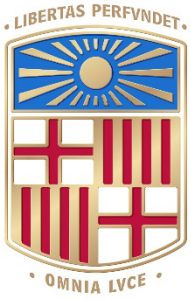

UNIVERSITAT DE BARCELONA

Final Degree Project

Biomedical Engineering Degree

User-centered integrated redesign of the Electrophysiology Room at the Sant Joan de Déu Pediatric Hospital

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Abstract

This project presents a comprehensive redesign proposal for the Electrophysiology Room at the Arrhythmia Unit of Sant Joan de Déu Children's Hospital (HSJD). The objective is to resolve existing structural and functional inefficiencies through a needs-driven, paediatric-adapted design. The approach follows the Biodesign methodology, progressing from the identification of needs to the proposal of solutions. The first phase involved shadowing procedures, interviews with clinicians and nurses, detailed questionnaires and benchmarking visits to six Spanish hospitals. This led to the collection and classification of over 40 needs across four categories: infrastructure, equipment, patient experience, and staff comfort. Each need was prioritised (must-have, nice to have, or not needed) based on CSUR standards, clinical workflows, and national recommendations. These needs were translated into a set of final essential and recommended technical requirements. For each, a tailored solution was proposed, integrating real-world observations and commercially available technologies. The proposal includes ceiling-mounted storage and power systems, improved lighting and temperature control, and better ergonomic conditions. All solutions were compiled into a full list of recommended equipment and illustrated in a conceptual layout plan. The project concludes that while technical design is key, subjectivity plays a major role in shaping what each team considers "ideal." Hence, the "perfect" EP room is not a universal standard but a dynamic solution that must respond to the unique needs of a clinical team at a specific point in time.

Keywords: Electrophysiology room, Paediatric cardiology, Biodesign methodology, Healthcare infrastructure, Medical equipment, Workflow optimisation, Ergonomics, Human-centred design

Resum

Aquest projecte presenta una proposta integral de remodelació de la Sala d'Electrofisiologia de la Unitat d'Arrítmies de l'Hospital Sant Joan de Déu (HSJD). L'objectiu és resoldre les ineficiències estructurals i funcionals existents mitjançant un disseny adaptat a pediatria i basat en necessitats reals. L'enfocament segueix la metodologia Biodesign d'Stanford, avançant des de la identificació de necessitats fins a la proposta de solucions. La primera fase va incloure observació directa de procediments, entrevistes amb personal mèdic i d'infermeria, qüestionaris detallats i visites de *benchmarking* a sis hospitals espanyols. Això va permetre recollir i classificar més de 40 necessitats en quatre categories: infraestructura, equipament, experiència del pacient i confort del personal. Cada necessitat es va prioritzar (imprescindible, recomanable o no necessària) d'acord amb els estàndards CSUR, el flux clínic i les recomanacions estatals. Aquestes necessitats es van traduir en un conjunt final de requeriments tècnics essencials i recomanats. Per a cadascun, es va proposar una solució concreta, integrant observacions reals i tecnologies comercials disponibles. La proposta inclou sistemes d'emmagatzematge i subministrament elèctric de sostre, control millorat de la il·luminació i la temperatura, i millores ergonòmiques. Totes les solucions es van recollir en una llista d'equipament recomanat i es van representar en un plànol conceptual. El projecte conclou que, tot i que el disseny tècnic és fonamental, la subjectivitat juga un paper clau a l'hora de definir què considera "ideal" cada equip. Així, la sala d'EP perfecta no és un estàndard universal, sinó una solució dinàmica adaptada a les necessitats d'un equip clínic en un moment determinat.

Paraules clau: Sala d'electrofisiologia, cardiologia pediàtrica, metodologia Biodesign, infraestructura sanitària, equipament mèdic, optimització del flux de treball, ergonomia, disseny centrat en la persona

Acknowledgements

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Lastly, I can never thank my parents enough for encouraging me to learn, explore, think, and dream even bigger, while teaching me to remain deeply grateful throughout the journey. Their unwavering support and quiet strength have been the foundation on which I've built not only this project, but also the person I am becoming.

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Abbreviations of concepts

AHA: American Heart Association

ALARA: As Low As Reasonably Achievable

BQC: Bloc Quirúrgic Central

CPM: Critical Path Method

CSUR: Centres, Services and Units of Reference

ECMO: ExtraCorporeal Membrane Oxygenation

EHR: Electronic Health Record

EHRA: European Heart Rhythm Association

EP: Electrophysiology

ERN: European Reference Network

ERP: Enterprise Resource Planning

HIS: Hospital Information System

HSJD: Hospital Sant Joan de Déu

HVAC: Heating, Ventilation and Air-Conditioning

ICS: Institut Català de la Salut

ICU: Intensive Care Unit

NPS: Net Promoter Score

MIR: Metge Intern Resident

PACS: Picture Archiving and Communication System

PCCB: Pediatric Cancer Center of Barcelona

PERT: Program Evaluation Review Technique

RF: Radiofrequency

SEC: Sociedad Española de Cardiología

SISCAT: Sistema Sanitari Integral d'utilització pública de Catalunya

SWOT: Strengths, Weaknesses, Opportunities, Threats

TEE: Transesophageal Ecocardiography

TFG: Treball de Final de Grau

TTE: Transthoracic Ecocardiography

VR: Virtual Reality

XR: X-rays

XUEC: Xarxa d'Unitats d'Expertesa Clínica

1. Introduction

Electrophysiology (EP) has become an essential discipline in the diagnosis and treatment of cardiac arrhythmias within cardiology, with increasingly complex procedures that demand highly specialised environments. The demand to reduce surgery duration time and risk increases the desire for newer and more optimised EP rooms. In paediatric care, these requirements become even more specific due to the physiological and emotional particularities of young patients.

Despite technological advances and the evolution of design standards in interventional cardiology spaces, many electrophysiology (EP) rooms remain outdated and fail to meet current needs. That is why this project addresses the integral redesign of the Electrophysiology Room in the Arrhythmia Unit at Sant Joan de Déu Barcelona Children's Hospital, taking into account the need for coexistence with its adjacent rooms. Although the unit maintains ambitious standards of care, its EP room, last renovated twelve years ago in 2013, presents apparent limitations in terms of spatial distribution, equipment, digital integration, and patient experience. This proposal aims to develop a renovation plan that meets current functional, technical, and human requirements through a user-centred and context-aware design approach.

1.1. Scope

From April of 2024 until June 2025, this redesigning project has formed a Biomedical Engineering Degree Final Degree Project (TFG for *Treball de Fi de Grau* in Catalan), developed in Sant Joan de Déu Paediatric Hospital in Barcelona (HSJD), a leading centre for maternal and child healthcare in Catalonia and throughout Spain. Founded in 1867, it offers a wide range of specialized medical services for children and young people, holding up to 69 national and European accreditations.

The primary objective of this project is to acknowledge the current of the Arrythmia Unit of HSJD and propose an integrated solution. The design of a clinical environment encompasses architecture, equipment, elements distribution, and healthcare tracks, among other elements. That is why, when planning a renovation project for an interventional room such as the Electrophysiology Room, it is essential to consider all peripheral rooms that are part of the same unit (further explained *in 2.3.1 Adjacent Spaces in an Electrophysiology Unit*). These spaces ensure the proper flow of both patients and medical staff, making them indispensable.

This project is a preliminary theoretical investigation, not considered for implementation in HSJD during its course. The adjacent rooms are only analyzed and considered from an infrastructure perspective, and are not included in the equipment plan as part of the main electrophysiology room. For the same reason, this project does not consider the current or real budget that HSDJ would employ for this exact project.

Having noted the previous considerations, this project comprises a review of the clinical and legal guides as well as current professional recommendations, the study and use of Stanford's BIODESIGN methodology (further explained in *3.1 The study of the method: Stanford's BIODESIGN process*) to acquire the requirements of the Unit, the analysis and classification of the extracted needs, an infrastructure study and proposal for the whole unit and a final equipment plan of the EP room.

Once the spatial limits of the project have been defined, its scope includes:

- Analysis of the initial conditions of the Electrophysiology Room at HSJD in Barcelona.
- Research and analysis of the methodology used in the design of an Electrophysiology Room to optimize project development and meet the needs of all stakeholders.
- Use of project conception and planning tools such as a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, a Work Breakdown Structure (WBS) with the corresponding diagram and dictionary, a PERT-CPM timeline with its critical path, and a Gantt chart to visualize task scheduling.
- Identification of stakeholders involved in the design process of the Electrophysiology Room.
- Collection of the needs outlined by stakeholders and their validation against legal frameworks and institutional recommendations. Followed by a filtered and prioritized list of needs, classified to facilitate stating the final requirements and the search for relevant solutions.
- Description of solutions implemented in external rooms visited, including solutions from EP rooms of six different hospitals such as Hospital Universitari de Bellvitge and Hospital Universitari Vall d'Hebron and rooms not necessarily dedicated to electrophysiology but also hemodynamics, vascular surgery, and operating rooms such as those in the Central Surgical Block (BQC) of HSJD.
- Analysis of multiple solution proposals to address the requirements and satisfy as many stakeholders as possible. The most optimal solutions will be selected through a combination of filtering and prioritization.
- Design of a floor plan for the Arrhythmia Unit at HSJD, including the Electrophysiology Room and the adjacent rooms mentioned earlier, ensuring space optimization within the EP room.
- Definition of an equipment plan for the new Arrhythmia Room at HSDJ.
- Evaluation and validation of the new integrated solution for the Arrhythmia Unit by the stakeholders involved.

1.1.1. Limitations

After defining the project scope, it is necessary to describe what may be included and what will not be covered, i.e., the project's limitations.

Given that HSJD is an active hospital with uninterrupted surgical activities, the requirements extraction, in-situ activities with professionals, and access to the EP room have been limited. Additionally, since the building already exists and is in operation, its main and fundamental architectural elements cannot be altered. This way, the options for redesigning the distribution of the EP room and its peripheral rooms have been minimal. This is the reason behind focusing most efforts on addressing the distribution and equipment challenges.

Furthermore, the introduction of innovative technologies does not include the optimization of existing institutional software, as it would constitute a structural change within the institution, which falls outside the scope of this project. These technologies include HIS (the *Health Information System* and its corresponding HER, or *Electronic Health Records*), ERP (the *Enterprise Resources Planning* and its corresponding finance management system), a pharmacy system and PACS (*Picture Archiving and Communication System*).

Moreover, a relevant limitation to consider is the overall duration of the project, which was constrained to 13 months. Despite efforts to plan and anticipate the necessary stages, a project of this nature, requiring coordination with multiple stakeholders, iterative feedback, and detailed data collection, can be affected by the limited timeframe. This has occasionally restricted the depth of the analysis and decision-making processes.

Lastly, although not included in this project, in future phases of the EP room renovation plan, the new design describing the final solution will be modelled in 3D to improve understanding among all professionals who will work in it.

1.2. Objectives

The objective of this project is to design the Electrophysiology Room, as defined in the project scope, to address currently unmet requirements identified by the Arrhythmia Unit team at Sant Joan de Déu Hospital in Barcelona. To achieve this, it is necessary to determine the needs of the medical staff and propose various infrastructure, technological and logistical solutions, all aimed at a comprehensive renovation of the room and a potential infrastructure upgrade of the entire Arrhythmia Unit.

Within the framework of this preliminary project, the goal is to establish an optimal and efficient methodology for designing the space that addresses the maximum number of identified needs.

The overall objectives of the Final Degree Project (TFG) are the following:

- Definition and analysis of functional and technical requirements of the EP Unit, specifically of the EP room.
- Research and evaluation of feasible solutions for each identified need.
- Integration of selected solutions into a final design and equipment plan for the new Electrophysiology Room at Sant Joan de Déu Hospital.

This project is conceived as a comprehensive redesign proposal for the Electrophysiology Room, taking into account the existing and future needs of the adjacent rooms at Sant Joan de Déu Hospital, to address the unresolved healthcare and technical requirements of the current space. Through a structured, user-centred methodology, the goal is to provide innovative, feasible solutions tailored to the paediatric context. The following chapters will elaborate on the background and framework that justify and shape this initiative.

2. Background

2.1 Introduction to Electrophysiology

Electrophysiology is a branch of cardiology that studies the heart's electrical system. This system is responsible for generating and transmitting electrical signals that cause the heart muscle to contract rhythmically. When these electrical signals are not transmitted correctly, arrhythmias can occur—disruptions in the heart's rhythm. Arrhythmias can manifest in different forms, such as tachycardia (fast heartbeats), bradycardia (slow heartbeats), or irregular rhythms, which may cause symptoms like palpitations, dizziness, or, in severe cases, increase the risk of stroke or sudden cardiac death [1].

Electrophysiological studies are the primary tool for **diagnosing** arrhythmias. These procedures are minimally invasive surgical interventions performed by catheterization. One catheter is introduced primarily through the femoral vein, accessed via the groin, and is directed to the heart to record electrical signals from various points of interest. This enables doctors to identify the origin of the arrhythmia and its impact on heart function. This procedure requires a high degree of precision. It is conducted in an electrophysiology room, where advanced imaging technology and medical equipment are used to monitor and treat electrical disturbances in the heart.

The most common **treatments** for arrhythmias include [2]:

- **Radiofrequency ablation**: This technique involves the use of high-frequency (500-750 Hz) sinusoidal currents to destroy or burn the area of cardiac tissue responsible for the arrhythmia

through thermal damage, secondary to the resistance of the alternating current (AC) circulation [3]. It is highly effective for patients with tachycardias or atrial fibrillation.

- **Cryoablation**: This type of ablation utilizes extreme cold (hypothermia) to freeze and disable abnormal cardiac tissue through biochemical damage [4]. The fact that this damage can be reversible or irreversible, depending on the temperature and exposure time, allows doctors to evaluate the efficacy or safety of potential ablation sites. It is particularly useful for certain types of arrhythmias where heat-based treatments are not preferred. However, this technique is not currently used at HSJD.

- **Implantable devices**: In some cases, patients with bradycardia or at risk of sudden cardiac death may require pacemakers or implantable cardioverter defibrillators (ICDs). These devices help maintain a proper heart rhythm or automatically correct dangerous arrhythmias. Moreover, implantable loop recorders, also known as implantable Holters, can be implanted in the EP room to continuously monitor and analyse cardiac rhythm over extended periods, aiding in the diagnosis of arrhythmias.

- **Antiarrhythmic medication**: Some patients can be treated with drugs that help control or suppress arrhythmias, although this option is often used as a complement or for mild cases.

2.2 Technology and medical equipment

To conduct these procedures with maximum precision, an electrophysiology room requires highly specialized equipment. The most commonly used technology is **fluoroscopy**, an X-ray technique that enables real-time, excellent visualization of catheters and devices, allowing professionals to guide the catheters safely through the vascular system [5]. This requires a fixed C-arm or monoplane fluoroscopy system (biplane systems would also be useful but are not necessary for EP) permanently installed in the ground or ceiling of the EP room, an angiography table with a radiolucent surface and high-resolution monitors. However, fluoroscopy exposes both patients and medical staff to radiation, driving the development of alternative technologies that reduce this exposure. Moreover, it has limited capacity to visualize heart's anatomy, requiring the use of complementary imaging modalities for detailed anatomical analysis.

An innovation that revolutionized the electrophysiology paradigm in the 1990s are the **3D electroanatomic mapping systems**, which allow the reconstruction of the heart's anatomy and electrical activity with high precision establishing a magnetic camp around and over the patient's body to know the exact position of a catheter that has been previously introduced into the patient's heart via catheterization.

This system minimizes the need for continuous X-ray use, thereby making surgeries safer, faster, and more precise [6]. These systems require a dedicated workstation with mapping software – usually placed in the control room –, magnetic or impedance-based field generators that may be permanently stored inside the EP room, location sensors integrated into the catheters, and connection modules to synchronize with other imaging or electrophysiology equipment that may also be permanently stored inside the EP room.

Additionally, **transoesophageal echocardiography (TEE)** utilizes ultrasound to obtain detailed images of the heart during procedures, thereby enhancing safety and effectiveness, particularly for cardiovascular structures that are not well visualized—or not visualized at all—via the transthoracic approach [7]. Ultrasound imaging works by emitting high-frequency sound waves through a probe; these waves reflect off internal structures and return as echoes, which are then processed to form real-time images. These systems typically include a central ultrasound unit (that may be stored inside or outside the EP room), visualization monitors (commonly integrated), and modality-specific probes, such as transoesophageal, transthoracic, or intracardiac catheters. However, **transthoracic echocardiography (TTE)** also remains a valuable tool for preprocedural assessment of ventricular function and postoperative monitoring. Other ultrasound modalities, such as intracardiac echocardiography (ICE) [8], are increasingly being used for real-time anatomical guidance, especially during complex ablation procedures, although it is not currently employed at HSJD.

Another essential tool is the **polygraph system**, which records and displays both surface (transthoracic) and intracardiac electrograms. These systems allow for real-time monitoring of the heart's electrical signals across multiple channels, providing crucial data for diagnosing arrhythmias and guiding ablation therapies. A typical polygraph setup includes an acquisition module connected to intracardiac catheters, surface ECG leads, amplifiers, and a display workstation where electrograms are visualized and annotated in real-time, usually both inside the room and in the control room.

Finally, **radiofrequency (RF) and cryoablation generators** are fundamental to the therapeutic phase of electrophysiological procedures. As mentioned in Section *2.1 Introduction to Electrophysiology*, RF generators use thermal energy to deliver precise lesions to arrhythmogenic tissue, while cryoablation systems apply extremely low temperatures to achieve tissue necrosis.

Considering the mentioned technologies, an electrophysiology room must also include:

- Energy generators for ablation procedures (radiofrequency or cryoablation).
- Advanced electrocardiographic monitoring to capture the heart's electrical signals in real-time.

- Intracardiac navigation systems to precisely position catheters within the heart chambers. Some examples are CARTO by Biosense Webster, EnSite NavX Precision mapping system by St Jude Medical, and Rhythmia by Boston Scientific [9].
- C-arm imaging system, which provides high-quality radiological images.

