Instituto Alberto Luiz Coimbra de
Pós-Graduação e Pesquisa de Engenharia
COPPE
UFRJ

# TOWARDS A METAMODEL TO SUPPORT THE CREATION OF INTERACTIVE SOFTWARE SYSTEMS FOR MANAGING THE LOCATION AND USE OF MEDICAL EQUIPMENT IN HEALTH CENTERS

Vitor Carneiro Maia

Tese de Doutorado apresentada ao Programa de Pós-graduação em Engenharia de Sistemas e Computação, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Engenharia de Sistemas e Computação.

Orientadores: Guilherme Horta Travassos
Christophe Kolski

Rio de Janeiro
Novembro de 2024

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TESE SUBMETIDA AO CORPO DOCENTE DO INSTITUTO ALBERTO LUIZ COIMBRA DE PÓS-GRADUAÇÃO E PESQUISA DE ENGENHARIA DA UNIVERSIDADE FEDERAL DO RIO DE JANEIRO COMO PARTE DOS REQUISITOS NECESSÁRIOS PARA A OBTENÇÃO DO GRAU DE DOUTOR EM CIÊNCIAS EM ENGENHARIA DE SISTEMAS E COMPUTAÇÃO.

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RIO DE JANEIRO, RJ – BRASIL
NOVEMBRO DE 2024

Maia, Vitor Carneiro

Towards a Metamodel to Support the Creation of Interactive Software Systems for Managing the Location and Use of Medical Equipment in Health Centers – Rio de Janeiro: UFRJ/COPPE, 2024

XIII, 174 p.: il.; 29,7 cm.

Orientadores: Guilherme Horta Travassos
Christophe Kolski

Tese (doutorado) – UFRJ/COPPE/Programa de Engenharia de Sistemas e Computação, 2024.

Referências Bibliográficas: p. 146 – 163.

1. Engenharia de Software. 2. Internet das Coisas. 3. Engenharia de Software Experimental. I. Travassos, Guilherme, *et al.* II. Universidade Federal do Rio de Janeiro, COPPE, Programa de Engenharia de Sistemas e Computação. III. Título.

# Agradecimentos

Agradeço à minha esposa Carla pelo amor, companheirismo, e por se dispor a se adaptar à vida fora do Brasil por um período tão longo. Agradeço aos meus pais e a toda a família pelo apoio, especialmente enquanto estivemos longe de casa.

Agradeço aos amigos do Brasil que estiveram conosco em todos os momentos. À Rebeca Motta e Taisa Guidini por terem me guiado neste caminho sempre que precisei. À Isabelle Oliveira-Machado, que nos apoiou em momentos importantes nos nossos primeiros dias em Valenciennes. E sou muito grato por ter conhecido novos amigos na França, pessoas de todos os continentes que vou levar sempre comigo.

Agradeço à professora Ana Regina Cavalcanti da Rocha, que me incentivou a iniciar o doutorado e me apoiou nesta transição. Aos meus orientadores Guilherme Horta Travassos, Christophe Kolski e Káthia Marçal de Oliveira pela presença constante, e por confiarem e acreditarem em mim. Obrigado pela oportunidade de realizar o doutorado em cotutela com vocês.

Agradeço especialmente à Káthia Marçal de Oliveira, que em diversos momentos foi nossa mãe em Valenciennes. Agradeço por nos apoiar em vários momentos difíceis, por nos defender sempre, e por ser nossa amiga. Nós te admiramos muito e somos eternamente gratos.

Agradeço a todos que aceitaram participar dos experimentos realizados tanto na França quanto no Brasil, e aos profissionais de saúde que se disponibilizaram para serem entrevistados. À Patricia Furtado da Silva e Lidvine Godaert pelo auxílio e apoio durante praticamente toda a pesquisa.

Agradeço aos professores Patrick Girard, Samira Si-said Cherfi, Juliana Silva Herbert, Flavia Coimbra Delicato e Claudio Miceli de Farias por aceitarem o convite para avaliar nossa pesquisa.

Agradeço ao Campus France, CAPES e CNPq pelo apoio financeiro. Também às equipes da UFRJ e da UPHF por todo o auxílio e suporte.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

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Vitor Carneiro Maia

November/2024

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Managing medical equipment in health centers is crucial, especially in emergency departments. However, due to the dynamic nature of these environments, the equipment may be unavailable for various reasons in different situations. Existing management tools rely on manual interventions, which increases the workload of the health professionals involved and does not track the continuous use of the equipment. This thesis proposes a generic solution approach to manage the location and use of medical equipment while minimizing manual interactions. A meta-model was developed to enable the creation of specialized IoT applications tailored to the specific needs of different types of health centers. The research began with a literature investigation on fundamental themes, followed by the meta-model conception, which evolved iteratively. Interviews with health professionals allowed the integration of information about the medical context. The feasibility of the meta-model was tested by two IoT software systems applied in experimental studies simulating simple hospitals. The main contribution of this work is the creation of an efficient meta-model to develop IoT applications suitable for medical equipment management, with a potential for continuous improvement for various health centers.

