		Design Consultant	200 hours	3.000,00 €
		Installers	96 hours	1.440,00 €
Indirect Costs			10%	16.416,90 €
Total Cost of Implementing the Final Solution			**180.585,90 €**	

As we can see it, the implementation of the final solution in one operating room, it would be expensive as it involves a multidisciplinary team, strict regulation, and material difficult to acquire. The total cost would reach approximately 180.000,00€.

9. Regulations and Legal Aspects

In the case of a control panel for integrated systems in an operating room, it does not need to be classified as a medical device, since it does not interact directly with the patient at any time. In fact, the technical panel we propose should only interact with the operating room and its respective systems. However, this device should accomplish various European certificates and standards to ensure that it is validated and can be implemented in the control of the operating room.

CE certification is a global requirement for many products sold in the European Union, ensuring compliance with safety and regulatory standards. It is necessary for your solution to meet legal requirements and access the European market. [66]

By complying with the Low Voltage Directive 2006/95/EC of the European Parliament and the Council of the European Union, it is ensured that the device complies with electrical safety requirements to protect users against electrical hazards. This Directive regulates equipment intended for use within certain voltage limits. [67]

The appliance complies with the Electro Magnetic Compatibility (EMC) 2004/108/EC Directive ensures that the device does not generate and is not susceptible to electromagnetic interference. This is important in a medical environment, where the accuracy and reliability of equipment must be protected from external interference. [68]

As part of this project has been carried out after a hospital observation, students who participate in studies in the Faculty of Medical Sciences are obliged to follow a regulation that refers to respecting the privacy and confidentiality of patients when we are doing this study in a hospital. This law is imposed by the following statement:

"*Orden SSI/81/2017, de 19 de enero, por la que se publica el Acuerdo de la Comisión de Recursos Humanos del Sistema Nacional de Salud, por el que se aprueba el protocolo mediante el que se determinan pautas básicas destinadas a asegurar y proteger el derecho a la intimidad del paciente por los alumnos y residentes en Ciencias de la Salud.*" [69]

10. Conclusions and future lines of action

The number of surgical procedures is increasing every year. We have been able to observe that operating rooms have great importance in the daily life of the hospitals since a great part of the healthcare activity of the centers is developed in them. Bearing in mind the great evolution that has taken place in the design of operating rooms, it is easy to understand that surgical theatres are taking part in the digital revolution that is happening. The implementation of video-guided surgeries or the incorporation of robotics surgery shows the future trend in operating rooms. The surgery performed is as important as the correct configuration of all the systems involved in the OR. An excellent setup of the operating room will allow to be more efficient during the surgery, obtaining better outcomes and reducing its cost.

The correct configuration of the operating room is managed by the technical panels, also known as control panels, which are those devices used to control the different systems that can be found integrated in an operating room. These have also evolved over time. Initially, they were modular and with buttons, in which only the most basic systems such as lighting, gas alarm, UPS alarm and interdepartmental communication of the hospital could be controlled. These older ones also included electrical sockets and the medical gas socket. However, the evolution of the years has led to devices that are managed in a more interactive and user-friendly way for the surgical team, even so, this evolution has not been implemented in all hospitals. In addition, the multitude of brands in the health sector make products for exclusive use for their company's equipment, which makes these control panels quickly go into failure when not using the specified equipment.

For example, in the Hospital Clinic of Barcelona, one of the most technologically developed, still has a large part of operating rooms with traditional technical panels and only in some of the newer ones incorporate digital solutions through fixed touch screens that allow the control of very few operating room systems such as temperature and ambient light.

During this project a new proposal for redesigning the technical panels of the operating room has been carried out. During this process a thorough study of all the components that we finally want to incorporate in this control panel has been carried out. After this study the following systems have been selected: Illumination and lighting, audiovisual, HVAC, medical gas alert system, UPS alarm control, operating table position, stopwatch, communication with other departments of the hospital, browser access, music access, and a new tool to register data of the control panel. It is also explained how this system can be integrated through servers that are connected to the central integration server that evokes into the graphic user interface.

It has also been decided that the interaction with the users will be with an iPad that will be fixed on the wall but at the same time it will be able to move around the operating room. With this integral solution we can see how digital integration is a possible reality that is becoming more and more important.