In summary, electrophysiology rooms are high-tech environments designed to treat complex arrhythmias with specialized equipment that facilitates access to the heart, minimizes procedural risks, and improves patient outcomes. As discussed in the following sections, continuous technological and organizational advancements have led to less invasive interventions, resulting in reduced risk, shorter post-operative recovery times, and decreased hospital costs, among other benefits. Moreover, the medical images innovation has allowed some surgeries to be completely non-ionizing, making interventions safer for both the patient and the professionals.

2.3 Functional Requirements of an Electrophysiology Room

An EP room must meet a series of functional requirements to ensure **safe**, **efficient**, and **high-quality care**. From an infrastructural perspective, the layout should enable good visibility of the surgical field, facilitate smooth circulation for staff and equipment, and separate sterile and non-sterile areas. Environmental control is essential, with recommended room temperatures between 20–22 °C and HEPA-filtered positive-pressure ventilation systems to ensure **laminar airflow and maintain a positive pressure**, thereby preventing infections [10][11]. Surfaces should be continuous, non-porous and antistatic to allow for thorough cleaning and disinfection, favouring materials that are seamless, durable, and easy to maintain.

Ergonomics also plays a key role; the arrangement of monitors, work surfaces, and medical equipment must support comfortable working postures and minimize physical strain during prolonged procedures. Moreover, radiological safety must be ensured, given that fluoroscopy involves the use of X-rays, through the use of structural shielding, such as lead-lined walls and doors, appropriate signage, personal protective equipment, and dosimetry control systems [12].

The room must be equipped to meet the technical and clinical needs of both the healthcare team and the patient. This includes integrated systems, such as those mentioned in *2.2 Technology and medical equipment*, along with **continuous patient monitoring and advanced life support equipment**, including defibrillators, airway management kits, and resuscitation carts [11]. Sufficient power outlets must be available to accommodate the multiple electronic systems in use, and gas supply ports—such as for oxygen, compressed air, and vacuum—are necessary to support anaesthesia and emergency

interventions. Seamless digital integration with the hospital's information and image management systems (HIS and PACS) is also essential to support data access and documentation workflows [13].

In paediatric electrophysiology, additional considerations must be taken into account. Equipment must be adapted to smaller body sizes, and **anaesthetic support** is often required, making the presence of a paediatric anaesthesiologist highly advisable. Efforts to minimize stress for the child and family, such as using **calm lighting** and creating **child-friendly environments**, are essential. Importantly, radiation exposure must be strictly controlled and kept to a minimum, by the ALARA (As Low As Reasonably Achievable) principle [14].

These infrastructural and technical considerations concern the main procedure room itself. However, a functional and efficient EP unit extends beyond this space. Several adjacent rooms play a crucial role in supporting procedures, coordinating multidisciplinary care, and enhancing patient safety, particularly in the pediatric setting. These supporting areas are standard components in most modern arrhythmia units and must be accounted for when planning or renovating such facilities. The requirements mentioned here will be further explored in subsequent chapters to define specific criteria for the proposed renovation.

2.3.1 Adjacent Spaces in an Electrophysiology Unit

Beyond the main procedure room, a well-designed electrophysiology (EP) unit typically includes several adjacent spaces that are essential for maintaining clinical efficiency, ensuring patient safety, and optimizing workflow. These areas support the procedures performed in the EP room and reflect the multidisciplinary nature of arrhythmia care. Their configuration is especially crucial when designing or renovating a specialized pediatric electrophysiology facility. Key adjacent spaces typically include:

- **Control Room**: As the name suggests, this room is where the activities inside the EP Room are monitored. It is connected to the main room via a large leaded window which protects it from radiation. Medical staff also uses this space to plan upcoming procedures and draft patient reports. Moreover, it is a room from which imaging and mapping systems are operated during procedures. Currently, HSJD contains 11 monitors that allow medical staff outside the room to view real-time data, including the polygraph, X-rays, and the patient's vital signs. Additionally, there are two monitors from which an engineer can guide cardiac electroanatomic mapping session.
- **Recovery Room**: Its primary function is to provide a waiting area for patients' families during procedures. Also, it is a room where patients are prepared before the procedure and monitored

during recovery afterwards. Currently, in HSJD, it has room for two beds, separated by a privacy screen. However, it serves as a passageway for various hospital staff.

- **Material Storage Room**: This annexed space is used to store both consumable and non-consumable materials needed for the procedures performed in the Electrophysiology Room.
- **Racks Room:** This small room houses the racks that support telecommunications between the Electrophysiology Room, the Control Room, and the hospital's network.

These spaces are standard in modern Arrhythmias or EP units and should be considered essential when designing or renovating facilities.

2.4 State of the Art

Before initiating the design process, it is essential to establish the current state of technology used in electrophysiology rooms, thereby setting the global context for this project.

Although fluoroscopy has traditionally been the primary imaging method in interventional cardiology, it is well known and scientifically proven that radiation exposure increases the risk of health issues for both patients and medical staff. Traditionally, the protection method for professionals working in the exposure field consisted of wearing lead aprons and dosimeters to ensure they did not exceed the annual recommended dose.

In recent years, the need to reduce this exposure has driven the adoption of ***fluoroscopy-free* or low-radiation procedures that utilize alternative imaging techniques**, such as 3D electroanatomic mapping and intracardiac echocardiography [15]. These techniques enable the real-time reconstruction of the heart's anatomy and electrical activity while protecting both medical staff and patients, thereby reducing radiation exposure time and procedure duration. Despite demonstrating effectiveness and safety, their use is limited due to high costs and technical challenges, which restrict their application to complex procedures, such as atrial fibrillation or ventricular tachycardia [16] [17].

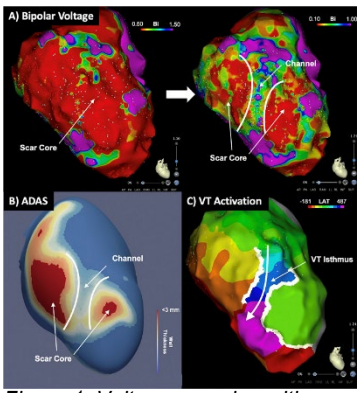

Figure 1: Voltage mapping with different algorithms using electroanatomic mapping systems. Adapted from Della Rocca et al., 2022 [18].

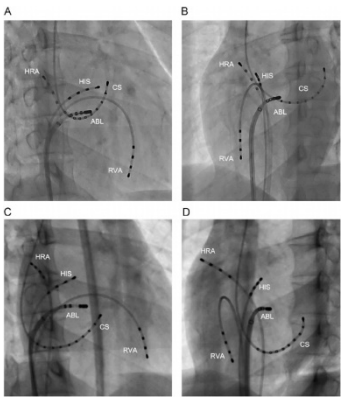

Figure 2: Fluoroscopic views of a catheter ablation. Adapted from Nakagawa et al., 2022 [19]

For this reason, hospitals with the necessary resources are focusing their renovation efforts on acquiring more sophisticated 3D cardiac mapping systems and more efficient X-ray imaging systems that achieve high-quality results with lower radiation exposure.

In line with this technological evolution, the design of electrophysiology rooms is also undergoing a significant transformation. One of the most important trends is the incorporation of **digital integration platforms**, which are capable of connecting imaging systems, mapping technologies, patient data, and communication tools, has become essential to ensure clinical efficiency and reduce procedural complexity [20] [21]. Additionally, ceiling-mounted towers are increasingly used to organize equipment efficiently, reduce floor clutter, and improve sterility control. Moreover, **ceiling-mounted systems** for imaging have also been used [22].

Modern EP labs are also evolving in terms of **lighting design**, adopting adaptive illumination systems that can adjust the intensity and color temperature based on the phase of the procedure and the needs of both the staff and patients. These systems not only support precision and visibility for clinicians but also improve the patient's comfort and anxiety levels [23][24].

Beyond protecting the health of both patients and healthcare professionals by reducing radiation, the design of these rooms is also shifting towards improving the patient experience, as seen at Hospital Universitari de Bellvitge [25].

Despite the research carried out, analyzing the most up-to-date electrophysiology rooms remains a challenging task. Firstly, hospitals do not typically publish detailed information on the design of these spaces, which limits access to and comparability of data. Additionally, there are currently no official, updated clinical guidelines or design standards specifically addressing the design of electrophysiology laboratories.

This fragmented landscape justifies the methodological choice of this project to prioritize **face-to-face visits to selected national and international reference centres**, allowing for direct observation of best practices and better understanding of the real needs of healthcare personnel. These visits serve as a crucial tool for collecting qualitative data, especially in the absence of standardized documentation and due to the difficulty in accessing published design information.

Finally, it should be noted that this document does not include a conventional market analysis, as there is no established competitive market for the design of electrophysiology rooms. Often, it is the hospitals themselves that lead the design process, adapting it to their specific needs, without viewing it as a competition between them.

2.5 State of the situation

Hospital Sant Joan de Déu (HSJD) in Barcelona is a leading healthcare institution in the maternal and child health sector in Catalonia, Spain, and internationally. Founded in 1867 and managed by the *Orde Hospitalari de Sant Joan de Déu*, the hospital combines clinical care, research, and teaching in collaboration with the University of Barcelona. It is renowned for its clinical excellence, patient-centred care, and strong commitment to technological innovation. Although privately owned, it has been a concerted centre, working in conjunction with the public administration, since 1973 [26].

Its strong focus on quality and innovation is reflected in clinical and satisfaction indicators. In 2023, the hospital achieved a Net Promoter Score (NPS) of 72.15 overall and 81.89 among inpatients, while also recording a risk-adjusted mortality index of 0.37, indicating 63% fewer deaths than expected based on case complexity. Likewise, the average length of stay is 23% shorter than that of similar hospitals in Spain, demonstrating both efficiency and quality of care [27].

As a high specialized institution, the hospital holds 69 national and European accreditations [28], which also enable its professionals to participate in research forums and studies on multiple medical conditions. Some of the most important ones include actively participating in 21 European Reference Networks (ERN) and being recognised in 34 categories in the Centres, Services and Units of Reference (CSUR for *Centres, Serveis i Unitats de Referència* in Catalan) within the national healthcare system and being part of the Network of Clinical Expertise Units (XUEC for *Xarxa d'Unitats d'Expertesa Clínica* in Catalan).

The hospital's **Arrhythmia Unit** [29] is a clear example of high specialization. It is a multidisciplinary service specialising in the diagnosis and treatment of complex cardiac rhythm disorders in children and adolescents. Recognised as Spain's only CSUR in paediatric electrophysiology, it performs approximately 300 surgical procedures annually, including 170 cardiac ablations, with a **99% immediate success rate**. The unit also integrates 24/7 remote monitoring, genetic screening in at-risk families, and training for caregivers and schools, reflecting its comprehensive, patient-centred approach. 24% of its patients come from outside the EU, highlighting its international prestige.

Over the past eight years, HSJD has undergone a profound structural and technological transformation, involving the renovation of several clinical and surgical areas. Among the most outstanding projects are the Paediatric ICU (2018), the Central Surgical Block (BQC) (2019), the digitalisation project *Còrtex* (2020), the expansion of the Neonatal Area (2021), and the inauguration of the Pediatric Cancer Center of Barcelona (PCCB) (2022), among others. These changes have positioned the hospital as a leading reference centre across Spain, both for its healthcare model and for the quality of its infrastructure.

However, the hospital's Electrophysiology room has not been included in this wave of renovations. Since the HSJD EP Room was last renovated in 2013, although it remains functional and hosts daily procedures, it presents several limitations that hinder its efficiency and alignment with current standards.

One of the main critical points is the **Philips Allura Xper FD20/20**, the EP room's fluoroscopy system. After 11 years of intense use, this piece of equipment has become technologically obsolete, offering inferior performance compared to newer systems that allow for reduced radiation doses and improved image quality. Replacing this device alone represents a significant investment, which justifies undertaking a complete renovation of the room.

Moreover, the current layout of the space and equipment does not optimize either staff mobility or the integration of innovative technologies, such as 3D cardiac navigation systems, which are essential in increasingly complex procedures. Additional limitations have been identified, including those related to air conditioning, visibility between rooms, cable management, and the availability of electrical outlets, as well as shortcomings in the patient experience and training opportunities for healthcare professionals.

This combination of factors underscores the need for a comprehensive redesign project of the Electrophysiology Room and its adjacent spaces within the Arrhythmia Unit, aligning with current requirements and best practices observed in other hospital centers.

This chapter has explored the clinical, technical, and spatial aspects that define a modern electrophysiology room, along with the current trends, international benchmarks, and limitations of the existing setting. This background establishes the foundation for analyzing the current facilities at Sant Joan de Déu, which will help identify specific needs and inform the design process in the following chapter.

3. Concept Engineering

The conceptual engineering phase lays the foundation for how the project will be approached and structured. In this case, it involved selecting an innovation methodology suited to the clinical context and defining the process to move from the identification of stakeholders and their needs to their classification and design opportunities.

3.1. The study of the method: Stanford's BIODESIGN process

A fundamental part of any design project is defining how users' needs will be gathered and transformed into viable solutions. In this case, the Biodesign method developed by Stanford University was chosen,

as it provides a clear, iterative structure focused on real needs, making it highly suitable for clinical environments. The choice of this approach was validated through an interview with Sofia Ferreira, Innovation Engineer at Hospital Sant Joan de Déu, who recommended its application in the context of this project.

The Biodesign method is a structured and systematic approach to innovation in medical devices and healthcare solutions, developed by Stanford University and extensively detailed in the book *Biodesign: The Process of Innovating Medical Technologies* [30]. This method focuses on identifying clinical needs, developing concepts, and implementing effective solutions. It is based on the principle of the 3 Is: Identify, Invent, and Implement [31].

In the first stage, the **needs identification phase**, the team immerses itself in the clinical context, observing procedures and speaking with healthcare professionals to understand daily challenges. From there, they gather detailed data through interviews, observations, and literature review to create a list of potential clinical needs. These needs are then prioritised based on potential impact, technical and commercial feasibility, and existing competition. This initial phase carries significant weight within the method, as it is believed that **a well-identified need is key to successful innovation**.

In this project, the *Identify* phase was tailored to the context of a clinical infrastructure redesign. Several methods were combined to ensure a broad and accurate understanding of existing challenges: immersive observation (*shadowing*) during real procedures, interviews with clinical staff of HSJD, a short questionnaire to gather perceptions and suggestions from professionals of other centres, and exploratory visits to other hospitals to compare different approaches. Together, these activities enabled the identification and prioritisation of user-centred needs to guide the rest of the process.

In the second stage, the **invention phase**, teams hold brainstorming sessions to generate and organise ideas and solution proposals. This is followed by a rigorous screening process that considers intellectual property, technical feasibility, and business model, to select the best concepts for prototyping and preliminary testing.

In the *Invent* phase, the identified needs were synthesised into broader design requirements, allowing for the exploration of different spatial configurations and equipment strategies. Rather than generating isolated ideas, the focus was on evaluating the overall room concept and the potential need for architectural or infrastructural changes to better align with clinical practices.

In the third and final stage of the Biodesign method, the **implementation phase**, the selected solution is developed in detail, considering all technical, operational, and contextual aspects. This includes the

elaboration of comprehensive plans, prototyping, and testing in real or simulated clinical environments to ensure that the solution meets the defined needs and aligns with user expectations. Additionally, regulatory requirements and safety standards are evaluated to ensure compliance, and key factors for successful deployment —such as usability, maintainability, and integration into existing systems— are assessed.

A detailed implementation plan is also defined, covering aspects like budget, execution timeline, required resources, and internal approvals. In some cases, a business or sustainability model may be necessary to support long-term feasibility and adoption.

In the *Implement* phase, the proposed solution was defined in detail, including the selection and justification of each equipment element based on functional needs and user input. This culminated in a comprehensive layout and equipment plan, designed to ensure clinical efficiency, safety, and long-term adaptability.

While the Biodesign methodology was originally conceived for the development of medical devices, it has been successfully adapted to other healthcare innovation areas — including care processes, organisational models, digital platforms, and even **physical spaces and hospital infrastructures**. In fact, its flexible and structured nature makes it particularly well-suited to any context where real clinical needs must drive the design of effective solutions.

As evidence of its impact, the method has already been applied to various fields such as **head and neck surgery** [32], **biophotonics** [33], and **haemodialysis treatment** [34]. These cases illustrate its potential to generate viable and impactful solutions that can be rapidly integrated into clinical practice.

In the context of this project —focused on redesigning the electrophysiology room at HSJD— the Biodesign method was chosen for its **clarity, focus on user needs**, and capacity to structure innovation efforts effectively. The next sections explain how each phase of the method has been adapted and applied to guide this process.

3.2. Identification of Needs

As explained in the previous section, this first stage comprises the set of activities that make up the identification phase of the Biodesign method, focused on understanding and prioritising the real needs of end users, in this case, the clinical and technical team working in the Electrophysiology Room.

3.2.1. Stakeholder Identifications

At the outset, it is important to identify the stakeholders involved in this project. In addition to myself, who will be carrying out the project, the interested or involved parties are: the medical team and the nursing team of the Arrhythmia Unit; the patient experience team, the bioengineering team and the innovation team at HSJD and the Patients and Families of the Arrhythmia Unit of HSJD.

In addition to the needs expressed by stakeholders, the legal framework surrounding the project is taken into consideration, along with institutional recommendations that may prove advantageous. Although the Biodesign method includes this aspect within the Invention phase, the legal aspects have been considered as requirements for the new room design to maintain coherence with the project's objectives. In this case, the regulatory and legal context is described in section *7. Regulations and Legal Aspects* of this document.

Following the recommendations of the Head of Bioengineering and Electromedicine at HSJD, Mr Fsc. Xavier Escayola, and in line with the Biodesign model, four methods were selected to identify and understand user needs. These methods are described in the following sections.

3.2.2. Shadowing and study of the current electrophysiology room

According to the Biodesign methodology, an early and essential phase in the needs identification process involves immersive observation in the real clinical setting. For this purpose, multiple shadowing sessions were carried out in the current electrophysiology (EP) room at Hospital Sant Joan de Déu, allowing for detailed observation of procedures, room usage, and team interaction with equipment.