Resumo da Tese apresentada à COPPE/UFRJ como parte dos requisitos necessários para a obtenção do grau de Doutor em Ciências (D.Sc)

# TOWARDS A METAMODEL TO SUPPORT THE CREATION OF INTERACTIVE SOFTWARE SYSTEMS FOR MANAGING THE LOCATION AND USE OF MEDICAL EQUIPMENT IN HEALTH CENTERS

Vitor Carneiro Maia

Novembro/2024

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Programa: Engenharia de Sistemas e Computação

A gestão de equipamentos médicos em centros de saúde é essencial, especialmente em locais como emergências. Entretanto, devido à natureza dinâmica destes ambientes, os equipamentos podem estar indisponíveis por razões variadas em diferentes situações. As ferramentas de gestão atuais dependem de intervenção manual, aumentando a carga de trabalho dos profissionais de saúde e não acompanha os usos constantes. Esta tese propõe uma abordagem genérica para gerenciar a localização e o uso de equipamentos médicos, ao mesmo tempo que minimiza as interações manuais. Foi desenvolvido um meta-modelo que permite a criação de aplicações IoT especializadas nesta finalidade, considerando as características específicas de diferentes centros de saúde. A pesquisa começa com uma investigação na literatura sobre temas fundamentais, seguida pela concepção do meta-modelo, que foi criado e evoluído iterativamente. Entrevistas com profissionais de saúde também foram realizadas para integrar informações sobre o contexto médico. A viabilidade do meta-modelo foi testada através de duas aplicações IoT, integradas a estudos experimentais que simularam hospitais simples. A principal contribuição deste trabalho é a criação de um meta-modelo que permite o desenvolvimento eficiente de aplicações IoT para gerenciar equipamentos médicos no setor de saúde, com potencial para aprimoramento contínuo e adaptação a diferentes tipos de centros de saúde.

Résumé de la thèse présentée à COPPE/UFRJ comme exigence partielle pour l'obtention du diplôme de Docteur en Sciences (D.Sc.)

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La gestion des équipements médicaux dans les centres de santé est cruciale, en particulier dans les services d'urgence. Cependant, en raison de la nature dynamique de ces environnements, ces équipements peuvent être indisponibles pour des raisons variées dans différentes situations. Les outils de gestion existants dépendent d'interventions manuelles, ce qui alourdit la charge de travail des professionnels de santé concernés et ne suit pas l'utilisation continue des équipements. Cette thèse propose une approche générique de solution pour gérer la localisation et l'utilisation des équipements médicaux tout en minimisant les interactions manuelles. Un méta-modèle a été développé pour permettre la création d'applications IoT spécialisées, adaptées aux besoins spécifiques de centres de santé de différents types. La recherche a commencé par une étude de la littérature sur des thèmes fondamentaux, suivie de la conception du méta-modèle, ayant fait l'objet d'évolutions de manière itérative. Des entretiens avec des professionnels de santé ont permis d’intégrer des informations sur le contexte médical. La faisabilité du méta-modèle a été testée par deux applications IoT dans des études expérimentales simulant des hôpitaux simples. La principale contribution de ce travail est la création d'un méta-modèle efficace pour développer des applications IoT adaptées à la gestion des équipements médicaux, avec un potentiel d'amélioration continue pour divers centres de santé.