The results are satisfactory since all the objectives proposed at the beginning of the project have been fulfilled. In this way, we have developed a semi-functional mockup of the graphical user interface of the new technical panel proposal. This platform has been developed using the Figma design software, and we can understand which is the user experience with the flowcharts and the video demonstration. All this interface has been created based on a specific aesthetic design based on Apple. Finally, we can see that this new theatre control panel will generate many changes in the preparation of the operating room before surgery and in the way the surgical team works.

If we raise our heads and look to the future, this project could and should grow. First of all, because it has been designed with the future in mind, as it is an operating room control tool, but also a data collection tool that will allow us to create intelligent systems to suggest and recommend the most optimal operating room configuration for a specific surgical technique or disease. However, the most obvious next future step is the implementation of this proposed technical panel in a real environment. This would not be an impossible step, as we have observed that it is technically and economically feasible. Therefore, if we comply with the corresponding regulation and have all the material and personnel available, we could talk about a fully real solution.

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Annex

This annex shows screenshots of the graphical user interface defined for the proposed redesign of the operating room integration. It is also highly recommended to watch the view to know better about the user experience. The mains screen for Gas Alarm System, UPS Alarm Control, Browser, Music and Configuration are shown in the Detailed Engineering Section.

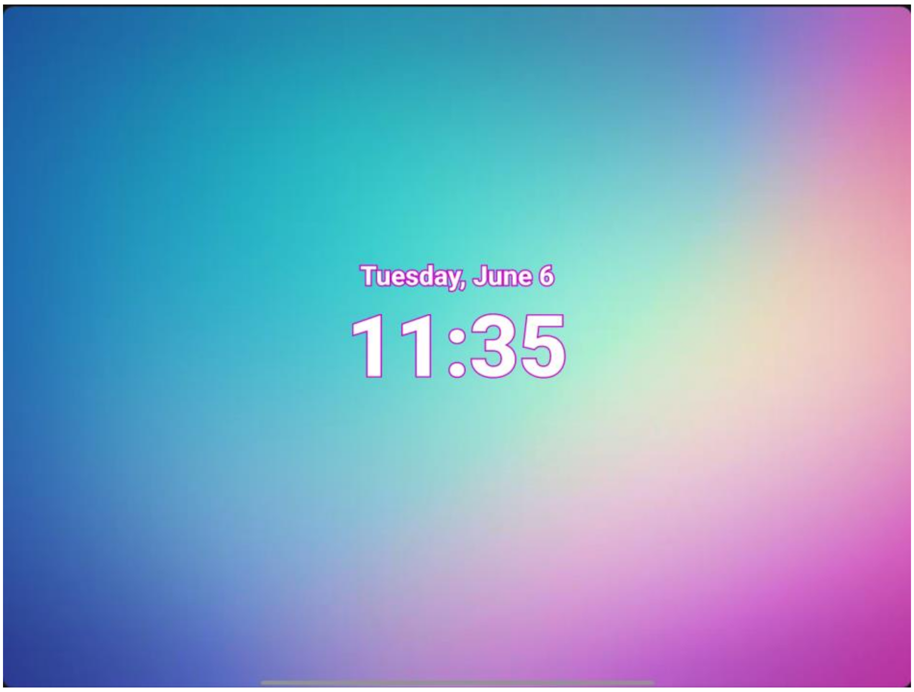

Figure 26. Lock screen.

Figure 27. Normal general menu with all available systems (left), and the same general menu with the icon of AV system enlarged due to hovering my finger (right).