The EP room is located within the **Hemodynamics Unit** and is shared with other interventional services. It is equipped with a **Philips Allura FD20/20 biplane fluoroscopy system**, which integrates with a **Maquet Alphamaquet 1150.01 surgical table**. A **ceiling-mounted monitor bridge** supports imaging and visualization, while additional **surgical lighting and shielding arms** are installed on a ceiling rail. More images can be seen in *Annex A: Additional pictures of HSJD's current electrophysiology room*.

Figure 3: General view of the EP room and biplane system.

The core equipment currently in use includes:

- **EP-TRACER® 38** electrophysiology recording system

- **CARTO® 3** and **EnSite™ X** electroanatomical mapping systems
- **SmartAblate®** RF generator and **CryoConsole®** for cryoablation
- **GE Vivid E95** and **Venue Fit** ultrasound machines
- **CADD-Solis** infusion pumps and **GE CARESCAPE™** patient monitors
- **External defibrillator**, **contrast injectors**, and an **anaesthesia workstation**

All these systems are mounted on **individual mobile carts**, with no integration between them. During procedures, frequent rearrangements are required, especially when alternating between EP studies, ablations, catheterizations, or device implantations.

The electrophysiology room is accessed through the main corridor of the Arrhythmia Unit, as seen in the whole unit blueprint in *Annex B. HSJD's Arrhythmia Unit current blueprint.* It is directly connected to the **control room**, which is separated by a lead-lined glass panel and wall, enabling partial visual contact. On one side, the room connects to a **preparation and recovery area (REA)**, while on the other, it is adjacent to a **shared equipment corridor**. Internally, the **procedure table is centrally located**, with **mobile devices placed around the perimeter**, and the **ceiling-mounted monitor system** positioned above. There are no modular divisions or infrastructure to support adaptable layouts.

The following issues were identified during shadowing and confirmed through internal reports and conversations with staff:

- **Significant cable congestion**, especially around the table's foot area, increasing safety risks
- **Insufficient built-in or ceiling-mounted storage**, leading to reliance on portable carts
- **No dedicated nursing workstation**, neither inside nor directly adjacent to the room
- **Limited visibility and interaction with the control room**, affecting coordination
- **Fixed locations for outlets and ceiling arms**, reducing room reconfiguration capacity
- **Connectivity failures** reported between some systems (e.g., SmartAblate® and EP-TRACER®)
- **Excess humidity**, flagged as a maintenance concern for equipment preservation

Environmental conditions were also noted. Lighting is fixed, with no dimming options or ambient adjustment, and **temperature control is centralized**, making it inaccessible to staff during procedures. These factors may affect both the **efficiency of complex procedures** and **paediatric patient comfort**.

Finally, conversations with nursing, anaesthesiology, and biomedical engineering staff confirmed that many of these structural and logistical issues — though not affecting procedural success directly — create **workflow inefficiencies**, **longer setup times**, and **greater physical strain** during prolonged procedures.

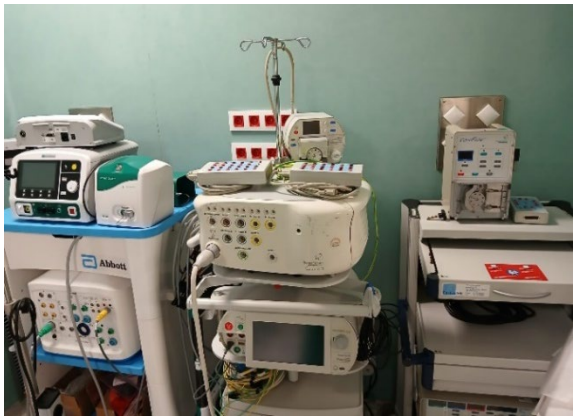

Figure 5: Equipment carts.

Figure 4: General view of the control room.

This shadowing exercise has revealed a comprehensive view of the current EP room's **technical limitations**, **ergonomic challenges**, and **workflow disruptions**. However, this is only the first step in identifying needs. To complement these observations, the next sections explore **interviews**, **questionnaires**, and **benchmark visits** conducted to gather diverse insights and build a well-rounded understanding of the requirements for a new EP lab.

3.2.3. Personal Interviews

To better understand the daily needs and challenges in the electrophysiology room, interviews were conducted with Dr. Fredy Chipa Ccasani and Dr. José Carlos Cruzalegui Gómez, both physicians in the Arrhythmia Unit at HSJD, as well as with two members of the nursing staff; Isaac Moll Adrián and Esther Aurensanz Clemente. These conversations provided valuable insights into the clinical workflow, room logistics, and overall functionality of the space.

From the medical side, a strong emphasis was placed on improving the **visualisation systems** within the room. For example, clinicians would benefit from being able to display data from mapping systems on larger screens and suggested incorporating tools to support teaching and training, such as ceiling-mounted cameras or auxiliary touch displays. They also mentioned the **limited digital connectivity**

between some systems (e.g., mapping software, PACS, and hospital networks). While these connectivity issues were frequently noted, they are considered outside the scope of this project, which focuses on physical space and equipment layout.

The nursing staff, on the other hand, expressed dissatisfaction with the **current spatial organisation**. The room's use for different types of procedures forces them to **relocate various devices and furniture daily**, which significantly disrupts workflow. A major point of concern was **cable management**, which they felt posed both logistical and safety challenges. They also highlighted the need for **dedicated nursing workstations**, both inside and outside the room, to facilitate documentation and coordination without interfering with ongoing procedures.

These opinions were further reinforced by informal conversations held with other members of the clinical and technical team, such as anaesthesiologists and biomedical engineers, who echoed many of the same concerns regarding workflow, space constraints, and equipment handling.

In summary, the interviews and complementary discussions revealed a shared desire among the clinical team for a **more coherent, standardised, and ergonomic setup**, with better support for documentation, safety, and teaching. These insights were integrated into the needs analysis and will guide decisions in the next phases of the design process.

3.2.4. External Benchmarking Visits

To complement the identification of needs and enrich the solution-generation process, visits to various hospital centres that have recently renovated their electrophysiology rooms have been planned.

The aim of these visits is to identify best practices, inspire new ideas, and understand real solutions adopted in other contexts.

Specifically, six leading hospital centres have been visited: Hospital Clínic de Barcelona, Hospital Universitari de Sant Pau, Hospital Universitari de Bellvitge, Hospital de la Vall d'Hebron, Hospital del Mar, and Hospital Universitari Dr. Josep Trueta in Girona. All of these have undergone substantial renovations in the past five years, making them **valuable benchmarks for this study**.

Central Surgical Block (BQC) of HSJD

As part of this benchmarking effort, a visit was first conducted to the **Central Surgical Block (BQC)** of **Hospital Sant Joan de Déu** itself along with an interview with the lead engineer of the area, Maria Victoria Ortiz. This internal reference point was particularly useful, as all eight operating rooms (four larger, four smaller) share the same structural infrastructure but differ in configuration depending on the clinical speciality.

Structurally, all rooms are equipped with three ceiling-mounted supply arms, each serving distinct functions: one for anaesthesia, one for surgical teams, and one as a flexible utility arm (commonly used by nursing staff). Except for infusion pumps, which remain on mobile carts, most equipment is ceiling-suspended, contributing to better floor clearance and hygiene. Despite these optimisations, some cables remain unavoidable, particularly those involving patient connections.

Figure 6. Surgery theatre of HSJD's BQC.

The ceiling also hosts three central arms: two supporting surgical-grade lights (with optional integrated cameras for educational purposes) and one with a surgical display monitor. All operating rooms include wall-mounted Brainlab screens capable of displaying up to four simultaneous sources, including live navigation, patient records, and imaging systems. These features enhance clinical workflow and teaching potential.

Differences between rooms mainly lie in the image acquisition technologies: one OR is integrated with a fixed single-plane CT scanner, while another is directly connected to a shared MRI room.

Material storage is addressed through a preoperative staging system, where dedicated portable cabinets are stocked overnight with all necessary supplies for the next day's surgeries. This ensures that personnel do not need to leave the sterile field during the procedure, minimising delays and maintaining asepsis.

A unique spatial feature is the visually differentiated sterile zone, marked by flooring colour, which corresponds to the optimal surgical zone beneath the laminar flow ceiling system. This system creates a negative airflow environment, pushing filtered air outward from the centre, supported by integrated HEPA filters. The goal is to maintain air quality with minimal particle and microorganism presence.

In terms of safety, each room is fitted with dedicated power backup units, capable of supporting full operational capacity for approximately 45 minutes in the event of an external power failure.

Waste management protocols are also carefully designed, with multiple, colour-coded bins placed strategically to encourage appropriate disposal.

Although the Biodesign method typically includes a market study as part of the Implementation phase, in this project this activity has been adapted to the Invention phase, as the objective is not to analyse competitors but to identify ideas applicable to a shared, non-competitive context.

These visits, therefore, serve as a qualitative benchmarking tool aimed at identifying unmet needs and understanding how other institutions address similar challenges, making them a key part of the Biodesigns's Phase 1 exploratory process.

Hospital Clínic de Barcelona

Hospital Clínic de Barcelona [35] is a public healthcare centre located in the city of Barcelona. It forms part of the Integrated Public Use Healthcare System of Catalonia (SISCAT for its name in Catalan *Sistema Sanitari Integral d'utilització pública de Catalunya*) and is jointly managed by the Government of Catalonia through the Catalan Health Service (*Servei Català de la Salut*) and the University of Barcelona. The Clínic serves as a community hospital for Barcelona Esquerra, with a population of 540,000 inhabitants, while also functioning as a tertiary and highly specialised hospital providing services to patients across Catalonia, mainly from the areas of Vallès Oriental and Osona, and, for specific procedures, to patients from other regions of Spain.

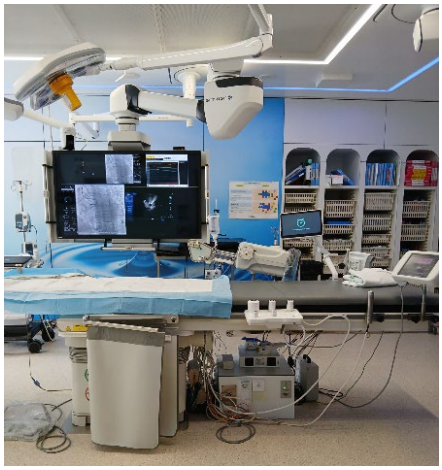

Figure 7: General view of an EP room.

Figure 8: Wall-mounted storage system.

The hospital has two electrophysiology rooms, each equipped with a floor-mounted Philips Azurion monoplane C-arm. Storage is managed as best as possible without a dedicated storage room. Within the procedure room itself, there are fixed cabinets located beneath the glass partition that connects to the control room, used primarily for medication. Only the minimum essential material is kept inside the room. Also, due to the room's limited size, no ceiling-mounted arms or towers are used; instead, mobile carts on wheels are employed, as those systems are only installed in operating systems in the Hospital Clínic, because of organisational and infrastructure

constraints. Staff commented that if there were more space available, they might consider installing an arm for the anaesthesia cart.

Regarding air sterilisation, the room uses new air outlets positioned above the operating table, along with a system of air recirculation grilles arranged in pairs at both the top and bottom of the room. Air enters through central (new) outlets and through grilles in the upper wall area (recycled air), and exits through the lower wall grilles. The air that leaves the room is directed to a climate control unit, where it is conditioned and finally sterilised via a HEPA filter.

The patient experience aspect is not given much consideration, which they acknowledge in a self-critical tone. The room's lighting consists of ambient lighting embedded in the ceiling, forming a rectangle concentric with the room itself. This system allows for easy colour changes via a convenient wall control, enabling the lighting to be adapted to the surgical needs and the comfort of the surgical team. In addition, there are two articulated interventional lights.

As a notable and important detail, the operating table is positioned perpendicular to the control room, meaning it faces the control room rather than being side-on, as it is at HSJD.

Hospital Universitari de Bellvitge

The Hospital Universitari de Bellvitge [36] is a public healthcare centre that forms part of the Catalan Health Institute (ICS). Inaugurated in 1972, it is in the municipality of L'Hospitalet de Llobregat, south of Barcelona. Its correspondent area includes the population of L'Hospitalet and other municipalities in the Baix Llobregat region, as well as patients from other areas in cases requiring highly specialised care.

Hospital de Bellvitge has over 900 beds and is a reference centre within the Spanish National Health System for high-complexity procedures in areas such as cardiac surgery, transplants, and oncology. In terms of teaching, it is affiliated with the University of Barcelona and plays a major role in training, hosting and educating around 400 professionals each year through the Resident Medical Intern (MIR for its name in Catalan *Metge Intern Resident*) programme, as well as other specialised healthcare training programmes.

Regarding the electrophysiology rooms, the hospital has a dedicated area on the second floor of the main building where three haemodynamic rooms and two electrophysiology rooms have been installed side by side. In front of these rooms, there are small storage areas, offices, changing rooms, and technical rooms, all located along a corridor that serves the procedure rooms.

Inside the two electrophysiology rooms, the procedure tables are positioned perpendicular to their respective control rooms. In addition to the door separating the control room from the procedure room itself, each room also has a second access point on the opposite wall through which patients enter.

Regarding the organisation of equipment within the rooms, each is equipped with two ceiling-mounted Getinge towers: one dedicated to anaesthesia equipment and the other for devices such as electrical generators for cardiac navigation systems and the polygraph. The first tower also includes some of the room's gas outlets, while the others are installed on one of the walls, intended for patients requiring ECMO or similar support. It is also worth noting that these towers feature protruding metal bars, which allow for the attachment and suspension of various elements.

Regarding imaging equipment, both rooms are fitted with a Philips Azurion ceiling-mounted monoplane C-arm. The fact that it is ceiling-mounted rather than floor-anchored allows for greater mobility of the clinical team but makes cleaning more difficult. In terms of cardiac electromagnetic navigation systems, one of the rooms is equipped with both the NavX system from Abbott and the Carto system from Biosense Webster, while the other room has only the NavX system. As for lighting, both rooms feature one large interventional light and an additional smaller one.

The rooms are not only equipped with the Philips CT arch, but also with an interventional table and a large overhead screen from the same manufacturer, allowing for easier integration and unified control of

Figure 10: Surgical table and main screen.

Figure 9: Ceiling-mounted storage system.

the equipment. As seen in *Figure 9*, the table is long enough to accommodate device programmers for implants or follow-ups directly on its surface.

The only difference between the two rooms is that one of them has two installed cameras: one offering a deep zoom function and the other providing a panoramic view of the room. Thanks to the Oristic product

by Ditec, the camera images can be streamed to the control room and to other areas within the hospital. It is worth noting that, to minimise the number of cables on the floor, these are routed from the control room through the ceiling and into one of the ceiling-mounted towers within the room.

The control rooms accompanying both procedure rooms are equipped with two monitors for the polygraph, two more for the cardiac navigation systems, three additional screens for reporting interventions, one for image management, and two for the Philips fluoroscopy system, which can directly render images obtained via X-ray fluoroscopy. Additionally, these rooms feature whiteboards for notes and strategically placed power outlets, as well as computer towers for each system positioned under desks measuring 70 to 80 cm in depth. On these surfaces, there is also a central charging station for all the Quali Digital headsets used by the professionals working there.

Right next to the door between the control room and the procedure room is a small sink, which proves very practical, saving staff from having to go to the dirty utility room for minor cleaning tasks.

To manage storage, the small storage rooms located across the corridor are fitted with smart cabinets. These are convenient, but since they can occasionally malfunction, it is important to have multiple suppliers to avoid stock shortages.

Both rooms are equipped with a device not found in any of the other hospitals mentioned in this document: the BIOTRONIK Zero-Gravity X-ray protection technology. This device is suspended from a ceiling-mounted movable arm and is designed to offer greater agility to the professional by reducing the physical weight they need to bear.

As the only drawback, professionals mention that in the room where cameras are installed, when the large main screen is rotated to the other side to facilitate device implantation, they must be very careful to ensure the camera does not collide with the screen's support arm.

Hospital Universitari de la Vall d'Hebron

The Vall d'Hebron University Hospital [37] is a public healthcare centre that forms part of the Catalan Health Institute (ICS). Established in 1955, it is located in the northern part of the city of Barcelona and is the hospital complex with the highest volume of interventions in Catalonia. Its catchment area covers three districts within the city itself: Horta-Guinardó, Nou Barris, and Sant Andreu.

The hospital, divided into three major care areas, has over 1,100 beds and is a reference centre within the Spanish National Health System for high-complexity procedures across multiple specialties. Regarding education, Vall d'Hebron Hospital is one of the teaching hospitals affiliated with the Autonomous University of Barcelona and annually trains over 600 doctors in the MIR programme.

Regarding the electrophysiology rooms, the hospital has two identical ones that share the same control room. They are located on the 9th floor of the General Area and were last renovated at the end of 2020. Each room houses the intervention table positioned perpendicular to the control room and includes three ceiling-mounted towers: one with various shelves for equipment related to cardiac navigators, one for electrical generators and other devices like the polygraph, and finally, one without shelves designated for the anaesthesiologist's use.

As shown in figures of *Annex C: External benchmarking visits*, most of the anaesthesia equipment is placed on a wheeled cart, as it is more practical to move it around the room when intervening from the patient's left side. Both the first and the last described towers have integrated gas outlets, dispensing with any other gas outlets, totalling two in all.

Figure 11: General view of the EP room.

Regarding other equipment in the rooms, both have the Philips ceiling-mounted Azurion monoplane CT scanner and two different electromagnetic navigators (Carto by Biosense Webster and NavX by Abbott). In terms of lighting, there is an intervention light and an ambient surrounding light embedded in the ceiling in the shape of a rectangle concentric to the room. Additionally, a camera with streaming capability is installed above the central monitor in the room. Both this monitor and the intervention table are also Philips products; thus, the control panel at the foot of the table is Philips as well.

To integrate the data and images generated in the room, the Getinge Tegris digital integration system is used. This system allows streaming of signals and images produced by the polygraph, CT scanner, navigators, echocardiographs, camera, and other devices both to the central monitor and to the monitors in the control room.