# Index

# Index of Figures

# Index of Tables

# Table of Acronyms

| Acronym | Meaning |
|---|---|
| 6LoWPAN | IPv6 over Low-Power Wireless Personal Area Networks |
| AI | Artificial Intelligence |
| AMQP | Advanced Message Queuing Protocol |
| AP | Access Point |
| BLE | Bluetooth Low Energy |
| CMMS | Computerized Maintenance Management Systems |
| CoAP | Constrained Application Protocol |
| COPPE | Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia |
| CPS | Cyber-Physical Systems |
| ECG | Electrocardiogram |
| EMI | Electromagnetic Interference |
| EPC | Electronic Product Code |
| FIOCRUZ | Fundação Oswaldo Cruz |
| GQM | Goal-Question-Metric |
| GPS | Global Positioning System |
| HTTP | Hypertext Transfer Protocol |
| ILBS | Indoor Location-Based Services |
| IoMT | Internet of Medical Things |
| IoT | Internet of Things |
| IPS | Indoor Positioning Systems |
| LAMIH | Laboratoire d'Automatique, de Mécanique et d'Informatique Industrielles et Humaines |
| LF | Low Frequency |
| MQTT | Message Queuing Telemetry Transport |
| MRI | Magnetic Resonance Imaging |
| NFC | Near Field Communication |
| PICO | Population – Intervention – Comparison – Outcome – Context |
| RFID | Radio Frequency Identification |
| RTK | Real-Time Kinematic |
| RTLS | Real-Time Location Systems |
| SAGAT | Situation Awareness Global Assessment Technique |
| SLAM | Simultaneous Localization and Mapping |
| SQL | Structured Query Language |
| SUS | System Usability Scale |
| UHF | Ultra-High Frequency |
| UID | Unique Identifier |
| UML | Unified Modeling Language |
| UWB | Ultra-Wideband |
| UUID | Universally Unique Identifier |
| VLC | Visible Light Communication |

# 1 Introduction

This chapter describes the research's context and motivation, leading to the definitions of the problem and the research question. It also describes the research methodology, summarizes the contributions and bibliographic production, and presents the outline for the rest of the thesis.

## 1.1 Context and Motivation

Health centers are patient-directed environments that deliver healthcare services. Their rules of functioning and the kind of services they provide depend on several factors, such as the types of facilities and illnesses treated[1]. Managing medical equipment (e.g., ultrasound scanners, wheelchairs, ventilators) is a challenging yet crucial activity in health centers, as the inability to quickly access these supplies in good conditions during emergencies can significantly impact a patient's life. Due to the dynamic routine of health professionals, medical equipment may not always be stored in the designated location after use nor undergo standard procedures such as disinfection (Nalini Priya et al., 2008; Oliveira, 2022). Certain assets are limited in number, and none may be available during an urgent situation.

A methodology that assists in the overall management is the Daily Huddle[2] (G. Mello et al., 2020), which involves daily meetings medical teams hold to align patient care activities and identify quality issues with medical equipment. During the COVID-19 pandemic, FIOCRUZ[3], a Brazilian public health research institution, adopted this methodology in its COVID-19 healthcare unit to increase the efficiency of internal communication and optimize conflict resolution and decision-making through active system monitoring. The team discussed medical equipment availability, usage, and condition through daily meetings. These meetings enabled the early detection of issues and facilitated the redistribution of resources. However, these resources' location and conditions, such as being infected or needing maintenance, were not managed continuously. When visiting the hospital, our research group observed difficulties in managing the area and using medical equipment when visiting the healthcare unit.

Already aware of these difficulties, similar problems were learned from professionals in a French hospital. The bladder scan is an example of a problematic piece

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[1] https://taxonomy.nucc.org/

[2] https://shorturl.at/2AA15

[3] https://portal.fiocruz.br/

of equipment that is very expensive. Only one is available for the entire geriatrics department. Nurses need to search for it daily across various floors. Small equipment like oximeters is frequently lost or forgotten in the pockets of clothes taken for washing. Adopting a methodology such as the Daily Huddle was not reported. However, they use software for managing equipment that knows where it was initially allocated but did not track who uses it in real-time.

During the pandemic, field hospitals were extensively established. Due to the lack of prior experience, many lessons were learned from them, such as the need for well-equipped Intensive Care Units (ICU), appropriately sized rooms, air filtering, and beds with the correct typology (Ribeiro et al., 2020). Since these hospitals are built for demanding and dynamic work situations, it is essential to follow a methodology or use a tool to assist in managing medical equipment. The eventual management of critical equipment needs to be improved in dynamic work situations such as the COVID-19 pandemic. Medical equipment such as electrocardiograms (ECGs), oximeters, and infusion pumps are used multiple times throughout the day and must be disinfected following the correct methods for use with the next patient (Sopwith et al., 2002).

Therefore, managing medical equipment is a daily challenge for health professionals, and having a well-defined solution could have saved more lives during the pandemic. However, such a solution must not interfere with the activities of health professionals or cause them to waste time, as they already have a heavy routine with many essential tasks. As a software solution, this problem can be addressed by applying the **Internet of Things (IoT)** paradigm (Atzori et al., 2010), through which medical equipment can be identified and monitored without the need for manual interventions, such as having to inform a software system that particular equipment is in use. With IoT, it would be enough to move the equipment around the environment, and the location information would be automatically updated and made available on dashboards for health professionals. The Internet of Medical Things **(IoMT)** refers to the application of IoT in health centers. IoMT software systems encompass sensors and infrastructure to collect patient biometric signals, allowing the monitoring of conditions such as neurological diseases, heart diseases, and diabetes. IoMT applications also enable remote collection of such parameters (Ravikumar & V, 2022; Vishnu et al., 2020). IoT applications in the medical context frequently focus on patients but not as often on monitoring medical equipment.