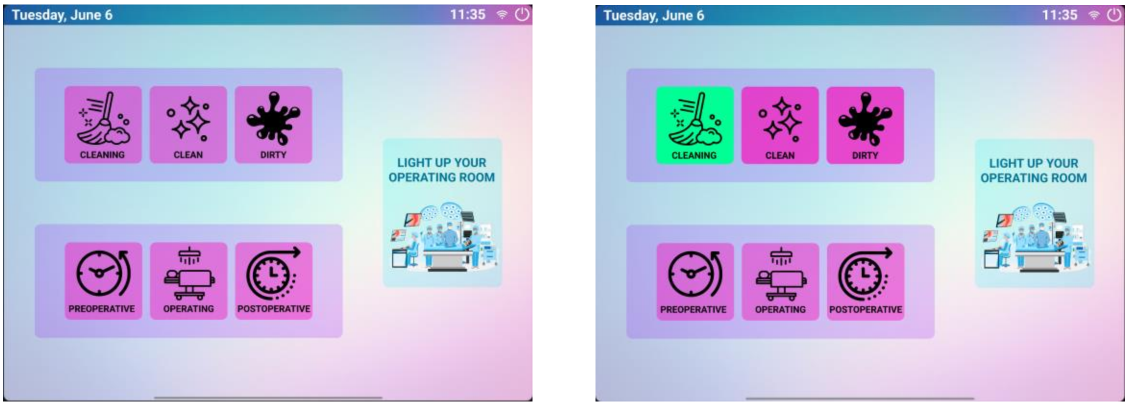

Figure 28. Initial screen of the light system control (left) and selected a preset light configuration by changing the color of the button (right).

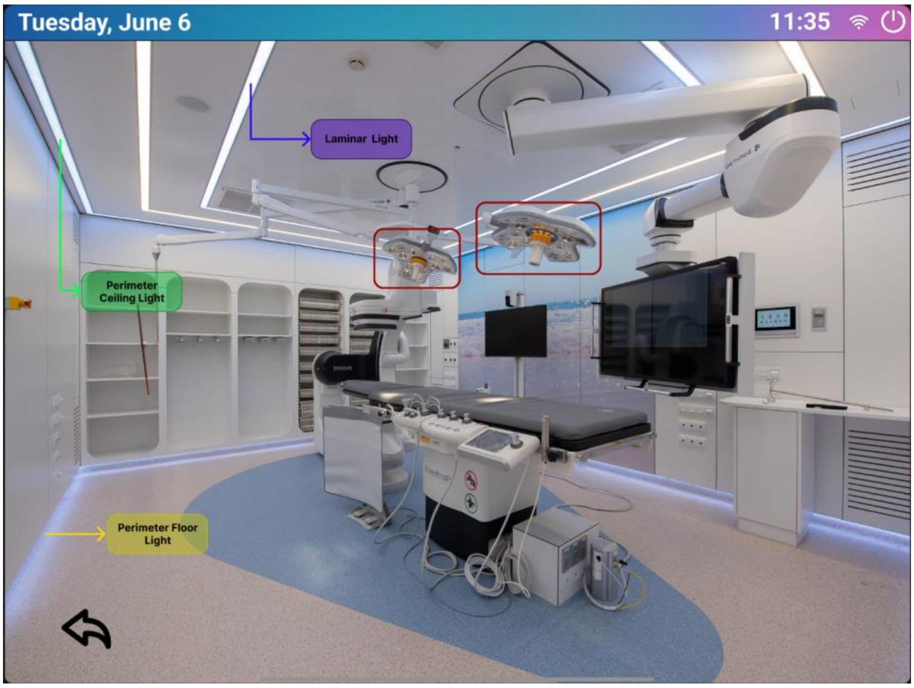

Figure 29. Customized light system control screen.