Figure 12: Ceiling-mounted storage system with power outlets.

It is noteworthy that throughout the Unit where the rooms are located, all consumable materials are stored in smart cabinets that log the existing stock and the time of insertion and removal. Additionally, to minimize the use of power strips, each room has over 30 power outlets.

Hospital de la Santa Creu i Sant Pau

The Hospital de la Santa Creu i Sant Pau [38] is a public healthcare center located in Barcelona, managed by the Healthcare Management Foundation of the Hospital de la Santa Creu i Sant Pau. Opened in 1930 at its current facilities, it is the heir to the old Hospital de la Santa Creu, founded in 1401, and is considered the largest modernist hospital complex in the world, declared a UNESCO World Heritage Site in 1997.

Currently, the hospital has 644 beds, handles over 35,000 hospital discharges annually, and manages nearly 160,000 emergency visits and 500,000 outpatient consultations each year. It is a tertiary referral center for Barcelona and Catalonia in multiple specialties, including cardiology, oncology, neurosciences, and transplants. The hospital employs over 4,000 healthcare professionals and has a strong commitment to research and teaching, being linked to the Autonomous University of Barcelona and its Research Institute, which promotes projects in biomedicine and healthcare innovation.

The Hospital de la Santa Creu i Sant Pau currently has two rooms dedicated to electrophysiology: a more general room for diagnostic and therapeutic arrhythmia procedures, and a specific room for device implants such as pacemakers and defibrillators. Additionally, a new electrophysiology room is under construction, which will incorporate technological and spatial improvements.

Regarding space organization, the hospital has a separate room for cleaning and disinfecting equipment, thus optimizing workflow within the electrophysiology rooms. There are currently storage areas inside the control room and in the two adjacent corridors. However, with the upcoming renovation, storage inside the control room is expected to be removed to gain space and improve layout.

In relation to equipment, the electrophysiology room has two sets of gas outlets and an advanced image transmission system. Thanks to installed cameras in the room, it is possible to broadcast procedures live to a room on another floor of the hospital, facilitating training and teaching in this field.

Figure 13: General view of the EP room during surgery [39].

Currently, the procedure table is positioned parallel to the glass of the control room, but the renovation plans to reorient it perpendicularly. Despite this change, the medical staff has expressed that they do not consider the current arrangement a significant inconvenience.

Hospital del Mar

The Hospital del Mar [40] is a public healthcare centre located in the Sant Martí district of Barcelona. It is part of the Parc de Salut Mar, a network of institutions dedicated to healthcare, research, and education. Opened in 1914, it is situated by the Mediterranean Sea and has been expanded and modernized over the years to provide high-quality healthcare services.

With more than 400 beds, Hospital del Mar is a reference centre in areas such as biomedical research and medical training, as well as a key centre for emergency medicine and traumatology. The hospital maintains a close collaboration with Pompeu Fabra University and is one of the key institutions involved in the training of healthcare professionals in Barcelona. Through the Resident Medical Program (MIR), the hospital annually hosts numerous doctors undergoing specialized training.

Beyond its clinical services, Hospital del Mar is recognized for its active participation in research, in collaboration with the Hospital del Mar Medical Research Institute, focusing on innovative projects in fields like oncology, mental health, and cardiovascular diseases.

Regarding its electrophysiology rooms, the hospital has two rooms, each with two access points: one from their respective control room, one connecting to the storage room for consumable materials, and a third connecting to the corridor used by patients. This last access features a reinforced door and access control system to prevent patients or companions from mistakenly entering the room during a procedure. Inside the rooms, the intervention table is positioned horizontally relative to the glass separating it from the control room, a layout favoured by the room's proportions—this distinguishes these rooms from others visited.

Figure 14: General view of the EP room during surgery.

In terms of room organization, two ceiling-mounted towers support the polygraph and generator devices for the navigators (three available: Carto by Biosense Webster, EnSite NavX by Abbott, and Rhythmia by Boston Scientific). Additionally, anaesthesia equipment and devices are stored on a wheeled cart for easy mobility around the room. To avoid cables on the floor, all cables run from the control room through the ceiling and enter one of the ceiling towers. However, due to the limited number of sockets in the room (fewer than 20), extension cords are still needed, resulting in cables being dangerously placed on the floor.

The main monitor and the monoplane CT arc are both Philips brand, with the CT arc being the Azurion floor model. The room, especially the intervention table, is illuminated by a ceiling-mounted intervention light on an articulated arm. Often, this lamp's light is insufficient, requiring an additional light on a wheeled stand to be used, which the professionals find suboptimal as it reduces manoeuvring space. They also express a desire for the light intensity to be adjustable.

In the corresponding control room, there is a centralized charging station for the headsets professionals use to communicate between rooms. In a corner, there is a sink for handwashing and minor cleaning tasks, although staff mention that its height is not optimal, being too low. The rest of the control room space is quite limited, and all staff report having little room to work.

Finally, these rooms have a drawback related to the positive pressure environment required in electrophysiology (and other surgical intervention) rooms. The main storage room with its own access is essentially a long corridor that connects at the other end to a corridor in the hospital's emergency area.

When the door between these two corridors is open, a strong airflow disrupts the positive pressure balance in the electrophysiology room, significantly increasing the risk of external air entering. Because of this, nursing staff avoid using the storage room access and instead take a longer route via the control room to reach it. This situation also causes them to bring a large amount of consumable material into the room before procedures begin, which further reduces space and highlights the need for careful planning regarding aerobiological control.

Hospital Josep Trueta de Girona

The Hospital Universitari de Girona Doctor Josep Trueta [41] is a public hospital managed by the Catalan Health Institute (Institut Català de la Salut), located in the northern area of the city of Girona. The hospital serves as the reference centre for seven Primary Health Care Areas, with more than 400 beds, and handles over 20,000 hospital admissions and 210,000 outpatient consultations annually. It is classified as a Level 2 healthcare centre, although it also offers some Level 3 specialties, such as neurosurgery, intensive care, pediatrics, and medical oncology.

Inaugurated in 1956, the hospital focuses on clinical care, research, and teaching. It maintains a close relationship with the Biomedical Research Institute of Girona (IdIBGi for its name in Catalan *Institut d'Investigació Biomèdica de Girona*) as well as with the Faculty of Medicine and the Faculty of Nursing at the University of Girona.

Regarding the hospital's Arrhythmia Unit, located on the 6th floor, it has two electrophysiology rooms. However, one of them, the older one, is solely used for pacemaker implant procedures. This room has been operational for over 15 years, while the newer room was renovated at the end of 2017. Due to the specificity of the first room, this study focuses on the electrophysiology room where all types of subspecialty procedures are performed.

Figure 15: General view of the EP room [41].

The room has two access points located at opposite ends of the same wall: one for patient entry, which is also used by the medical team, and the other for patient exit. Between these two access points and separated from the intervention room by a leaded glass window, is the control room, which has a parallel view of the procedure table. The positioning of the table is well received by the medical team, who report preferring to face the main screen, located to the left of the patient, rather than facing the intervention

team. However, during the rare instances when the room is used for pacemaker implantation and the screen is moved to the right of the patient, it ends up being completely out of view from the control room.

Until a few months ago, two cameras were installed above the main screen and on the ceiling, allowing for live broadcasting of procedures, but they were removed due to the hospital's patient confidentiality policies.

The room's main fluoroscopy system is the ceiling-mounted Azurion C-arm model by Philips, the same brand as the main display and the intervention table, forming a well-integrated ecosystem. The medical team is satisfied with the functionalities of the system and its compatibility with the other devices. Additionally, the room is equipped with a Philips polygraph, which can be viewed and controlled both on the main room screen and on a Philips monitor in the control room, facilitating procedures where no one is present in the control room and the system must be managed from within.

The only drawback mentioned is the lack of a dedicated support for the keyboard used to operate the polygraph, which is currently placed directly on the patient, making it an inconvenient and suboptimal solution.

3.2.5. External questionnaire

To further understand what EP room staff, including doctors, nurses, biomedical engineers, and EP unit leaders, value in an electrophysiology room, an questionnaire was distributed to gather a wider range of professional insights. This tool enabled the project to capture diverse experiences from different countries and institutions, offering a complementary, exploratory view to the in-depth observations carried out at HSJD. The model form of this questionnaire can be seen in *Annex D: Questionnaire form model.*

The questionnaire was designed as a brief and open-ended survey, addressed to healthcare professionals working in Electrophysiology Units. Its objective has been to collect qualitative insights on the needs and preferences of staff working in EP rooms. The participants were asked to provide one or more examples of potential improvements in four specific categories: Equipment and devices, Infrastructure, Patient experience and Staff comfort and working conditions.

A total of **26 responses** were received from professionals working in **13 different hospitals**, located across **8 countries**: Spain, Colombia, Brazil, Mexico, Uruguay, Argentina, the Netherlands, and Georgia. The participants included 20 doctors, 1 nurse, 4 biomedical or support engineers, and 1 EP unit chief. Although the survey was not intended to be statistically representative, it provides valuable orientational insights into shared priorities and challenges across international EP laboratories.

The answers received were generally consistent, suggesting a strong alignment among EP professionals regarding what elements require more attention in an electrophysiology room. This section presents a summary of the most relevant insights collected from the questionnaire responses.

Equipment and Devices

A recurring theme across respondents was the need to **update or expand electrophysiology equipment**. In total, 22 out of 26 professionals indicated the need of acquiring new or more advanced devices. This reflects a clear motivation to increase procedural capacity, reduce dependence on outdated systems, and align with current medical technology standards.

Additional observations included **minimising radiation exposure** (noted by two respondents), **procedure recording and transmission for teaching purposes** (mentioned by two participants), **upgrading electroanatomical mapping systems** (raised in one response), and **improving system integration and ensuring robust technical support** (mentioned by several professionals). These comments point to a common demand for modern, versatile, and well-integrated equipment that supports safe and effective interventions.

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Infrastructure

In this category, **storage was the most prominent topic**, with 11 participants calling for either expanded or reorganised storage capacity. Of these, 5 specifically requested **ceiling-mounted units**, which would help free up floor space and simplify material access.

Other common needs included **changes to the room layout or overall expansion** (noted by four respondents), **improved electrical and gas outlet positioning** (also cited in four responses), **redesigning access points** (brought up by two participants), and **noise isolation** measures such as better soundproofing for the control room (mentioned in one response).

Although 4 participants reported no issues with their current infrastructure, the feedback strongly supports a redesign focused on **spatial flexibility, storage optimisation, and cleaner technical organisation**.

Patient Experience

There was widespread agreement on the need to create a more **patient-friendly and calming environment**.

The most frequently mentioned features were **auditory stimuli** such as music or calming soundscapes (cited in twelve responses), **visual stimuli** including relaxing visuals or video content (mentioned by nine respondents), and **adjustable lighting systems** (proposed by ten participants) to adapt intensity and colour to the clinical context or patient sensitivity. Additional suggestions included **creating a tranquil and reassuring environment** and **ensuring optimal temperature** (each mentioned in three responses), as well as **improving communication with patients**, for example through informational channels about the procedure (mentioned once).

Only one respondent stated that no changes were needed in this area. These insights reflect a shared goal of **humanising the EP experience** and minimising anxiety, particularly for paediatric or vulnerable patients.

Staff Comfort and Working Conditions

This category received some of the most detailed and varied responses. The top needs included **dedicated rest and relaxation areas**, especially for use during long or complex procedures (suggested by ten respondents), **noise and distraction reduction** as a key to improved focus and reduced fatigue (highlighted in nine responses), **better ergonomic workstations and furniture** to improve comfort, efficiency, and safety (mentioned by nine participants), and **improved temperature and lighting control**, with several noting issues related to centrally regulated systems (cited in six responses).

Other comments raised broader concerns such as **burnout**, **lack of sufficient staff**, and the need for **more spacious control and work areas**.

Together, these suggestions demonstrate the importance of not only designing for technical performance but also for **staff well-being**, comfort, and sustainability in daily workflows.

With all the qualitative data collected and categorized, the next step consists of analyzing and synthesizing the identified needs. This process aims to translate the broad and diverse input from stakeholders into a structured set of actionable requirements, which will guide the conceptual and detailed design phases of the project.

3.2.6. Analysis and synthesis of needs

This section concludes the conceptual engineering phase of the project. With a broad and representative set of qualitative inputs gathered and categorized, the focus now shifts to ensuring these insights are translated into concrete design directions. In the next stage, the **detailed engineering phase**, the identified needs will be **analysed in depth, grouped into strategic categories, and prioritised** based

on clinical relevance, feasibility, and alignment with institutional goals so they are translated into requirements.

The needs gathered through shadowing, interviews, questionnaires, and external visits have been preliminarily structured into four main categories: **Equipment and Devices**, **Infrastructure**, **Patient Experience**, and **Staff Comfort and Working Conditions**. The following lists summarise approximately ten of the most frequently mentioned or most impactful needs in each category:

A. Equipment and Devices

- Acquisition of **new or more advanced EP devices** to perform a wider range of procedures.
- Better system **integration** across mapping, imaging, navigation, and recording platforms.
- Maintenance and **technical support** to reduce downtime and ensure reliability.
- Incorporation of **teaching tools** such as ceiling-mounted cameras and external display touchscreens.
- Capability to **record and stream procedures** for educational and documentation purposes.
- Equipment that enables **lower radiation use**.
- **Elimination** of outdated or **inefficient devices**.
- Improved interoperability between systems to avoid duplicated tasks and data fragmentation.
- **Devices and connectors** organised for rapid setup and transition between procedures.
- Inclusion of **paediatric-friendly equipment** where applicable.

B. Infrastructure

- Reorganisation and **expansion of storage**, with ceiling-mounted units to free floor space and improve accessibility.
- Redesign of the room layout to **optimise procedural flow** and minimise equipment relocation.
- Improved positioning and **flexibility of electrical and gas outlets** to avoid wire clutter and increase safety.
- Expansion or better **spatial separation of the EP room and control area** to reduce overcrowding.
- **Modular or mobile furniture** and devices to support frequent setup changes.
- **Acoustic isolation of the control room** to improve communication and reduce distractions.
- Improved **zoning between sterile and non-sterile areas** for safety and efficiency.
- Dedicated **nursing and auxiliary documentation areas** inside and outside the EP room.
- **Simplification of wired connections** between key systems.

- **Better lighting design** in infrastructure (ceiling integration, procedure-specific lighting).

C. Patient Experience

- Integration of calming **auditory stimuli** (e.g., music, nature sounds) to improve the procedural environment.
- Use of **visual stimuli** such as screens, calming projections, or ambient visuals.
- Installation of **adjustable lighting** (colour and intensity) to adapt the atmosphere to each patient and intervention.
- Enhanced **temperature control** systems to ensure patient comfort and prevent cold stress.
- Design of the space to promote a **soothing and non-threatening environment**, especially for paediatric patients.
- **Reduction of noise and disturbing stimuli** during preparation and recovery.
- Possibility to play **patient-chosen media** for distraction and emotional support.
- Clear **visual separation between equipment and the patient's field of view**.
- **Personalisation** of lighting or visuals when possible.
- Improved **patient information flow** before and after the procedure (e.g., visual signage or digital info).

D. Staff Comfort and Working Conditions

- Dedicated **rest and relaxation areas** nearby, especially for long interventions.
- **Ergonomic workstation design** to improve posture, efficiency and reduce fatigue.
- Improved **noise control** and reduction of distractions in both the EP and control rooms.
- Environmental controls for **temperature and lighting** that can be adjusted by staff.
- **Increased workspace** and surface area in both the control room and procedure room.
- Better **separation between documentation/coordination zones and clinical zones**.
- Improved **organisation of cables and connections** to avoid hazards and reduce visual clutter.
- Optimisation of **room flow** to minimise unnecessary movements.
- Staff-centred design to reduce emotional fatigue and **burnout risk**.
- **Improved lighting levels** in workstations, especially in control areas.

These lists provide a foundation for the upcoming **requirement definition and solution ideation process**, where each need will be examined in terms of feasibility, potential impact, and alignment with hospital policies and resources. This synthesis ensures that the subsequent design phases remain

grounded in real user feedback and operational context, while also allowing space for innovation and optimisation.

4. Detailed Engineering

The detailed engineering phase builds upon the comprehensive identification and analysis of needs carried out in the initial stages of the project. At this point, all the insights gathered from user engagement, direct observation, and benchmarking have been synthesized and translated into clear, prioritized requirements. With the definition and prioritization of requirements, this project completes Phase 1 (Identify) and moves into the early steps of Phase 2 (Invent) of the Biodesign methodology, where possible solutions are explored and evaluated in response to the established needs. However, the project does not advance into Phase 3 (Implement), as no real-world deployment or validation of the redesign is carried out. This ensures that the proposed interventions are firmly grounded in the clinical context and user experience, while acknowledging the scope and limitations of the current work.

4.1. Prioritization and Filtering of Needs

Building upon the categorised lists of needs identified in the previous phase, the aim of this stage is to translate those needs into a structured set of functional and technical requirements through a filtering and prioritization process. This transformation process has been carried out in collaboration with Júlia Meca, a biomedical engineer of the Arrhythmia Unit of HSJD, ensuring clinical, technical, and institutional alignment.

Each need has been evaluated according to its relevance and viability, as it is important that the final requirements are included in the scope of this project. To determine if the needs can become requirements, each one has been tagged as:

- Must-have: essential or normative requirements
- Nice to have: items that would contribute with great value but are not essential
- Not needed: not that relevant needs or out of this project's scope

To classify the needs in the most objective way, the main source of decision has been, first, official documentation and recommendations and, moreover, the results extracted from each need's identification method separately.

As the Arrhythmia Unit at HSJD is part of the CSUR network as the reference unit on arrhythmias in pediatric ages (Centres, Services and Units of Reference in the Spanish National Health System), the room must comply with strict standards regarding infrastructure and equipment [42]. These standards were used as non-negotiable references when prioritizing the needs. In addition, a technical report outlining **recommendations for interventional cardiology units** was consulted [43]. While not legally binding, it served as a supplementary guide for decisions where specific EP regulations were lacking.