Another issue faced in health centers is knowing whether objects are in a condition to be used, which cannot be solved simply by location tracking. For example, equipment might be dirty or close to breaking down. With **context awareness** (Abowd et al., 1999; Calvary et al., 2003), an IoT software system can not only track the location but also understand the context, interpret the significance of the locations, and infer the current status of the medical equipment. It is possible to go even further with **situation awareness** (Endsley, 1988a), which allows the implementation of functionalities that predict the future. Based on historical data about medical equipment's location and status and other data such as patient information, an IoT software system can implement a wide range of smart functionalities, such as predicting that a specific patient will need a wheelchair. It is important to note that such systems can be implemented with little or no explicit human-computer interaction with health professionals, whose primary input would be their movement and the movement of the equipment, which already happens naturally.

While a software solution for managing medical equipment's location and use, if designed for a specific hospital, it may not be easily transferable to others due to each health center's unique processes, infrastructure, and operating rules. Therefore, we propose a **metamodel** that could be designed generically to facilitate the creation of numerous applications. Metamodels provide high-level abstraction specifications that different models can follow. This approach allows for the development of IoT software systems tailored to the specific requirements of countless health centers. It is particularly beneficial for facilities such as field hospitals, which are often set up rapidly or in emergencies where equipment is urgently needed. To our knowledge, no previous studies have been focused on metamodels for creating IoT software systems for managing the location and use of medical supplies, emphasizing context and situation modeling.

## 1.2 Problem Definition and Research Question

Health centers, especially those involving emergency care, face difficulty locating medical equipment when health professionals need it. Once the equipment is found, it must be in usable condition. For example, a wheelchair might not have been cleaned after its last use, or an electrocardiogram might have been stored without printer paper. In very dynamic situations, it can also happen that more than one health professional simultaneously needs the same piece of equipment. Although the professionals resolve these situations during their day-to-day work, they represent an extra work overload.

These situations should be avoided so that health professionals can focus on their most crucial task: patient care.

In the same way, owing to the nature of tasks performed in health centers, it would be more fitting if a proposed IoT software system did not increase the number of activities performed by health professionals to the extent possible to avoid increasing work overload. This research is motivated by investigating how to model the problem of managing the location and use of medical equipment in health centers. The focus is the management of medical equipment, and to address this, the research proposes integrating equipment directly as elements of the software solution through the **Internet of Things** paradigm. Unlike conventional software systems where users explicitly input management data, IoT enables medical equipment to provide information via sensor-equipped devices. Through **context awareness**, these systems can also understand the environment, such as the layout of hospital rooms or the types of health professionals present, to comprehend how the medical equipment is used. Through **situation awareness**, IoT software systems could implement functionalities that enhance the capabilities of the health center by utilizing historical data from various sources, making the environment itself smart. For instance, the system could notify users that the equipment currently in use is about to break down and indicate the location of a nearby piece of equipment of the same type.

One crucial issue for addressing this goal is identifying which technologies allow the localization of objects in indoor areas such as health centers. Such localization must be done automatically so that this functionality does not interfere with health professionals' daily activities. One of the most well-known technologies for this end is Radio Frequency Identification (RFID), which can find nearby tagged objects without user intervention (Finkenzeller, 2010). At the first moment, we decided to research it further.

However, a single application applies to a specific health center. Each health center has unique characteristics and needs, resulting in similar yet different software systems. This research proposes elaborating a **metamodel** for building **IoT**, **context-aware**, and **situation-aware** software systems specialized in managing medical equipment. Envisioned as fundamental requirements, these concepts address the problem of locating medical equipment while promoting reduced human-computer interactions between healthcare professionals and the target software system.

This modeling should encompass all the generic and fundamental features in any of these systems and allow instantiation to serve as a foundation for developing specific applications. By **instantiating** a metamodel, other models are created for building particular software systems. The metamodel must be adaptable to different health centers.