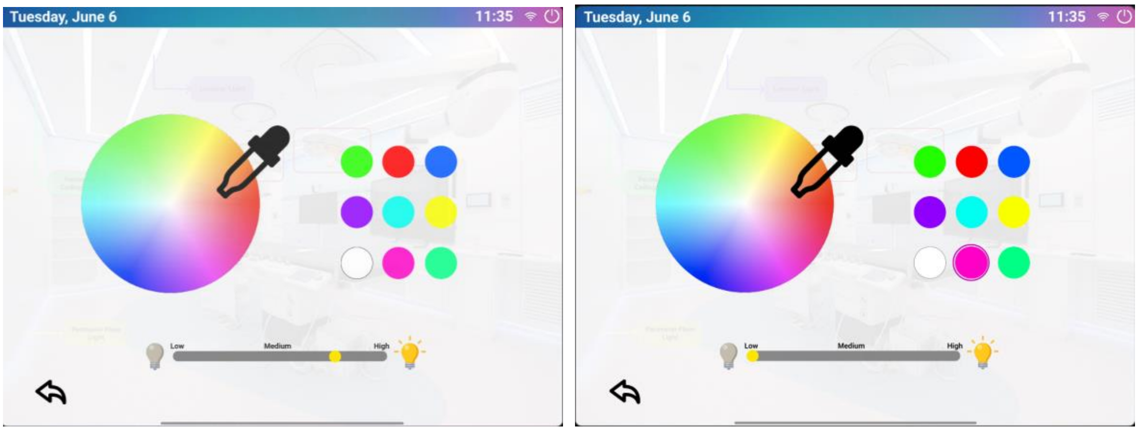

Figure 30. Screen to customize the perimeter light of the ceiling and floor; and of the lamellar light with customization of the brightness (left) and selection of the preset lilac color for the RGB lights (right).

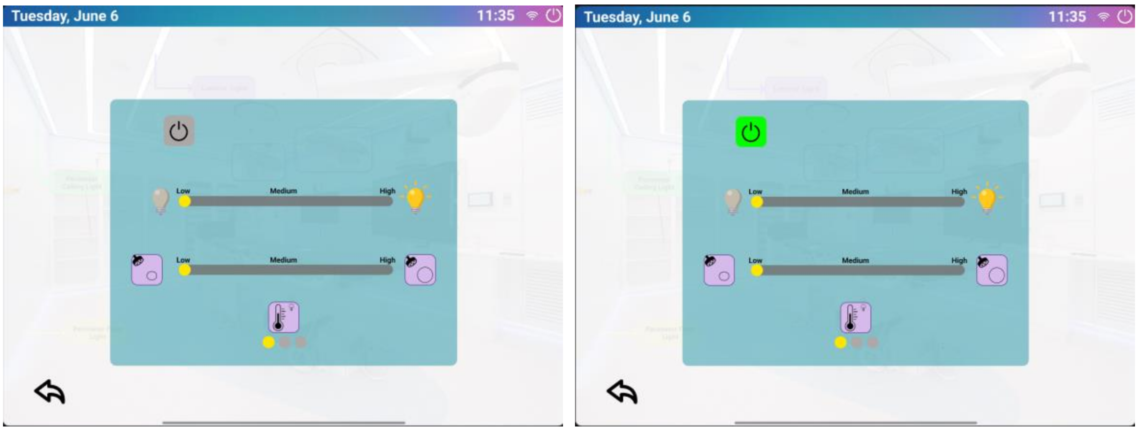

Figure 31. Screen for customizing the operating light without a camera (left) and turning on the lamp by clicking the start button that will change the color (right).

Figure 32. Customized brightness when the lamp is on (left) and the temperature at the third temperature setting that the lamp allows (right).

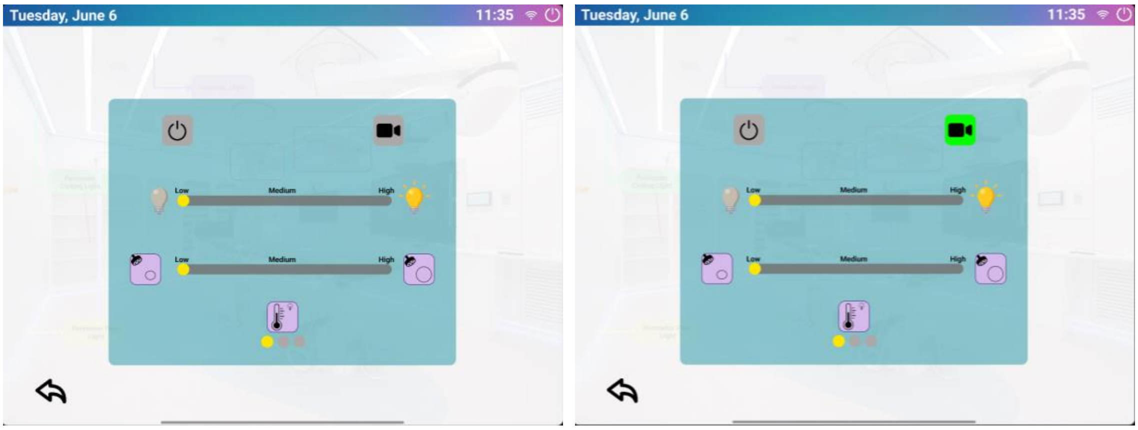

Figure 33. Screen for customizing the operating light with a camera (left) and turning on the lamp by clicking the start button that will change the color (right).