Based on this methodology and criteria, the section *Annex F. Prioritization and filtering of needs* presents the prioritised list of requirements across the four established categories. Their individual justifications and technical implications will be developed in detail in the design proposal phase.

These prioritised requirements will serve as the foundation for the next phase of this project: the generation of possible solutions and the definition of a redesigned electrophysiology room that meets the identified needs in a realistic, feasible, and innovative way.

4.2. Final requirements definition

Based on the prioritisation process outlined in section 4.1, this section consolidates the final set of **functional and technical requirements** that will guide the room's design. These requirements result from the integration of diverse inputs, including user insights, institutional constraints, regulatory obligations, and benchmarking observations, and are now categorised by level of criticality.

To ensure traceability, each requirement has been assigned a unique code and divided into one of two categories:

- **Essential Requirements (ER)**: These refer to *non-negotiable* functional and regulatory demands that are fundamental to the safety, usability, and clinical efficacy of the future electrophysiology room. They must be incorporated into the final design.
- **Recommended Requirements (RR)**: These represent *valuable additions* that, while not strictly necessary, enhance the overall performance, comfort, or educational value of the room. Their inclusion depends on available resources, technical compatibility, and institutional preferences.

These two levels of priority ensure that **core needs are fully met**, while also maintaining **flexibility** to implement improvement-oriented features where feasible.

An important consideration in this classification is the **paediatric context** of the electrophysiology unit at HSJD. All patients undergoing procedures are **fully sedated**, which significantly reduces the impact of certain patient experience features (e.g., audiovisual distractions or ambient stimuli). As a result, several

suggestions collected through questionnaires and interviews have been excluded or relegated to the "recommended" category.

Essential Requirements (ER):

- ER1. Acquisition of advanced EP equipment to expand procedural capability
- ER2. Radiation reduction through suitable imaging systems
- ER3. Fast setup capability with organised connectors and device docks
- ER4. Inclusion of paediatric-specific devices and accessories
- ER5. Ceiling-mounted storage units to optimise floor space
- ER6. Room layout optimised for workflow and sterility
- ER7. Overhead or wall-mounted electrical and gas outlets
- ER8. Separation between sterile and non-sterile zones
- ER9. Proper cable management integrated in infrastructure
- ER10. Staff-controlled temperature and lighting systems
- ER11. Safe circulation and ergonomic work areas for staff

Recommended Requirements (RR):

- RR1. Integrated audiovisual systems for teaching and documentation
- RR2. Mobile or modular furniture for procedural flexibility
- RR3. Acoustic isolation of the control room
- RR4. Dedicated nursing and auxiliary documentation stations
- RR5. Enhanced patient comfort elements (music, visuals, ambient)
- RR6. Ergonomic and staff-centred space design

4.3. Detailed analysis and proposed solutions

4.3.1. Essential Requirements

ER1. Acquisition of advanced EP equipment to expand procedural capability

While the goal is not to broaden the range of procedures, it is essential to conduct them under optimal conditions. Having the **CARTO 3 (J&J MedTech)** [44], **EnSite Precision (Abbott)** [45] and/or the **RHYTHMIA (Boston Scientific)** [46] mapping systems ensures procedural versatility and accurate electroanatomical mapping and ablation and is consistent with CSUR standards.

ER2. Radiation reduction through suitable imaging systems

Paediatric patients are especially vulnerable to ionising radiation, making dose management crucial. The integration of systems like the **Azurion 7 M20 with FlexArm** (Philips) [47], **Artis Q.zen ceiling** (Siemens Healthineers) [48] or **Allia IGS 5 with AutoRight** (General Electric Healthcare) [49] supports radiation minimisation protocols, in line with the ALARA principle. When it comes to choosing whether the C-arm system should be anchored on the floor or ceiling-mounted, the main solution would be based on a ceiling-mounted system due to the strength points repartition in the ceiling thanks to the railing system in front of the single point anchor of the floor systems. The ceiling of the room would need structural reinforcement anyway if any storage ceiling-mounted systems are installed. Instead, the floor may not need that reinforcement if the C-arm system is ceiling-mounted.

ER3. Fast setup capability with organised connectors and device docks

Quick setup is essential when transitioning between device implantation (left-side operator) and ablations (right-side operator). The procedural screen must be relocatable to both sides of the table, like the **FlexVision Pro** (Philips) [50] and the **Artis Large Display** (Siemens Healthineers) [51] are able to do. Colour-coded connectors and ceiling-mounted docking units like **Movita** systems (Dräger) [52] or **Maquet Moduevo PLG-II SKY** (Getinge) [53] are also recommended for a faster setup.

ER4. Inclusion of paediatric-specific devices and accessories

Most adult systems are usable, but certain accessories, mostly fungible material, are indispensable: e.g., 4Fr catheter and paediatric electrodes. The **TruSystem 7500** (together with the C-arm Artis of Siemens Healthineers) [54] or similar adjustable-height radiolucent table like the one provided with the Azurion C-arm by Philips ensures ergonomic access and safe positioning for smaller patients.

ER5. Ceiling-mounted storage units to optimise floor space

HSJD's EP room can accommodate a ceiling-mounted column for devices like RF generators or navigation consoles. **Maquet Moduevo** (Getinge) [53] systems are benchmarked solutions (used at Hospital Universitari Vall d'Hebron) to keep critical systems off the floor and within reach.

ER6. Room layout optimised for workflow and sterility

Sliding lead-lined doors will be added to the dual access points (both located on one wall) to ensure the room remains closed during procedures. Clear sterile/non-sterile zoning and direct access to the control room without crossing sterile areas are planned. It is important that the technical room and the storage room are accessible without having to cross the EP room.

ER7. Overhead or wall-mounted electrical and gas outlets

To prevent floor cable congestion, power and gas should come from a ceiling pendant, like those at the BQC of HSJD or Hospital Universitari Vall d'Hebron. The already mentioned in ER3, **Maquet Moduevo PLG-II SKY** system from Getinge [53] can help enormously with the wire management. However, not all the gas and electrical sockets must be on this ceiling-mounted module but there have to be a few electrical accesses in different points of the EP room and, at least, another set of gas outlets on the wall for patients coming to the EP room with an ECMO (ExtraCorporeal Membrane Oxygenation) or similar system.

ER8. Separation between sterile and non-sterile zones

CSUR guidelines suggest visual zoning through coloured flooring, with central **laminar flow** from ceiling HEPA filters such as the ones from **ATA Medical** [55], adaptable to the C-arm and ceiling-mounted module configuration. This prevents airborne contamination and defines procedural space.

ER9. Proper cable management integrated in infrastructure

All connections between the control and EP rooms should travel via **ceiling ducts** from the control room to the EP room and drop centrally. Wall trunking can be used for fixed cabling, but no wires should cross open floor space. Though this is a similar requirement to ER3 and ER7, it is important to point out the importance of this requirement, as it would mean a huge improvement for the safety and ergonomics of the room.

ER10. Staff-controlled temperature and lighting systems

Three lighting levels are required according to the identified needs: (1) surgical lighting like the **Aurora Four Surgical Light** of Skytron [56] or the **XMT range Surgical lights** of Surgiris [57], capable of disturbing minimally the laminar flow and almost eliminating its own shade while offering diverse temperature and coloured lighting, (2) ambient adjustable lighting embedded in the ceiling (RGB LED), and (3) continuous floor-perimeter LEAD cleaning light, like in Hospital Clinic Surgery theatres. HVAC (Heating, Ventilation and Air-Conditioning) control must be accessible from within and outside of the room.

ER11. Safe circulation and ergonomic work areas for staff

Following professional preferences at HSJD and benchmarking (e.g., Hospital Universitari de Bellvitge), the procedure table will be positioned **perpendicular to the control room window**. This improves visual control and communication while performing either device implants (professionals mainly on the left of the patient) or electrophysiology studies (professionals mainly on the right of the patient). Adjustable-height workstations like the adaptable computer workstations from **GCX** [58] and unobstructed paths are mandatory.

4.3.2. Recommended Requirements

RR1. Integrated audiovisual systems for teaching and documentation

Two ceiling-mounted medical-grade cameras are proposed: one over the main screen, another at the table foot for a wide-angle view. An ideal example would be the wall or ceiling-mounted **HD PTZ live video room cameras** from Stryker [59].

RR2. Mobile or modular furniture for procedural flexibility

Interventions vary depending on patient age and clinical purpose. Trolleys with swappable trays, adjustable arms, and lightweight carts (like **Ergotron** workstations [60]) allow custom room configuration. Ceiling-mounted modules, though having powerful mobility across the room, do not have full mobility. This is why, according to the identified needs, the anaesthesia workstation can remain as a mobile module such as the **Carestation 750 Anesthesia Delivery System** of GE Healthcare [61] or the **Fabius MRI** of Dräger [62].

RR3. Acoustic isolation of the control room

The control area should include **dual-pane acoustic glass**, sealable pass-through ports, and a **Metaflex** door [63] with 30–40 dB reduction capacity from the STB Group.

RR4. Dedicated nursing and auxiliary documentation stations

Inside the room, there should be a computer workstation where doctors and nurses can review patient information and produce the intervention-related documentation. A great option would be the already mentioned in ER11, the adaptable computer workstation from GTX. Outside, an additional nurse station ensures procedural notes are entered without sterile field interruption.

RR5. Enhanced patient comfort elements (music, visuals, ambient)

For children, environmental control pre- and post-procedure is key. A wall-mounted **MDSC-8358** screen from Barco [64] can play calming videos or cartoons as well as surgical images. Since patients are sedated in the interventions performed in the EP room, in-procedure visuals like virtual reality (VR) glasses systems are optional but could be explored in future awake workflows.

RR6. Ergonomic and staff-centred space design

Ergonomic upgrades include a **ceiling-hung lead apron** like the ZERO-GRAVITY Hinged Swing Arm model of BIOTRONIK [65] (as in Hospital Universitari de Bellvitge), anti-fatigue and adjustable ergonomic stools like the **Cleanroom stools** from Bimos [66]. **Sky Factory** [67] light panels could simulate daylight for psychological benefits of professionals and patients.

4.4. Integration of solutions

4.4.1. Final Selection of Equipment

To carry out the selection of the necessary equipment for the new Electrophysiology Room, all critical devices and systems used in the procedures planned for the unit, such as implants/explants of cardiac devices and arrhythmia diagnosis/treatment, were listed and analysed.

Each item currently in use was evaluated by the Arrhythmia Unit's clinical team, led by Dr. Georgia Sarquella-Brugada, with input from the nursing team. Devices were rated on a scale of 1 to 5 based on functionality and usability *when new*, regardless of their current age or wear. This ensures the evaluation reflects potential performance.

The evaluation followed these criteria: items rated **5** are considered optimal and can be **reacquired**, the ones rated **4** are acceptable and eligible for **renewal** while items rated **<4** are **candidates for replacement** and those rated **<2** will **not be re-elected**.

The current state of devices has not been fully audited; therefore, any device approved for reuse in terms of model will be considered as a **new acquisition** in this project.

A detailed equipment list is presented in *Annex H. Evaluation of current equipment in the HSJD's EP Room*, including device brand, model, units, and clinical feedback. A key principle followed during selection was: **if it works well, there is no need to change it.** The goal was to streamline innovation to only those areas where improvement is necessary, maximising efficiency and user familiarity.

The evaluation focused exclusively on clinical performance and user experience. Devices that were already well rated and with no identified issues were not explored further to prevent unnecessary complexity and resource expenditure. Instead, the emphasis was placed on aligning the selection with the essential requirements outlined in section *4.3.1 Essential Requirements*.

Following this process, **34 out of 40 items** received a score of **5** and can be retained, while **4 devices** scored **4**. Devices receiving lower scores will be evaluated for commercial alternatives, as discussed in section *3.2.4. External Benchmarking visits* and *4.3. Detailed analysis and proposed solutions*.

In addition to the equipment listed and rated in *Annex H*, it is important to note that some elements, although not explicitly mentioned in the requirements section, are either recommended by CSUR guidelines or deemed essential for the basic functioning of any electrophysiology room. For example, the presence of a crash cart and an adequate defibrillation system is mandatory for emergency preparedness.

In large-scale hospital renovation projects such as this one, the refurbishment of specialised rooms like the EP lab is often awarded through a **public tender**. This process typically involves one of the major medical technology providers, such as **Philips**, **GE Healthcare**, or **Siemens Healthineers**, taking responsibility for both infrastructure planning and the supply of critical equipment.

In the current EP room at HSJD, the **C-arm fluoroscopy system**, the **surgical table**, and the **main procedural display** are all manufactured by **Philips**, and these have been well received by the clinical staff in terms of usability, reliability, and support. Based on this feedback, and the fact that all benchmarked EP rooms visited as part of this study also use Philips Azurion systems (either floor- or ceiling-mounted), it is reasonable to consider Philips as a strong candidate to lead the room's renovation.

For this reason, the Azurion 7 M20 with FlexArm, the Azurion Table, and the FlexVision Pro monitor have been included in the final equipment list in *Annex H: Final selection equipment and devices for the new HSJD's EP room*.

In contrast, the **ceiling-mounted gas and electrical outlets**, as well as the **overhead storage modules**, have been attributed to **Getinge's Moduevo system** in the proposed solution, due to its excellent reputation and recommendations obtained during benchmarking visits, particularly at Hospital Universitari Vall d'Hebron.

It is important to note that this project **does not include a detailed budget**, as most of the equipment listed in *Annex H* is **not sold through traditional retail channels**. Instead, these devices and systems are procured directly by hospital systems or national healthcare providers via contracts with manufacturers. Consequently, **public price listings are generally not available**, and acquiring pricing information would require formal quotation requests from each provider.

While this limitation restricts the development of a full cost-benefit analysis at this stage, the prioritisation of devices has been made according to **clinical necessity**, **usability**, and **alignment with the defined technical requirements**. If this proposal is carried forward, detailed costing and supplier negotiations would be integrated into the implementation phase, following internal procurement protocols and regulatory frameworks.

Furthermore, the **storage area** of the electrophysiology unit could be significantly enhanced by incorporating **intelligent storage systems**, like those observed at Hospital Universitari de Bellvitge. These smart cabinets allow for **real-time inventory tracking**, reduce material retrieval times, and ensure procedural kits are pre-organised in advance. Although not included in the current list of core requirements, this represents a valuable future-oriented upgrade for the unit.

Similarly, **other areas of the department**, such as the **control room** and **recovery areas**, could benefit from further ergonomic adjustments, reorganisation of computing systems, improvements in environmental control and improvement of the patients and their families experience in the REA room. These additional interventions fall outside the scope of the present redesign but are recommended for **future phases of improvement** within the Arrhythmia Unit of HSJD.

4.4.2. Spatial Configuration and Layout Proposal

To complete the integration of the proposed solutions into a coherent design, a **preliminary architectural layout** of the future Electrophysiology Room has been developed (see *Figure 16*). This layout represents a spatial proposal that aims to **synthesise all essential and recommended requirements** outlined previously.

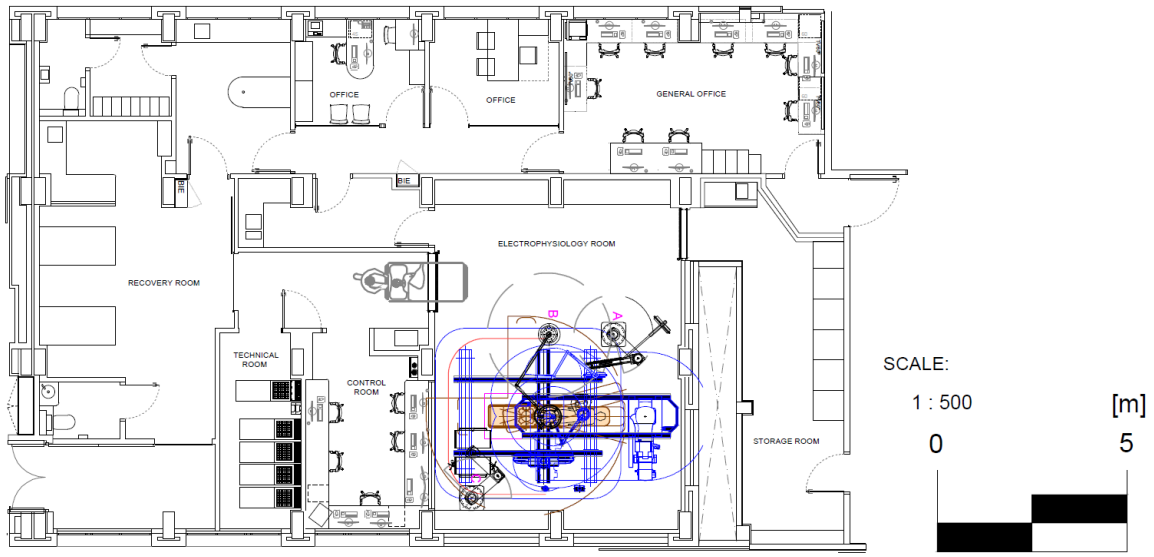

Figure 16: Preliminary layout proposal of the Electrophysiology Room at HSJD.

The plan was created using **AutoCAD software** based on the original architectural blueprint of the current EP room, observations and layouts from benchmarked hospitals and functional zoning needs and clinical workflow identified throughout this project.

This drawing **is not the result of a professional architectural design**, and its purpose is **indicative and conceptual**, rather than definitive. It serves as a **strategic design vision** that would later require detailed architectural validation and adaptation by professionals during project implementation.

Key elements included in the layout:

- **Procedure table** placed perpendicular to the control room window, enabling optimal visual contact and team coordination.
- **Ceiling-mounted monitor and pendant** with integrated electrical and gas outlets (e.g., Getinge Moduevo PLG-II SKY).
- **Ceiling-mounted storage arm** for radiofrequency (RF) generators and navigation consoles, located behind the procedural area.