So, this thesis addresses the problem of managing the location and use of medical equipment in health centers, reducing explicit human-computer interactions where applicable, and considering the different characteristics of various health centers. The research question can be formulated as follows: *How can we support the engineering of interactive software systems for managing the location and use of medical equipment in health centers, considering environmental constraints and with little explicit human-computer interactions?*

## 1.3 Research Goal

The research aims to provide a metamodeling capable of supporting the creation of IoT applications for managing the location and use of medical equipment. To that end, the metamodel must be generic enough to represent characteristics of different health centers and classes, including IoT, context awareness, situation awareness, and technologies enabling data communication and implementing implicit interactions. It must be flexible, offer choices, and allow its structure to be reduced or extended for the target health center. IoT software systems built from the metamodel should effectively provide the specified functionalities for managing the location and use of medical equipment.

Once completed, the proposed metamodel is expected to encourage health centers that struggle with equipment management issues to build such software systems. It will likely speed up the development of these systems in field hospitals and other facilities that provide emergency services.

## 1.4 Methodology

Based on (Neto et al., 2010), the research methodology is divided into three parts (Figure 1.1): **Literature Investigation**, **Metamodel Conception**, and **Feasibility**. The methodology is based on research on fundamental topics and interviews with experts to gather the necessary knowledge for developing the metamodel. During the **Literature Investigation**, studies on essential issues related to the object's location are conducted. We start by investigating indoor localization technologies, focusing first on RFID due to its several positive characteristics, such as having a unique identifier and being low-cost and battery-free. The results are applied in the **Metamodel Conception**, during which versions of the metamodel are gradually evaluated through an iterative process. After several iterations, the **Feasibility** begins once the metamodel is considered robust enough. The feasibility of applying the metamodel is tested through its instantiation, development of software systems, and application in two experimental studies.

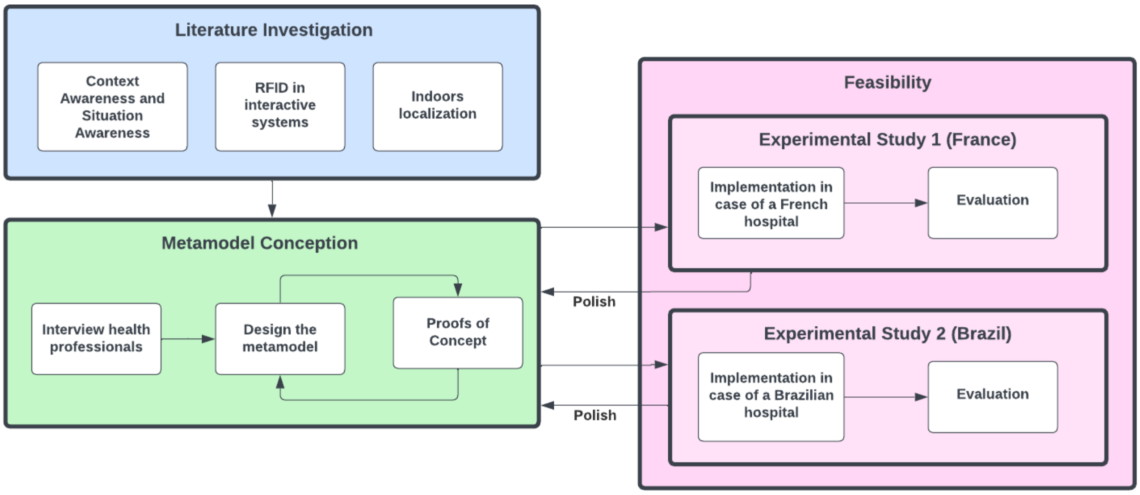

Figure 1.1 – Research Methodology

In the **Literature Investigation** (Chapter 3), literature reviews were performed as follows:

- **Overview of context awareness and situation awareness**: A traditional literature review was conducted to understand better the various interpretations of context awareness and its related concepts, looking for general purpose and conceptual studies. To better understand situation awareness beyond its classical definition (Endsley, 1988a), a traditional literature review sought studies discussing definitions, applications, and presenting models or methodologies. The findings of this overview are listed in Chapter 2.
- **Investigate RFID in interactive systems**: RFID was initially chosen as the primary technology in our proposed applications due to its favorable characteristics promoting context-aware software systems development. This decision led to systematic literature mapping. This investigation showed that other options should be adopted instead of RFID depending on the requirements of the target system. It allowed a deep understanding of the overall usage of radio technologies in interactive systems.

- **Investigate indoor localization:** One of the objectives of the software systems built from the metamodel is to locate medical equipment within the indoor areas of health centers, so it is necessary to research strategies and technologies for this purpose. The investigation of RFID suggested that several options could be adopted besides radio technologies, which led to another literature review focused on secondary studies.