Figure 34. Screen for customizing the audiovisual system (left) and configuring the single-signal viewing mode and the monitor for the output that will change part of the color of the button (right).

Figure 35. Screen for selecting the source for the single-signal viewing mode (left) and turning on the microphone (right).

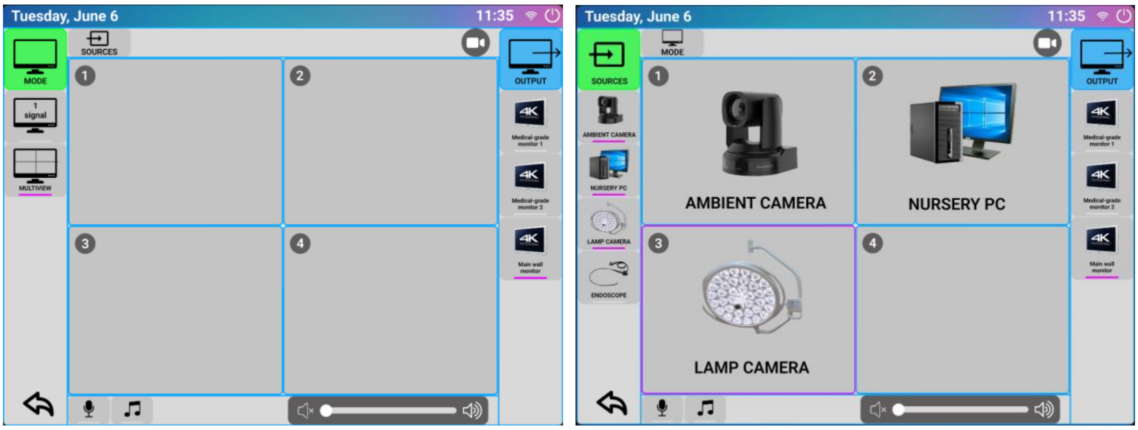

Figure 36. Screen for configuring the multi-signal viewing mode (left) and selecting the desired sources to be seen in the output monitor selected (right).

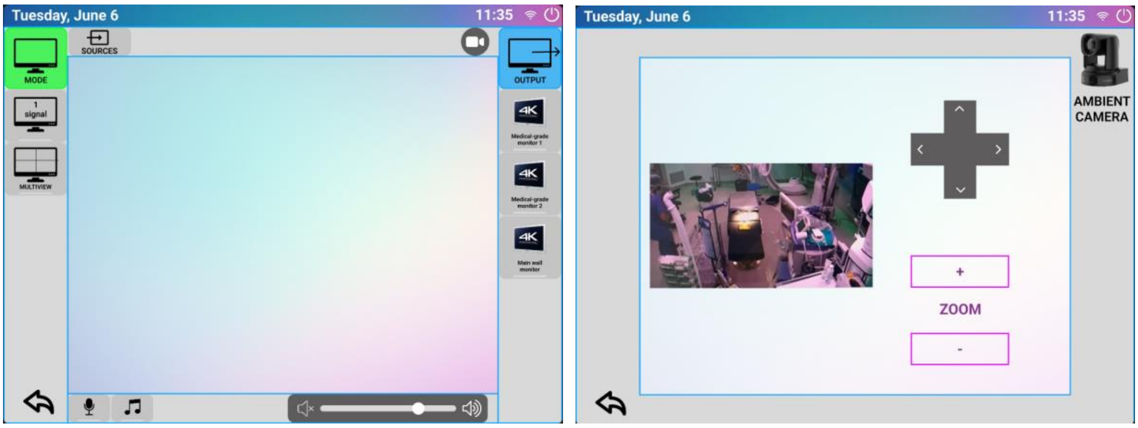

Figure 37. Screen for configuring the volume of the speakers (left) and configuring several features of the ambient camera (right).