- **Surgical light** placed centrally over the patient area (e.g., Surgiris XMT Range).
- **Ceiling-mounted Zero-Gravity lead apron system** to reduce staff fatigue.
- **Lead glass protective screen**, strategically placed to separate radiation zones.
- **Sliding door** installed at the access to the **storage room**, replacing the swing door to improve sterility and circulation.

The space maintains clear division between **sterile and non-sterile areas**, with careful attention to staff movement, cable routing, and equipment positioning. Zones for **documentation**, **anaesthesia**, and **storage** are also planned to minimise workflow interruptions.

5. Technical viability

When planning this project, it can be really useful to analyze the internal and external factors that can affect – positively or negatively- the development and success of the project. One way to do so is performing a SWOT analysis where there are internal origin factors (Strengths and Weaknesses) and external origin ones (Opportunities and Threats). The *Annex I. SWOT matrix* describes the SWOT analysis for this project.

6. Execution chronogram

This section outlines the organisation of the work, its division into work packages and tasks, and the subsequent representation in various diagrams that help visualise the different processes involved in the project. The aim of this structure is to make the achievement of the objectives defined at the beginning of the project more manageable.

6.1. Tasks definition

To carry out this project, it is important to divide its total duration into work packages. These, in turn, can be broken down into manageable tasks that facilitate project monitoring. This hierarchical organisation of the project's components is visually represented in the Work Breakdown Structure (WBS).

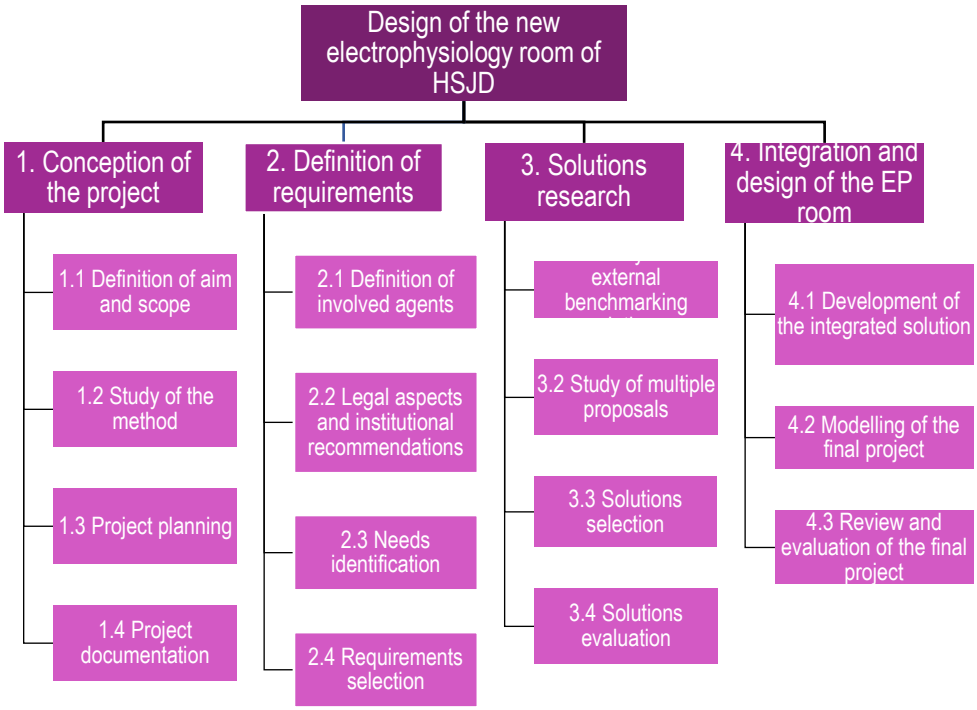

Figure 17: Work packages and tasks diagram of the WBS.

6.2. Precedence analysis

To place the various tasks outlined in the WBS diagram (*Annex J. Precedence analysis and duration of each task*) along a timeline, it is necessary to define their precedence relationships and estimated duration. Each task is assigned a letter, and its successor tasks are identified. The duration of each task is estimated based on the approximate number of hours required to complete it. Additionally, June 20th, 2025, has been set as the deadline for completing the project (as it is the oral defense of the project).

6.3. WBS Dictionary

The tasks of the WBS that make up this project are described in the *Annex K: WBS dictionary*. Mentioning the person responsible for each task has been omitted since, being a bachelor's thesis project (TFG), the only person responsible for each task is the author of the work. Additionally, it has been considered that the hourly rate for the human resources involved in this project is 20€ per hour. However, the WBS dictionary includes the description of each task along with their deliverables and the acceptance criterion.

6.4. Stages and milestones

To monitor the project from a different perspective, the project phases and milestones are outlined as seen in *Annex L: Stages and milestones of the project*. The achievement of milestones serves as a reference point within the schedule, thus helping to determine the project's progress at any given moment. On the other hand, the phases in this case correspond to the work packages, as these have been defined

based on the chronological order of the project, except for task 1.4, which is carried out throughout the entire duration of the project.

6.5. PERT/ CPM diagram

To better plan this project, a PERT/CPM diagram was also made (*Annex M: PERT/CPM diagram*), a chart that combines both techniques to facilitate the visualization and planning of the tasks into which the project has been divided, along with the relationships between them. The CPM technique contributes the so-called critical path, which includes all activities that must be completed within the established duration without any slack or margin.

In the PERT/CPM diagram, the various tasks are represented as processes along arrows (indicating their duration in number of days), which lead to different numbered nodes. Within these nodes, the top section indicates the task identifier, the left-hand side shows the optimistic completion time (the minimum time required to complete the task), and the right-hand side shows the pessimistic completion time (the maximum time required).

The duration of each task, their precedence relationships, and the project deadline have been previously defined in *Annex J*.

In this way, all activities form part of the critical path except for tasks F, I, and M (corresponding to WBS tasks 2.2, 3.1, and 4.1, respectively). These tasks have slack or margins of 30, 20, and 10 days, respectively.

6.6. GANTT diagram

Finally, among the project's time planning tools is the GANTT chart (in *Annex N. GANTT diagram*). This diagram shows the project schedule by representing the tasks into which it has been divided along a timeline, helping to visualize the project's temporal planning. On the x-axis, time is represented in days, and on the y-axis, the tasks are numbered according to the WBS (in red, those that belong to the critical path, and in blue, those that do not).

7. Economic viability

This study involves the design of the new electrophysiology room at HSJD, but not its implementation. Therefore, the only costs considered in this project are those related to the author's design work. To calculate the economic value associated with the WBS tasks, a rate of 20€ per hour of work has been established, which results in the estimated cost of 6480€, as seen in *Annex O: WBS tasks associated*

costs. However, since this is a bachelor's thesis (TFG), these costs are not covered by any entity, as the work is educational in nature, and therefore, the author will not receive any salary.

If we also take into account meetings with the tutor and the director (we can estimate one meeting every two months, each lasting one hour, over the 10-month duration of the project) and visits to other centers (at least 5, each hypothetically lasting one hour), we can make an approximate calculation by estimating that, on average, the professionals involved are paid 25€/hour. Based on this, the cost associated with these activities amounts to 375€, which, when added to the total cost in *Table 26*, defines a total project cost of 6855€.

Nevertheless, to understand how this project would be financed in the context of HSJD with the intention of implementing the proposed final solution, an interview was conducted with Mr. Fsc. Xavier Escayola, as mentioned before. Projects carried out over the past 10 years have not started with a fixed established budget. On the contrary, the budget has fluctuated throughout the project due to the hospital's various sources of funding. The uniqueness of the hospital allows it to receive funding from three sources: donations, CatSalut, and grants. Therefore, throughout the course of the project, the expected and available budget may fluctuate.

Finally, it is worth mentioning that the hypothetical implementation budget for the room will be included as a requirement in the new design. In other words, while the budget will not be part of this project, the design will take into account the approximate budget that the hospital could allocate for implementation.

8. Regulation and legal aspects

The construction or renovation of an Electrophysiology (EP) Room in Catalonia is subject to various safety, infrastructure, equipment, and quality regulations. These legal frameworks ensure the safety of patients and professionals, the technical adequacy of systems, and the overall quality of care.

One of the most strictly regulated aspects of an EP room is its use of ionising radiation, since X-ray-based fluoroscopy is the primary imaging modality. The room must comply with national regulations regarding radiation protection for both patients and healthcare personnel. These include the law on occupational risk prevention [68], the decree on radiation protection for workers [69], and other royal decrees related to medical use of X-rays [70], patient health protection [71], and the recommendations of the Nuclear Safety Council [72].

In addition, the equipment used in the room must meet European and Spanish medical device regulations [73], ensuring certified safety and performance for all devices involved in electrophysiological procedures.

From an infrastructure and quality perspective, all hospital units, including EP labs, must adhere to ISO 9001:2015 quality standards [74] and to specific regulations concerning climate control and air quality in surgical areas [75]. HVAC systems must be designed following national technical standards [76], while overall energy efficiency and thermal comfort must align with national and European building codes [77].

Electrical safety is also a critical aspect of the project. The installation must follow current low-voltage regulations [78], medical-grade electrical safety standards [79], and general electromagnetic compatibility guidelines [80]. This ensures safe and reliable power supply for all equipment, especially in a high-dependency unit like the EP room.

At the regional level, Catalan healthcare regulations require accreditation and authorisation of all medical units, in accordance with planning laws and the Catalan Health Organisation Law [81][82]. These regulations ensure that all new infrastructure developments follow strict planning and approval protocols.

Finally, several institutional recommendations have guided this project. While the last national guidelines for EP lab equipment were published by the Spanish Society of Cardiology in 2001 [83], and a broader report on cardiology units was issued by the Spanish Ministry of Health in 2011 [84], this project has instead relied more heavily on the 2004 international consensus endorsed by the Heart Rhythm Society (HRS) and the European Heart Rhythm Association (EHRA) [85], which sets comprehensive standards on safety, equipment, and team structure.

9. Conclusion

This project aimed to design a renovated Electrophysiology Room for the Arrhythmia Unit at Sant Joan de Déu Children's Hospital (HSJD), tailored to the needs of both the clinical team and the paediatric population it serves. To do so, a comprehensive, user-centred approach was taken, grounded in Biodesign methodology. The process included identifying unmet needs through interviews, shadowing, questionnaires and benchmarking; categorising and filtering these needs; translating them into concrete requirements; and proposing realistic, coherent solutions for infrastructure, equipment, and workflow.

Through this detailed exploration, it became evident how complex and subjective the design of a medical environment can be. While clinical safety and technical standards serve as non-negotiable cornerstones, many other aspects, such as spatial layout, cable management, storage, and lighting, are heavily

influenced by personal preferences, institutional culture, and professional habits. What one team finds functional and intuitive, another might find impractical.

This project has therefore not only proposed an improved layout and equipment package based on existing regulations (such as CSUR guidelines) and best practices (identified through benchmarking with other leading hospitals), but it has also offered a deeper reflection: **Is there really such a thing as the "ideal" EP room?** The answer appears to be both yes and no.

There may be no single universally ideal room, no one-size-fits-all solution, but there *is* an ideal electrophysiology room for a specific team, in a specific hospital, at a specific moment in time. This ideal emerges only when the unique needs of its users are deeply understood. That is why the initial stages of needs identification, staff interviews, and benchmarking have proven to be so vital to this process.

The final result is a functional and flexible design proposal that integrates essential requirements such as paediatric-adapted equipment, enhanced radiation protection, improved ergonomic layout, and intuitive cable and device organisation. It also suggests recommended features such as educational video recording systems, enhanced ambient experience for children, and acoustic control.

Although this design is technically detailed and aligned with national regulations, it must be noted that its implementation would require professional architectural input and institutional approval. Given the complexity and scale of such renovations, hospitals typically go through a public procurement process in which vendors such as Philips, Siemens Healthineers, or GE Healthcare may provide full reform packages, including both infrastructure and medical equipment. In fact, Philips, already the provider of the current C-arm, table, and monitor at HSJD, with high satisfaction from the staff, appears as a natural candidate for future implementation.

It is also important to acknowledge the architectural limitations of the current Arrhythmia Unit. Any structural expansion or redistribution of adjacent spaces would require a far more in-depth and technical feasibility study, potentially involving structural engineers and hospital planners.

In conclusion, this project offers a grounded, innovative, and realistic design tailored to the current and evolving needs of the HSJD electrophysiology team. Its greatest strength may lie not only in its proposed solutions, but in its thorough methodology, one that others may replicate to define their *own* version of the "ideal" electrophysiology room.

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11. Annexes

Annex A: Additional pictures of HSJD's current electrophysiology room

Figure 18. General view of current HSJD's EP room.

Figure 19. General view of current HSJD's EP room.

Figure 20: REA of HSJD's Arrhythmia Unit.

Figure 21: Ceiling-mounted main screen of HSJD's EP room.

Figure 22: Entrance of storage room of HSJD's Arrhythmia Unit.

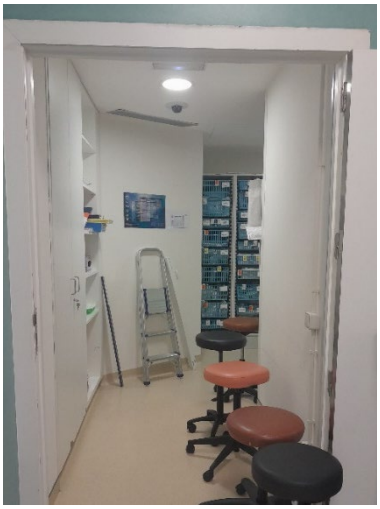

Figure 23: Storage room of HSJD's Arrhythmia Unit.

Annex B. HSJD's Arrhythmia Unit current blueprint

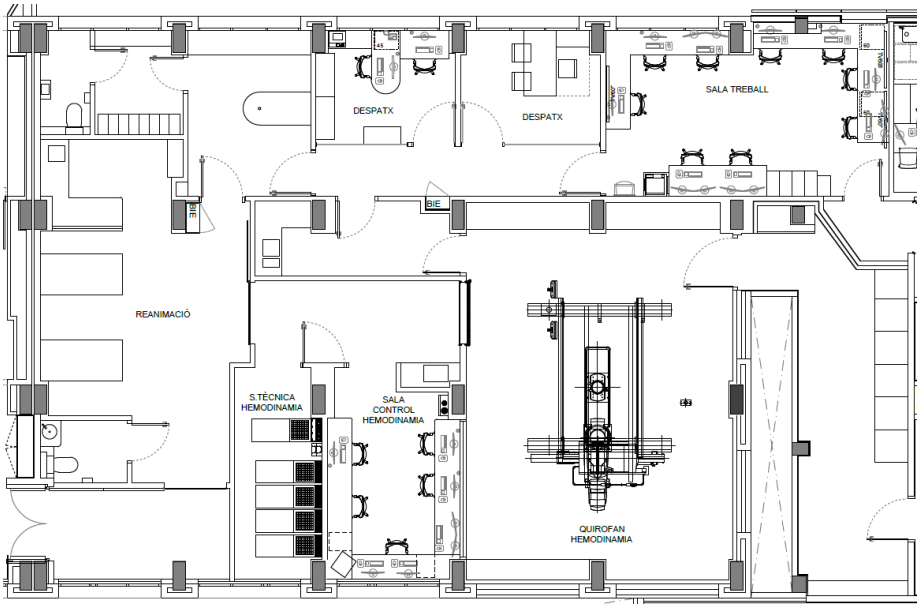

Figure 24: Current blueprint of the HSJD's Arrhythmia Unit.

Annex C: External benchmarking visits

Figure 25: Philips Azurion ceiling-mounted monoplane C-arm of Hospital Universitari de Bellvitge.

Figure 26: Anaesthesia equipment and crash cart from Hospital Universitari Vall d'Hebron.

Figure 27: Ceiling-mounted storage system from Hospital Universitari Vall d'Hebron.

Annex D: Questionnaire form model

Due to the large volume of data, the full set of questionnaire responses (104 pages) is not included in this appendix. However, the complete document can be provided upon request.

Dreaming of an Improved Electrophysiology Lab | *Soñando con un Laboratorio de Electrofisiología optimizado*

- English -

My name is Clàudia Torres, and I am a Biomedical Engineering student currently working on my final degree project, focused on redesigning the electrophysiology laboratory at Sant Joan de Déu Barcelona Children's Hospital. The aim of this project is to enhance the lab's design to optimize efficiency, improve patient experience, and create a better working environment for healthcare professionals.

To achieve this, we have identified four key areas of improvement:

1. Equipment and devices
2. Infrastructure
3. Patient experience
4. Facilities and working conditions for professionals

I am gathering insights from professionals working in EP labs to better understand their needs and challenges. If you have experience in this field, I would greatly appreciate your input through this short questionnaire, which will take less than five minutes to complete (just 1 or 2 examples for each answer will be enough).

Your feedback will be invaluable in shaping a more functional and patient-centered EP lab.

Thank you for your time and collaboration!

- Español -

Mi nombre es Clàudia Torres y soy estudiante de Ingeniería Biomédica. Actualmente estoy realizando mi proyecto de fin de grado, enfocado en el rediseño del laboratorio de electrofisiología del Hospital Sant Joan de Déu Barcelona. El objetivo de este proyecto es mejorar el diseño del laboratorio para optimizar la eficiencia, mejorar la experiencia del paciente y crear un mejor entorno de trabajo para los profesionales sanitarios.

Para lograrlo, hemos identificado cuatro áreas clave de mejora:

1. Equipos y dispositivos
2. Infraestructura
3. Experiencia del paciente
4. Instalaciones y condiciones de trabajo para los profesionales

Estoy recopilando información de profesionales que trabajan en laboratorios de electrofisiología para comprender mejor sus necesidades y desafíos. Si tienes experiencia en este campo, agradecería mucho tu participación en este breve cuestionario, que tomará menos de cinco minutos en completarse (con 1 o 2 ejemplos por respuesta será suficiente).

Tu opinión será fundamental para diseñar un laboratorio de electrofisiología más funcional y centrado en el paciente.

¡Gracias por tu tiempo y colaboración!

Figure 28: Questionnaire form model (first part).

1. **What is the hospital or health center that you work in?** *
   ¿En qué hospital o centro de salud trabajas?