The **Metamodel Conception** (Chapter 4) comprises an iterative cycle in which the metamodel constantly evolves with new concepts based on the knowledge obtained from the literature investigation. Given that the literature investigation does not address the medical context, at some point, interviews were performed with health professionals to evolve the metamodel with information about this subject. Therefore, this chapter presents these two main issues as follows:

- **Interview health professionals**: Semi-structured interviews were conducted with health professionals to understand better how medical equipment is used and managed in health centers, thereby complementing the literature investigation with specific information about the medical context.
- **Design and evaluation of the metamodel**: The metamodel gradually evolved through new conceptual research. The iterative cycle resulted in three representations. Two of these, containing many modeled fundamental concepts, were tested through **proofs of concept**.

When a particular representation of the metamodel was considered robust enough; we applied it in software development and experimental studies to verify its **Feasibility** (Chapters 5 and 6). The metamodel's purpose is to serve as a basis for building IoT software systems for managing the location and use of medical equipment in health centers, so the studies should evidence it. We established a **Tailoring Methodology** to instantiate the metamodel based on requirements and create applications based on technology choices. The experimental studies are briefly described as follows:

- **First experimental study**: A robust representation of the metamodel, representing every fundamental concept, was instantiated through the **tailoring methodology** and used to create an application simulating a part of a French hospital. The application was applied in an experimental study to analyze the metamodel's completeness and feasibility.

- **Second experimental study**: Another experimental study was performed to allow further evaluation of the metamodel after the first one. The metamodel was polished, instantiated through the **tailoring methodology**, and used to create an application simulating a part of a Brazilian hospital. In the second experimental study, it was possible to develop a consolidated metamodel, instantiating it and making an IoT software system for managing the location and use of medical equipment in a simple simulated hospital. The application effectively used the metamodel without requiring further modifications to its structure.

This research offers an innovative approach to managing medical equipment in health centers by developing a metamodel for building IoT applications. As an academic contribution, the study presents the evolution of the metamodel, detailing all its stages and explaining the decisions that led to its evolution until it reached a consolidated representation. The research also contributes by applying the concepts of context awareness and situation awareness in a critical scenario. Since the proposed metamodel is generic and deals with object management, it opens up possibilities for further research in areas beyond the medical context, such as factory supply tracking.

From an industry perspective, the research presents a practical solution that can optimize the efficiency of medical centers by facilitating equipment management and making the environment smarter without adding to the workload of health professionals. By enabling real-time tracking and status monitoring, the proposed metamodel has the potential to reduce workload, prevent equipment shortages during emergencies, and improve patient outcomes. Additionally, the metamodel facilitates and guides the development of applications, aiming to make the development process faster. It also intends to create low-cost applications, making management systems more accessible to small health centers. An annex provides bibliographic contributions obtained throughout this research (*Annex A – Bibliographic Production*).

## 1.5 Thesis Outline

The thesis is organized into six chapters.

- **This Chapter** presented the context, motivation, problem, and research question. Then, it described the methodology and summarized the bibliographic production.
- **Chapter 2** presents the background of the research's fundamental concepts: IoT, context awareness, situation awareness, metamodels, and software systems in health centers. Amidst the concepts, it also presents related works.

- **Chapter 3** presents the systematic literature mapping of RFID in interactive systems and the literature review about indoor localization.
- **Chapter 4** presents the whole metamodel conception, which was created and evolved from the fundamental concepts until reaching a robust representation. It also describes the interviews with medical professionals.
- **Chapter 5** presents the first experimental study to determine the feasibility of applying the proposed metamodel to developing IoT software systems for managing the location and use of medical equipment in health centers.
- **Chapter 6** presents the second experimental study, which builds upon the first study's results to determine the feasibility of applying the metamodel to developing IoT software systems.
- **Chapter 7** presents final considerations and contributions, lists limitations, and describes future works.

# 2 Background and Related Works

This chapter presents fundamental concepts of the research: Internet of Things (IoT), context awareness, situation awareness, metamodels, and software systems in health centers. It also presents related works addressing these concepts.

## 2.1 Background

This section provides an overview of the fundamental concepts and technologies. It introduces the Internet of Things (IoT), it explores context awareness, situation awareness, and metamodeling, which form the theoretical foundation of this research.

### 2.1.1 Internet of Things

The **Internet of Things (IoT)** is a paradigm that holds immense significance in software systems. It is based on the pervasive presence of identifiable objects (*things*) that can interact and cooperate to reach common goals. In IoT software systems, data can be identified, sensed, collected, communicated, and interpreted to deliver value. (Atzori et al., 2010). ***Things*** in IoT may be equipped with identification, sensors, actuators, and communication capabilities (Nazari Shirehjini & Semsar, 2017). Ashton (Ashton, 2009) unintentionally coined the term IoT in 1999 while presenting a solution that used sensors and RFID tags to identify products in supply chain processes. IoT enables data to be interchanged between *things*, and by employing actuators, the *things* can be enhanced to interact with the natural world. (Giusto et al., 2010).