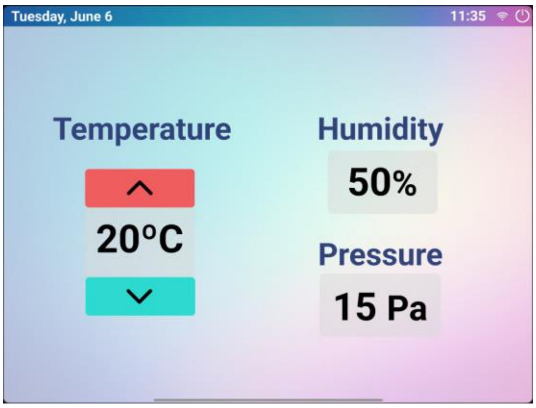

Figure 38. Main screen for controlling the temperature, where are also displayed the values for pressure and humidity.

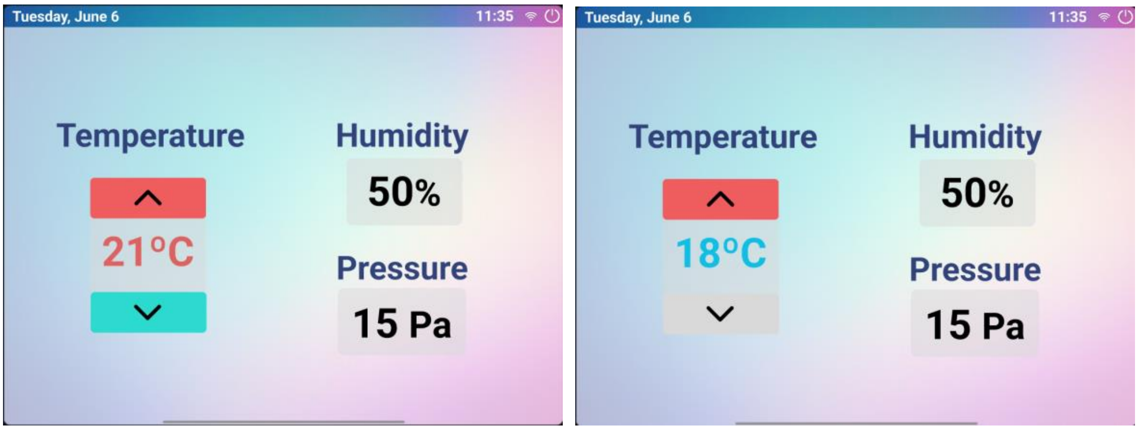

Figure 39. Screen for raising the temperature one grade (left) or lowering two grades (right).

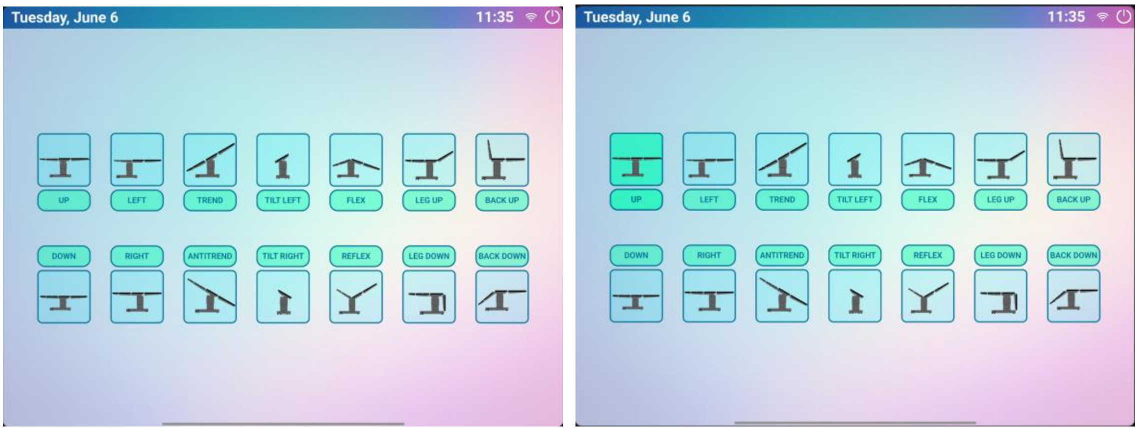

Figure 40. The main screen for controlling the surgical table position (left) and the screen controls the raise of the surgical table while is pressed the button with the change of color (right).