   _____

2. **Which is your role in the electrophysiology team (doctor, nurse, nursing assistant, etc.)?** *
   ¿Cuál es tu rol en el equipo de electrofisiología (médico, enfermero/a, auxiliar de enfermería, etc.)?

   _____

3. **When it comes to the equipment and devices, considering the following examples and more:** *
   - Upgrading specific devices
   - Incorporating new innovative or useful devices
   - Getting rid of inefficient pieces of equipment
   - Purchasing devices that will allow performing new/more techniques
   - Allowing the possibility to record and stream the surgery

   I would specifically improve:

   _____

   En cuanto a los equipos y dispositivos, considerando los siguientes ejemplos y más:
   - *Mejorar dispositivos específicos*
   - *Incorporar nuevos dispositivos innovadores o útiles*
   - *Eliminar equipos ineficientes*
   - *Adquirir dispositivos que permitan realizar nuevas/más técnicas*
   - *Permitir la posibilidad de grabar y transmitir la cirugía*

   Yo mejoraría específicamente:

   _____
   _____
   _____
   _____
   _____

Figure 29: Questionnaire form model (second part).

4. **When it comes to the infrastructure, considering the following examples and more:** *
- Including new/more ceiling units to store devices
- Including moveable gas or electricity sockets
- Change the distribution of the room
- Change the orientation of the surgery table with respect to the control room
- Change the position of the accesses (or add new ones)
- Re-distribute the storage or change the storage system

I would specifically improve:

_____

En cuanto a la infraestructura, considerando los siguientes ejemplos y más:
- *Incluir nuevas/más unidades de techo para almacenar dispositivos*
- *Incluir tomas de gases o electricidad móviles*
- *Cambiar la distribución de la sala*
- *Cambiar la orientación de la mesa de cirugía respecto a la sala de control*
- *Cambiar la posición de los accesos (o añadir nuevos)*
- *Redistribuir el almacenamiento o cambiar el sistema de almacenamiento*

Yo mejoraría específicamente:

_____
_____
_____
_____
_____

5. **When it comes to the patient experience, considering the following examples and more:** *
- Add new illumination systems that allow color and intensity regulation
- Incorporate any type of visual or auditory inputs

I would specifically improve:

_____

En cuanto a la experiencia del paciente, considerando los siguientes ejemplos y más:
- *Añadir nuevos sistemas de iluminación que permitan regular el color y la intensidad*
- *Incorporar cualquier tipo de entradas visuales o auditivas*

Yo mejoraría específicamente:

_____
_____
_____
_____
_____

Figure 30: Questionnaire form model (third part).

6. **When it comes to the professionals/workers' comfort, considering the following examples and more:** *
- Improving workstations and furniture
- Enhancing lighting and temperature control
- Reducing noise and distractions
- Creating spaces for rest or relaxation

I would specifically improve:

_____

En cuanto al confort de los profesionales/trabajadores, considerando los siguientes ejemplos y más:

- Mejorar los puestos de trabajo y el mobiliario
- Mejorar la iluminación y el control de temperatura
- Reducir el ruido y las distracciones
- Crear espacios de descanso o relajación

Yo mejoraría específicamente:

_____

_____

_____

_____

_____

Figure 31: Questionnaire form model (Fourth part).

Annex E. Main characteristics of external benchmarking visited rooms

	Nº EP rooms	Nº ceiling storage systems	C-arm system	Illumination	Possibility of live streaming	Electroanatomical mapping systems	Antiquity	Table position relative to control room
Hospital Universitari de Bellvitge	2	2	Monoplane ceiling-mounted Philips Azurion	1 main surgical light and 1 smaller additional light	Yes	Carto and NavX	Last trimester 2023	Perpendicular
Hospital universitari de la Vall d'Hebron	2	3	Monoplane ceiling-mounted Philips Azurion	1 main surgical light	Yes	Carto and NavX	2021	Perpendicular
Hospital del mar	2	2	Monoplane Philips Azurion	1 main surgical light	No	Carto, NavX and Rhythmia	2016	Parallel
Hospital de Sant Pau	3	0	Monoplane Philips Azurion	1 main surgical light	Yes	Carto, NavX and Rhythmia	Unknown	Parallel
Hospital Clínic	2	0	Monoplane Philips Azurion	2 main surgical lights	No	Carto and NavX	Second trimester 2024	Perpendicular
Hospital Doctor Josep Trueta de Girona	2	0	Monoplane ceiling-mounted Philips Azurion	1 main surgical light and 18 dimmable ceiling-integrated lights	No	Carto and NavX	Last trimester 2017	Parallel

Table 1: Main characteristics of external benchmarking visited rooms.

Annex F. Prioritization and filtering of needs

Equipment and devices

Need	Priority	Main Source
Acquisition of **new or more advanced EP devices** to perform a wider range of procedures.	Must-have	Questionnaires and CSUR guidelines
Better system **integration** across mapping, imaging, navigation, and recording platforms.	Not needed or out of scope	Interviews and benchmarking
Maintenance and **technical support** to reduce downtime and ensure reliability.	Not needed or out of scope	Interviews
Incorporation of **teaching tools** such as ceiling-mounted cameras and external display touchscreens.	Nice to have	Interviews and benchmarking
Capability to **record and stream procedures** for educational and documentation purposes.	Nice to have	Benchmarking
Equipment that enables **lower radiation use**.	Must-have	Questionnaires and CSUR guidelines
Elimination of outdated or **inefficient devices**.	Nice to have	Shadowing
Improved interoperability between systems to avoid duplicated tasks and data fragmentation.	Not needed or out of scope	Interviews
Devices and connectors organised for rapid setup and transition between procedures.	Must-have	Shadowing and benchmarking
Inclusion of **paediatric-friendly equipment** where applicable.	Must-have	Interviews and CSUR guidelines

Table 2: Equipment and devices needs prioritization.

Infrastructure

Need	Priority	Main Source
Reorganisation and **expansion of storage**, with ceiling-mounted units to free floor space and improve accessibility.	Must-have	Shadowing and questionnaires
Redesign of the room layout to **optimise procedural flow** and minimise equipment relocation.	Must-have	Shadowing and interviews
Improved positioning and **flexibility of electrical and gas outlets** to avoid wire clutter and increase safety.	Must-have	Shadowing

Expansion or better **spatial separation of the EP room and control area** to reduce overcrowding.	Nice to have	Benchmarking
Modular or mobile furniture and devices to support frequent setup changes.	Nice to have	Interviews
Acoustic isolation of the control room to improve communication and reduce distractions.	Nice to have	Benchmarking
Improved **zoning between sterile and non-sterile areas** for safety and efficiency.	Must-have	Benchmarking and CSUR guidelines
Dedicated **nursing and auxiliary documentation areas** inside and outside the EP room.	Nice to have	Interviews
Simplification of wired connections between key systems.	Must-have	Shadowing
Better lighting design in infrastructure (ceiling integration, procedure-specific lighting).	Nice to have	Questionnaires

Table 3: Infrastructure needs prioritization.

Patient Experience

Needs	Priority	Main Source
Integration of calming **auditory stimuli** (e.g., music, nature sounds) to improve the procedural environment.	Nice to have	Questionnaires
Use of **visual stimuli** such as screens, calming projections, or ambient visuals.	Nice to have	Questionnaires
Installation of **adjustable lighting** (colour and intensity) to adapt the atmosphere to each patient and intervention.	Nice to have	Questionnaires
Enhanced **temperature control** systems to ensure patient comfort and prevent cold stress.	Nice to have	Questionnaires
Design of the space to promote a **soothing and non-threatening environment**, especially for paediatric patients.	Nice to have	Shadowing and interviews
Reduction of noise and disturbing stimuli during preparation and recovery.	Not needed or out of scope	Interviews
Possibility to play **patient-chosen media** for distraction and emotional support.	Nice to have	Questionnaires
Clear **visual separation between equipment and the patient's field of view**.	Not needed or out of scope	Questionnaires

Personalisation of lighting or visuals when possible.	Not needed or out of scope	Questionnaires
Improved **patient information flow** before and after the procedure (e.g., visual signage or digital info).	Not needed or out of scope	Questionnaires

Table 4: Patient experience needs prioritization.

Staff comfort

Needs	Priority	Main Source
Dedicated **rest and relaxation areas** nearby, especially for long interventions.	Not needed or out of scope	Interviews
Ergonomic workstation design to improve posture, efficiency and reduce fatigue.	Nice to have	Questionnaires
Improved **noise control** and reduction of distractions in both the EP and control rooms.	Nice to have	Questionnaires
Environmental controls for **temperature and lighting** that can be adjusted by staff.	Must have	Shadowing and questionnaires
Increased workspace and surface area in both the control room and procedure room.	Nice to have	Shadowing and interviews
Better **separation between documentation/coordination zones and clinical zones**.	Nice to have	Interviews
Improved **organisation of cables and connections** to avoid hazards and reduce visual clutter.	Must have	Shadowing
Optimisation of **room flow** to minimise unnecessary movements.	Must have	Shadowing
Staff-centred design to reduce emotional fatigue and **burnout risk**.	Nice to have	Questionnaires
Improved lighting levels in workstations, especially in control areas.	Nice to have	Questionnaires

Table 5: Staff comfort needs prioritization.

Item	Brand	Model	Units	Punctuation

Anaesthesia system machine	Draeger	Fabius GS Premium	1	5
Blood analysis system	Allere	Epoc	1	2
BIS module	Covidien	Vista	1	5
BIS module	Mindray	6800-30-50486	1	5
Coagulometer	GEM	HEMOCHRON 100	1	5
CO2 module	Mindray	6800-30-50558	1	5
Contrast delivery system	MALLINCKRODT // GUERBET	903300G // ANGIOMAT ILLUMENA INJECTOR	1	5
Cryoablation system	Medtronic	Cryocath 10000-008-04	1	Not used
Doctor-nurse monitor	Mindray	Benevision N22	1	5
Doppler	Sonicaid	D104R	1	5
Electroanatomical mapping system	Johnson-Johnson	FG-5400-00	1	5
Electrosurgical unit	Valleylab	FORCE FX	1	5
External pacemaker	Philips	TP-300	1	5
External pacemaker	APC	EV4543	1	5
Fridge	Rabider	FF180	1	5
Heater system	Covidien	-	1	5
Hyperthermia electrical blanket	Kanmed	OPERATERM 200 W	1	5
Intrasurgical PC	Rein Medical	Clinio	-	5
Irrigation pump	Stockert Gmbh	SMARTABLATE M4900103	1	5
Medical warming cabinet	Em-Med	2D	1	5
Mobile examination light LED-OSRAM	Provita	serie 5 led mobil 238199	1	5
Modules Rack	Mindray	115-046943-00	1	5
Multiparametric monitor	Draeger	INFINITY DELTA	1	5
NMT module	Mindray	115-018518-00	1	5
Pacemaker programming unit	Abbott	Merlin Modelo 3650	1	5
Pacemaker programming unit	Medtronic	2090	1	5
Patient monitor	Mindray	Benevision N1	1	5
Polygraph	Cardiotek	EP-TRACER 38 SYSTEM	1	5
Pulse oximeter	Nellcor	Bedside	1	5
Pumps Rack	BD -Becton Dickinson	80300UNS02-72	1	5
Radiofrequency ablation system	Stockert Gmbh	SMARTABLATE M4900102	1	5
Sistema RX vascular	Philips	ALLURA Xper FD20/20	1	4
Sternum saw	Stryker	SYSTEM 7 STERNUM SAW	1	5
Syringe pump	BD -Becton Dickinson	GH GUARDRAILS PLUS	4	4
Transoesophageal echography probe	Philips	S8-3t	1	5
Transoesophageal echography probe	Philips	X7-2T	1	5
Vaporizer	Draeger	Sevorane	1	5
Volumetric pump	BD -Becton Dickinson	GP GUARDRAILS PLUS	2	4
Volumetric pump	Terumo	TE-L800	1	4
Video recorder	Panasonic	MD 830	1	Not used

Annex G. Evaluation of current equipment in the HSJD's EP Room

Table 6: Evaluation of current equipment in the HSJD's EP Room.

Annex H: Final selection equipment and devices for the new HSJD's EP room

Item	Brand	Model	Units
C-arm fluoroscopy system	Philips	Azurion 7 M20 with FlexArm	1
Radiolucent surgical table	Philips	Azurion Table	1
3D Electroanatomical mapping	J&J MedTech / Abbott	CARTO 3 / EnSite Precision	2
Main display monitor	Philips	FlexVision Pro	1
Radiofrequency ablation generator	Stockert GmbH	SMARTABLATE M4900102	1
Irrigation pump	Stockert GmbH	SMARTABLATE M4900103	1
Electrophysiology polygraph recorder	Cardiotek	EP-TRACER 38 SYSTEM	1
Pacemaker programmers	Medtronic / Abbott	2090 / Merlin 3650	2
Anaesthesia system	Draeger	Fabius GS Premium	1
Multiparametric monitors	Mindray / Draeger	Benevision N1 / Infinity Delta	2
Doctor-nurse monitor	Mindray	Benevision N22	1
BIS modules	Covidien / Mindray	Vista / 6800-30-50486	2
CO_2 module	Mindray	6800-30-50558	1
NMT module	Mindray	115-018518-00	1
Syringe pumps	BD	GH GUARDRAILS PLUS	4
Volumetric pumps	BD / Terumo	GP GUARDRAILS / TE-L800	3
Pumps rack	BD	80300UNS02-72	1
Modules rack	Mindray	115-046943-00	1
Pulse oximeter	Nellcor	Bedside	1
Transoesophageal echo probes	Philips	S8-3t / X7-2T	2
Contrast delivery system	Guerbet / Mallinckrodt	Illumena Injector	1
Doppler	Sonicaid	D104R	1
External pacemakers	Philips / APC	TP-300 / EV4543	2
Electro-surgical unit	Valleylab	FORCE FX	1
Medical warming cabinet	Em-Med	2D	1
Fridge	Rabider	FF180	1
Hyperthermia blanket	Kanmed	OPERATERM 200 W	1
Heater system	Covidien	–	1
Intrasurgical PC	Rein Medical	Clinio	1
Mobile LED exam light	Provita	Serie 5 LED mobil	1
Cryoablation system	Medtronic	Cryocath 10000-008-04	1
Ceiling-mounted storage units	Getinge	Moduevo	1
Ceiling pendant with sockets	Getinge	Moduevo PLG-II SKY	1
Surgical light (shadowless)	Surgiris	XMT range	1–2
RGB ceiling + perimeter LED	–	Custom RGB / LED floor strip	Full
Wall-mounted patient TV	Barco	MDSC 8358	1
Integrated audio system	Philips	Smart Audio	1
Streaming cameras	Stryker	HD PTZ live camera (wall & table foot)	2
Ceiling-hung lead apron	BIOTRONIK	ZERO-GRAVITY	1
Wall workstation (medical-grade)	GCX	Adjustable wall mount	2
Anti-fatigue stools	Bimos	Cleanroom stools	2–3
X-ray radiation shielding screen	Mavig	OT8000 series	1
Crash cart	–	Standard	1

Table 7: Final selection equipment and devices for the new HSJD's EP room.

Annex I. SWOT matrix

	Internal origin	External origin
Negative aspects	- **Temporal limitations:** The project has less than half a year for development, limiting the scope of research. - **Limited space:** The possibility of changing the overall layout of the rooms is not considered due to the complex architecture of the building, which restricts design flexibility. - **Technological integration:** The project does not include optimization of current software or image data flow, focusing only on infrastructure and equipment.	- **Regulations and standards:** Changes in government regulations may require additional adjustments to the project or render proposed solutions obsolete. **- Resistance to change:** Stakeholders may show resistance to changes in the room's space or equipment, and conflicting needs may arise.
Positive aspects	- **Multidisciplinary team:** The Arrhythmia Unit has a specialized team of cardiologists, electrophysiologists, and nursing staff, providing valuable input for the project. - **Previous experience:** The hospital has successfully renovated other areas recently, such as the Pediatric ICU and the Pediatric Cancer Center. - **Existing technological infrastructure:** The current electrophysiology room already has a solid base, facilitating the integration of new equipment and technologies.	- **Innovation and benchmarking:** Visits to other hospitals and the search for innovative solutions provide fresh ideas and best practices that can be implemented. - **Professional feedback:** The use of interviews, questionnaires, and hypothetical room sketches allows for the collection of a wide range of needs and suggestions from users. - **Rapid technological development:** Ongoing technological advances may allow for the future incorporation of new solutions or upgrades.

Table 8: SWOT matrix.

Annex J. Precedence analysis and duration of each task

Work package	Task	Letter	Predecessors	Successors	Duration
1. Conception of the project	1.1 Definition of aim and scope	A	-	B	40 days
	1.2 Study of the method	B	A	C	20 days
	1.3 Project planning	C	B	E, F	10 days
	1.4 Project documentation	D	-	End	300 days
2. Definition of requirements	2.1 Definition of involved agents	E	C	G, I	15 days
	2.2 Legal aspects and institutional recommendations	F	C	H	15 days
	2.3 Needs Identification	G	E	H	30 days
	2.4 Requirements selection	H	F,G	J	20 days
3. Solutions research	3.1 Analysis of external benchmarking visits solutions	I	E	K	120 days
	3.2 Study of multiple proposals	J	H	K	90 days
	3.3 Solutions selection	K	I,J	L	10 days
	3.4 Solutions evaluation	L	K	M, N	15 days
4. Integration and design of the EP room	4.1 Development of the integrated project	M	L	O	30 days
	4.2 Modelling of the project	N	L	O	40 days
	4.3 Review and evaluation of the final project	O	M,N	End	10 days
-	End	-	D,O	-	300 days

Table 9: Precedence analysis and duration of each task.

Annex K. WBS dictionary

Task name	**Definition of aim and scope**
Work package	**Conception of the project**
WBS code	**1.1**
Description	
Definition of the project objectives along with its scope and, consequently, its limitations.	
Related deliverables	
1.	E.1.1.1 Document including objectives, scope and limitations of the project
Definition of acceptance criterion	
The objectives must be clear and concise while the scope must be clearly delimited.	
Estimated cost	300 €
Estimated duration	15 hours
Successors	B
Predecessors	-
Deadline	02/10/2024

Table 10: Description of task "Definition of aim and scope".