**Interactions** in IoT can be split into two categories: *human-thing* interaction (HTI) and *thing-thing* interaction (TTI). HTI refers to the interaction between humans and *things*, and TTI refers to the interaction among *things* (Andrade et al., 2017). For both categories, the interaction may be implicit or explicit. **Explicit interactions** refer to traditional interactions in software systems, such as pressing buttons on a user interface. **Implicit interactions** refer to the implicit collection of inputs, such as interpreting gestures and actions or collecting data from sensors. (Poslad, 2009). IoT is crucial in enabling and enhancing these interaction types, showcasing its potential and versatility.

The **architecture** of IoT applications is usually presented in layers (Buyya & Dastjerdi, 2016; Wu et al., 2010). Their number and meanings vary with each author, but the involved concepts are often the same. This layered architecture provides a systematic and structured approach to IoT application design and development. Considering the classification by Wu et al. (2010), reproduced in Figure 2.1, the **Perception Layer** is the most basic level of IoT applications, encompassing physical devices, such as sensors, that can perceive the properties of *things*. The **Transport Layer** is the next level, transmitting the collected data. The **Processing Layer** is the next level, responsible for storing, analyzing, and processing the received information. The **Application Layer** is the next level, which utilizes the processed data to create applications that provide services to users. An additional level, the **Business Layer**, acts as a manager of various integrated IoT applications capable of forming a business model.

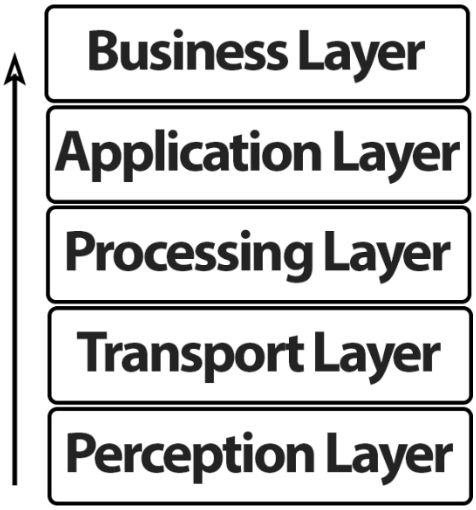

Figure 2.1 – IoT layers according to Wu et al. (2010)

The **Perception Layer**, a crucial component of IoT, comprises devices capable of collecting data from *things* in the environment. Sensors and cameras can perceive the parameters of users, objects, and the environment. These devices must implement some network protocol infrastructure to communicate the perceived data. This underscores the importance of data collection and its impact on the system's functionality.

**Protocols** that enable this communication play a crucial role in the IoT landscape. These include Wi-Fi, Bluetooth Low Energy (BLE), and LoRa (Farahsari et al., 2022; Hayward et al., 2022). Wi-Fi is a standard option, as most locations already have Wi-Fi networks, and it is available on various devices, such as smartphones. The IoT software system will also be unstable in places with unstable Wi-Fi connections. Another standard option is BLE, which operates on the same frequency as Wi-Fi and is also present in many devices. Its disadvantage compared to Wi-Fi is the need for pairing and the inability to pair with many devices simultaneously. LoRa is a protocol that allows communication of small amounts of data over kilometers. The choice of communication protocols will depend on specifications, highlighting the technical complexity and the need for expertise in the field.

However, network protocols only provide a means for data to be communicated; they are not responsible for the communication itself. In the **Transport Layer**, the data goes through messaging protocols such as MQTT, CoAP, AMQP, and HTTP, among others (Wytrębowicz et al., 2021). MQTT and CoAP are messaging protocols for constrained devices, such as microprocessors. AMQP has more advanced features and is heavier. HTTP is a standard web protocol that can also be used in IoT. Messaging protocols can move data from the devices to the **Processing Layer**. In other words, for a device to be considered IoT, it needs to be accessible on a network and implement a way to send perceived data onward.

MQTT natively uses a publish-subscribe communication model, which implements a central broker that receives messages on topics and distributes them to devices subscribed to those topics. It has quality of service (QoS) ranging from 0 to 2, where zero does not guarantee delivery, one guarantees delivery but may duplicate messages, and two ensures unique data delivery. The higher the level, the greater the network overhead. CoAP is a client-server protocol but can also be used as a publish-subscribe. AMQP provides this and other communication models.