Figure 41. The main screen for controlling the stopwatch.

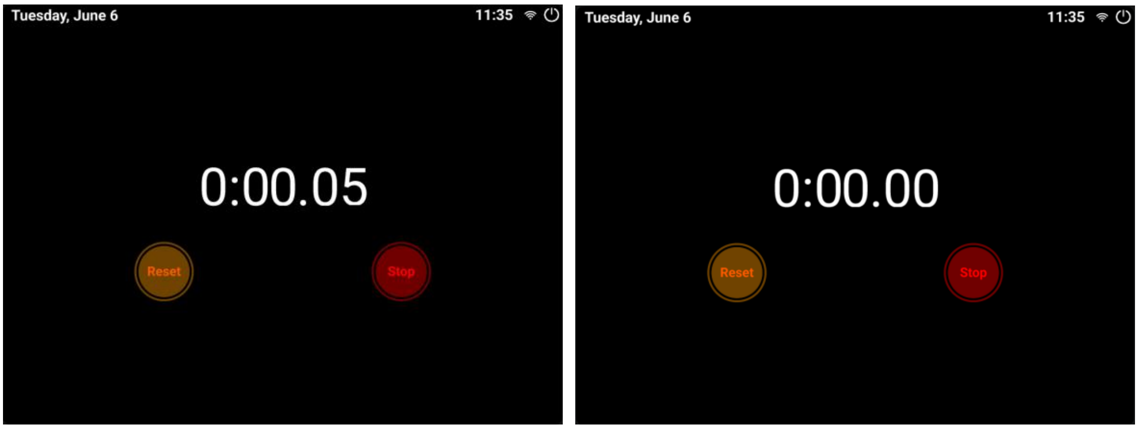

Figure 42. The screen while time is running (left) and how it looks when you reset it (right).

Figure 43. The main screen for the communication tool (left) and the screen with the cardiac arrest contact preselected (right).

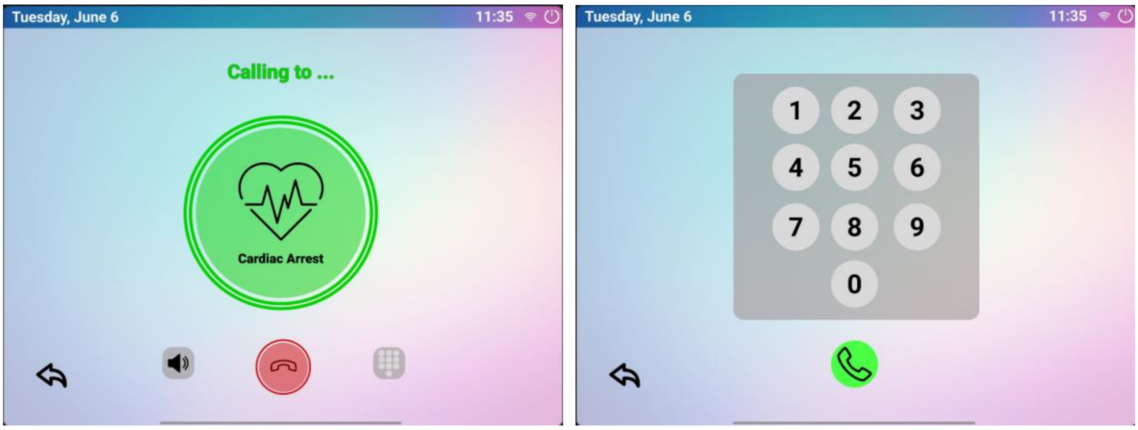

Figure 44. The screen while the system is calling the cardiac arrest department (left) and the screen if you want to call a personalized phone number (right).