Task name	**Study of the method**
Work package	**Conception of the project**
WBS code	**1.2**
Description	
Analysis of the methods that will be used to address the scope of the project.	
Related deliverables	
2.	E.1.2.1 Document of the choice and analysis of the methodology used
Definition of acceptance criterion	
The justification for the choice of methods to be used and the respective definitions must be included.	
Estimated cost	160 €
Estimated duration	8 hours
Successors	C
Predecessors	A
Deadline	22/10/2024

Table 11: Description of task "Study of the method".

Task name	**Project planning**
Work package	**Conception of the project**
WBS code	**1.3**
Description	
Conceptual and temporal organization of the project development. The stages, tasks and deliverables will be described, framing the different tasks within a time limit.	
Related deliverables	
3.	E.1.3.1 WBS dictionary and diagram
4.	E.1.3.2 PERT-CPM chronogram and critical path

5.	E.1.3.3 GANTT diagram
6.	E.1.3.4 SWOT matrix
Definition of acceptance criterion	
It will be necessary to create EDT, PERT-CPM and GANTT diagrams for the optimal visualization of the time periods planned for each part of the project.	
Estimated cost	120 €
Estimated duration	6 hours
Successors	E, F
Predecessors	B
Deadline	01/11/2024

Table 12: Description of task "Project planning".

Task name	**Project documentation**
Work package	**Conception of the project**
WBS code	**1.4**
Description	
Documentation collected and generated during the course of the project and, in addition, a report that will be submitted as a final project. The deadline includes the project presentation date, where this task would end by showing a previously prepared presentation. This task includes the documentation generated from the monthly monitoring with the tutor and the director.	
Related deliverables	
7.	E.1.4.1 Report of the final degree thesis (TFG)
8.	E.1.4.2 Defense of the final degree thesis (TFG)
Definition of acceptance criterion	
This task must include, at a minimum, the project report following the criteria set by the UB and the presentation that will be shown on the day of the TFG defense.	
Estimated cost	2000 €
Estimated duration	100 hours
Successors	End
Predecessors	-
Deadline	20/06/2025

Table 13: Description of task "Project documentation".

Task name	**Definition of involved agents**
Work package	**Definition of requirements**
WBS code	**2.1**
Description	
Selection and justification of the agents involved in the project.	
Related deliverables	
9.	E.2.1.1 Document defining the agents involved
Definition of acceptance criterion	
The agent's involvement and consideration in the project must be recorded.	
Estimated cost	160 €

Estimated duration	8 hours
Successors	G, I
Predecessors	C
Deadline	16/11/2024

Table 14: Description of task "Definition of involved agents".

Task name	**Legal aspects and institutional recommendations**
Work package	**Definition of requirements**
WBS code	**2.2**
Description	
Description of the legal framework from which the project must be approached and, therefore, the legal requirements. It will also be necessary to include those recommendations from institutional organizations that may be useful when considering future proposed solutions.	
Related deliverables	
10. E.2.2.1 Collection paper of the legal framework and institutional recommendations	
Definition of acceptance criterion	
It is necessary to clearly and concisely state those legally mandatory and non-mandatory requirements along with their source of issuance and the name of the document that contains them.	
Estimated cost	160 €
Estimated duration	8 hours
Successors	H
Predecessors	C
Deadline	16/11/2024

Table 15: Description of task "Legal aspects and institutional recommendations".

Task name	**Needs identification**
Work package	**Definition of requirements**
WBS code	**2.3**
Description	
This task will collect the needs of the Electrophysiology Room by all the agents involved described in task 2.1.	
Related deliverables	
11. E.2.3.1 Collection of needs obtained through shadowing 12. E.2.3.2 Collection of needs obtained through personal interviews 13. E.2.3.3 Collection of needs obtained through external questionnaires 14. E.2.3.4. Collection of needs obtained through benchmarking external visits	
Definition of acceptance criterion	
The needs of each agent must be clearly detailed and the way in which they were obtained.	
Estimated cost	320 €
Estimated duration	16 hours
Successors	H
Predecessors	E
Deadline	16/12/2024

Table 16: Description of task "Needs identification".

Task name	Selection of requirements
Work package	**Definition of requirements**
WBS code	**2.4**
Description	
This task consists of selecting those requirements that will later be considered when looking for solutions. In order to select them, it is necessary to filter and prioritize them according to the legal framework and the scope of the project.	
Related deliverables	
15. E.2.4.1 Classification of requirements according to typology 16. E.2.4.2 Filtering and prioritizing needs 17. E.2.4.3 Definitive lists of requirements	
Definition of acceptance criterion	
For the acceptance of this task, the requirements must be classified according to their typology (equipment, space management, air conditioning, patient experience, others), filtered and prioritized according to the legal framework described in task 2.2 and the scope of the project. Finally, a definitive list of requirements must be drawn up for which a solution will subsequently be sought.	
Estimated cost	200 €
Estimated duration	10 hours
Successors	J
Predecessors	F, G
Deadline	05/01/2025

Table 17: Description of task "Selection of requirements".

Task name	Analysis of benchmarking visits solutions
Work package	**Solutions research**
WBS code	**3.1**
Description	
For this task, the aim is to examine precisely the characteristics of visited rooms in other hospitals to observe how they have been designed and how some requirements have been solved.	
Related deliverables	
18. E.3.1.1 Collection of precise descriptions of solutions in external electrophysiology rooms	
Definition of acceptance criterion	
Descriptions of the rooms visited (at least 5) must be collected, detailing those parts that may be interesting to solve the requirements established in task 2.4.	
Estimated cost	1000 €
Estimated duration	50 hours
Successors	K
Predecessors	E
Deadline	16/03/2025

Table 18: Description of task "Analysis of benchmarking visits solutions".

Task name	Study of multiple proposals
Work package	**Solutions research**
WBS code	**3.2**

Description	
Once the requirements have been established, it is now possible to search for and study different solution proposals for each of them established in task 2.4. Task 3.1 will be a great source of proposals.	
Related deliverables	
19. E.3.2.1 Document with multiple solution proposals for the established requirements	
Definition of acceptance criterion	
At least 2 proposals must be considered for each requirement, allowing the grouping of some requirements that can be resolved jointly.	
Estimated cost	800 €
Estimated duration	40 hours
Successors	K
Predecessors	H
Deadline	06/04/2025

Table 19: Description of task "Study of multiple proposals".

Task name	**Selection of solutions**
Work package	**Solutions research**
WBS code	**3.3**
Description	
Once the multiple solution proposals for each requirement have been made, they must be filtered according to benchmarking, workflow and the current existing infrastructure and list of equipment along with the legal framework described in task 2.4. Finally, a list of definitive solutions is delivered that will be considered for the integrated solution of the room design.	
Related deliverables	
20. E.3.3.1 Filtering possible solutions 21. E.3.3.2 Definitive list of solutions	
Definition of acceptance criterion	
It is important to detail the proposed solutions so that they are unambiguous.	
Estimated cost	120 €
Estimated duration	6 hours
Successors	L
Predecessors	I, J
Deadline	16/04/2025

Table 20: Description of task "Selection of solutions".

Task name	**Evaluation of solutions**
Work package	**Solutions research**
WBS code	**3.4**
Description	
The definitive solutions described in task 3.3 are presented to the agents involved and are evaluated according to the needs and the set of them.	
Related deliverables	
22. E.3.4.1 Solutions evaluation document	

Definition of acceptance criterion	
This task must include validation of the solution proposals by the agents involved.	
Estimated cost	160 €
Estimated duration	8 hours
Successors	M, N
Predecessors	K
Deadline	01/05/2025

Table 21: Description of task "Evaluation of solutions".

Task name	**Development of the integrated solution**
Work package	**Integration and design of the EP room**
WBS code	**4.1**
Description	
Once the solution proposals have been established and evaluated, it is necessary to study how all of these are integrated into a single space; the room space and the entire Arrhythmia Unit.	
Related deliverables	
23. E.4.1.1 Integrated solution description document	
Definition of acceptance criterion	
It is necessary for this task to contemplate how the various solutions will interact in the delimited space of the project.	
Estimated cost	360 €
Estimated duration	18 hours
Successors	O
Predecessors	L
Deadline	31/05/2025

Table 22: Description of task "Development of the integrated solution".

Task name	**Modelling of the final project**
Work package	**Integration and design of the EP room**
WBS code	**4.2**
Description	
In order to visualize the total design solution of the room, it is necessary to represent the integrated solution in the form of a sketch or plan on a scaled representation of the real space of the electrophysiology room and the space of the Arrhythmia Unit.	
Related deliverables	
24. E.4.2.1 Sketch or blueprint of the integrated solution	
Definition of acceptance criterion	
The deliverable associated with this task must include a sketch or plan where the integrated solution can be visualized in a clear and sharp manner.	
Estimated cost	500 €
Estimated duration	25 hours
Successors	O
Predecessors	L

Deadline	06/06/2025

Table 23: Description of task "Modelling of the final project".

Task name	**Review and evaluation of the final project**
Work package	**Integration and design of the EP room**
WBS code	**4.3**
Description	
This last task consists of reviewing and evaluating the final design of the electrophysiology room and the Arrhythmia Unit.	
Related deliverables	
25. E. 4.3.1 Final design review document	
Definition of acceptance criterion	
This task must review and evaluate the integrated solution and its modelling to specify any inconvenience that may arise in its hypothetical implementation or during the oral defence.	
Estimated cost	120 €
Estimated duration	6 hours
Successors	End
Predecessors	M, N
Deadline	20/06/2025

Table 24: Description of task "Review and evaluation of the final project".

Annex L: Stages and milestones

Stage	Milestone	Description	Included tasks	Deadline
1. Conception of the project	M1. Definition and approach of the project	The project begins by setting out its objectives and limitations, together with the methodology to be used and the agents involved. Furthermore, the project is framed within a legal framework and institutional recommendations.	1.1 Definition of aim and scope	16/11/2024
			1.2 Study of the method	
			1.3 Project planning	
			1.4 Project documentation	
2. Definition of requirements			2.1 Definition of involved agents	
			2.2 Legal aspects and institutional recommendations	
	M2. Application of information collection methods	Shadowing techniques, personal interviews, group dynamics and external visits are applied to obtain requirements and valuable information for possible solutions.	2.3 Needs identification	06/04/2025
			2.4 Requirements selection	
3. Solutions research			3.1 Analysis of external benchmarking solutions	
			3.2 Study of multiple proposals	
	M3. Selection of solutions and final design	Final stage of the project in which the solutions are collected and selected and integrated to model the final design of the electrophysiology room and the Arrhythmia Unit.	3.3 Solutions selection	20/06/2025
			3.4 Solutions evaluation	
4. Integration and design of the room			4.1 Development of the integrated project	
			4.2 Modelling of the project	
			4.3 Review and evaluation of the project	

Table 25: Stages and milestones of the project.

Annex M. PERT/CPM diagram

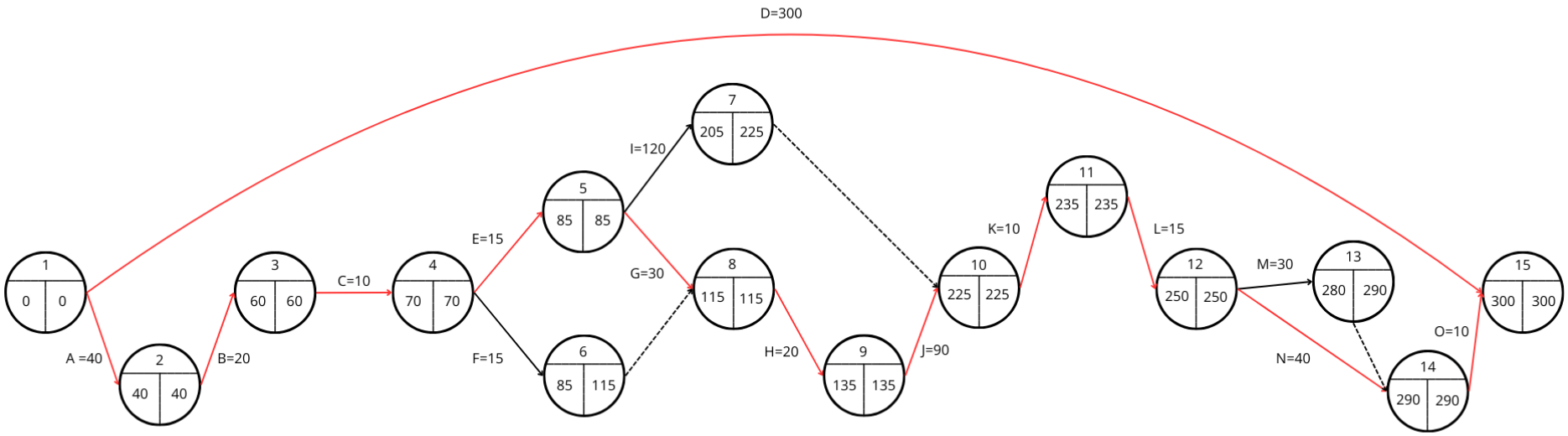

Figure 32: PERT/CPM diagram.

Annex N. GANTT diagram

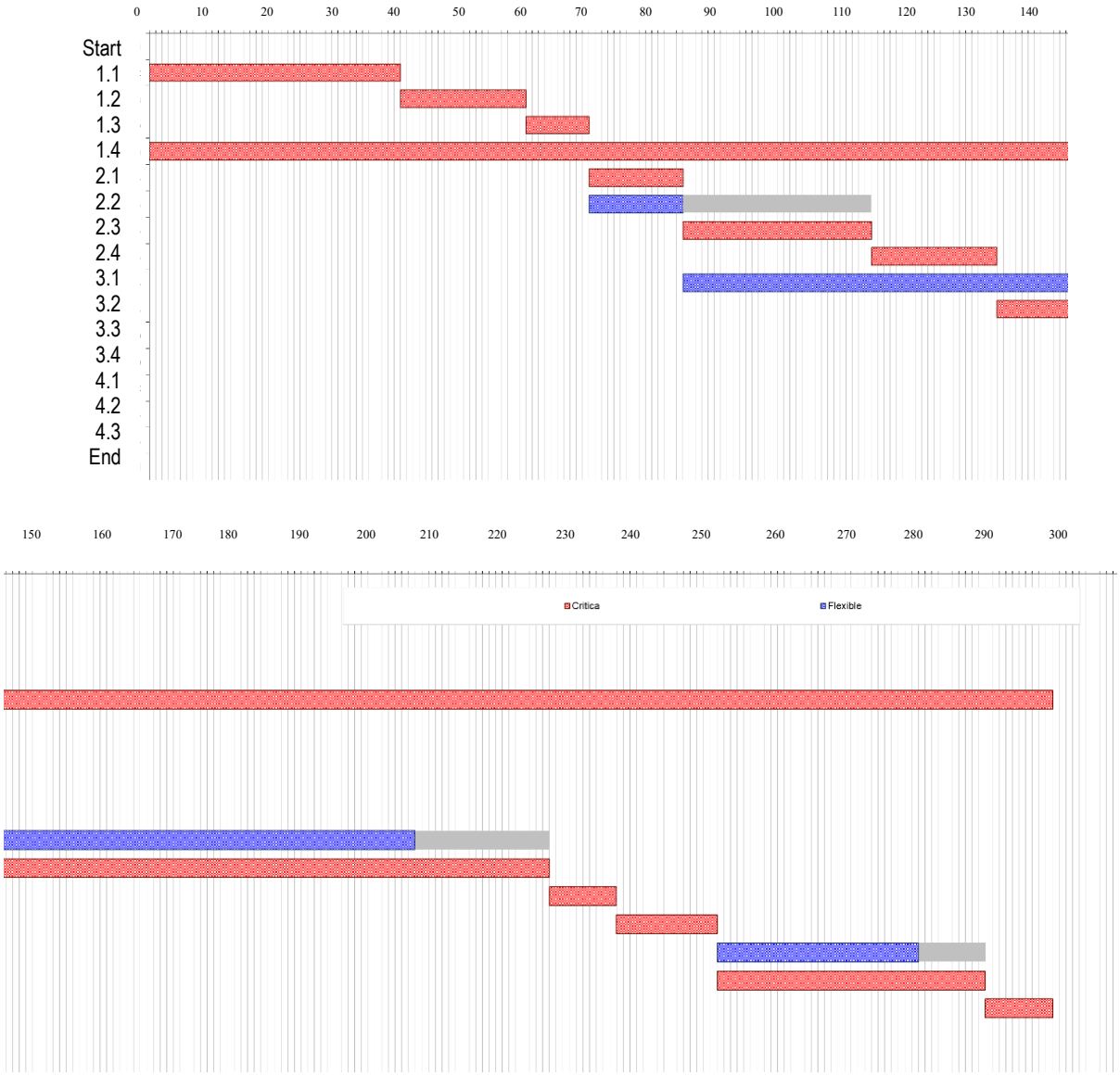

Figure 33: GANTT diagram.

Annex O: WBS tasks associated costs

Work package	Task	Letter	Estimated cost (€)
1. Conception of the project	1.1 Definition of aim and scope	A	300
	1.2 Study of the method	B	160
	1.3 Project planning	C	120
	1.4 Project documentation	D	2000
2. Definition of requirements	2.1 Definition of involved agents	E	160
	2.2 Legal aspects and institutional recommendations	F	160
	2.3 Needs identification	G	320
	2.4 Selection of requirements	H	200
3. Research of solutions	3.1 Analysis of external benchmarking solutions	I	1000
	3.2 Study of multiple proposals	J	800
	3.3 Solutions selection	K	120
	3.4 Solutions evaluation	L	160
4. Integration and design of the EP room	4.1 Development of the integrated project	M	360
	4.2 Modelling of the project	N	500
	4.3 Review and evaluation of the project	O	120
Total			**6480 €**

Table 26: WBS tasks associated costs.