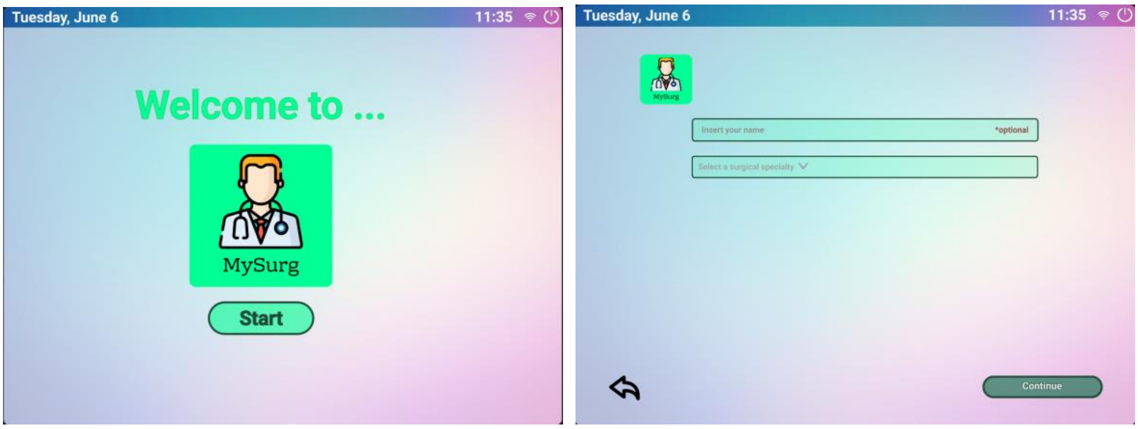

Figure 45. The main screen for MySurg tool (left) and the screen for introducing the surgeon's name and surgical specialty (right).

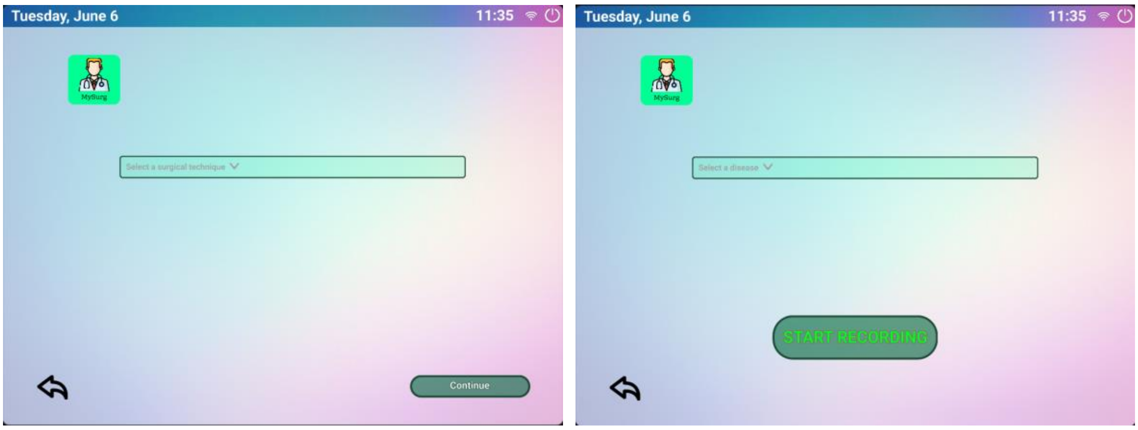

Figure 46. The screen for introducing the surgical technique (right) and the screen for introducing the disease and starting the recording of data (left).

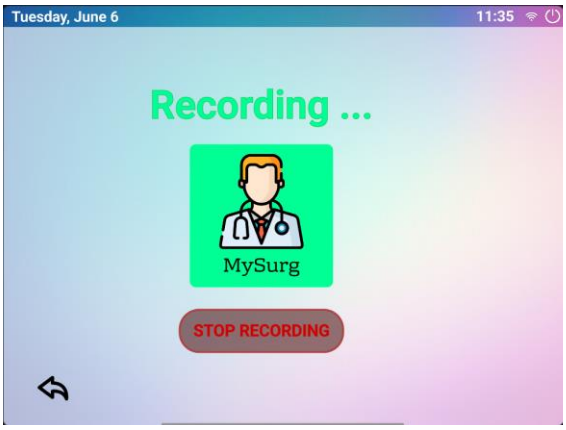

Figure 47. The screen for closing data recording when surgery comes to an end.