### 2.1.2 Context Awareness

One of the earliest definitions of **context awareness** (Schilit & Theimer, 1994) refers to the application's ability to discover and react to changes in the environment where they are situated, which involves monitoring information about the surroundings. Another early study (Brown et al., 1997) states that context-aware applications change their behavior according to the user's context and provide information based on location, time, season of the year, and temperature, among others.

**Context** is any information that can be used to characterize the situation of an entity. **Context-aware** systems use context to provide relevant data and services to the user, where relevancy depends on the user's task. Context awareness comprises three essential behaviors: the presentation of information and services to a user, the automatic execution of a service, and the tagging of context to information for later retrieval (Abowd et al., 1999). The context (Figure 2.2) is split into three entities: the **system's users**, the **physical environment** where interactions with the system can occur, and the **computational platform** composed of hardware and software (Calvary et al., 2003).

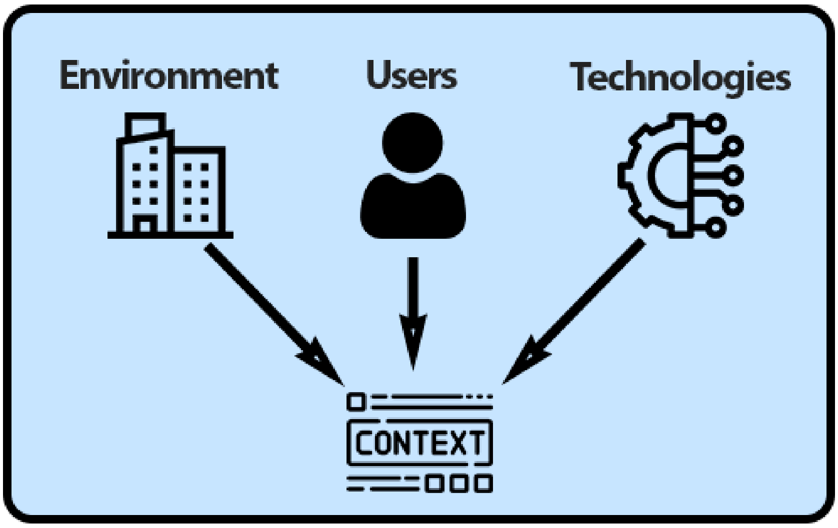

Figure 2.2 – The context, split into environment, users, and technologies

**Location-aware** systems (Harle & Hopper, 2008) use location information to enable computers to interact and react to their environment. They also show mobile users' location to provide quick and necessary communication (Lee et al., 2006). **User-aware** systems (Veselic et al., 2021) enable the system to recognize users' intentions and help them in their planned movement. User-aware technologies adapt to the user without receiving explicit commands (Mortensen, 2009).

Within the **environment** (Calvary et al., 2003), information can be interpreted and classified as answers to what, where, when, how, who, and why (Poslad, 2009). Such as temperature and light intensity (what); a location, destination, or route (where); the absolute or relative time of an event (when); how the context is created over a computational infrastructure (how); the users in terms of their personal preferences, activities, and relationship with other users (who); and the purpose of implementing such context (why). The **user** refers to humans interacting with the system regarding their traits and action capabilities. Users have a social link with other users (Kubicki et al., 2013; Poslad, 2009). The social environment is a human factor, representing social interaction and group dynamics. Just the presence of a particular person may affect how another person behaves (Tesoriero & Vanderdonckt, 2010).

IoT enables the development of context-aware software systems. Sensor devices are deployed in an environment where objects and users interact. The IoT software system can perceive user actions to understand *things'* usage. In the context of IoT software systems for managing the location and use of medical equipment, which is the focus of the research, data about how the equipment is used within the environment should be collected. Several types of management can be implemented from these data, such as cleaning and maintenance status.

### 2.1.3 Situation Awareness

**Situation awareness** is defined as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status shortly (Endsley, 1988a). It is considered a particular kind of context-awareness, where situations are viewed as logically aggregated pieces of context (Anagnostopoulos et al., 2007). Situation-aware systems (Figure 2.3) **perceive** what is happening, **understand** the situation, **predict** the impact, and **decide** whether to interfere and **act** by preventing something, anticipating it, or providing information beforehand. A **situation** is a finite sequence of actions that have occurred, which might change over time, describing human behaviors, applications, and environmental states (Anagnostopoulos et al., 2007). In other words, a situation-aware system perceives what is happening in the environment over time, and by analyzing perceptions in a time interval, it is possible to comprehend a situation.

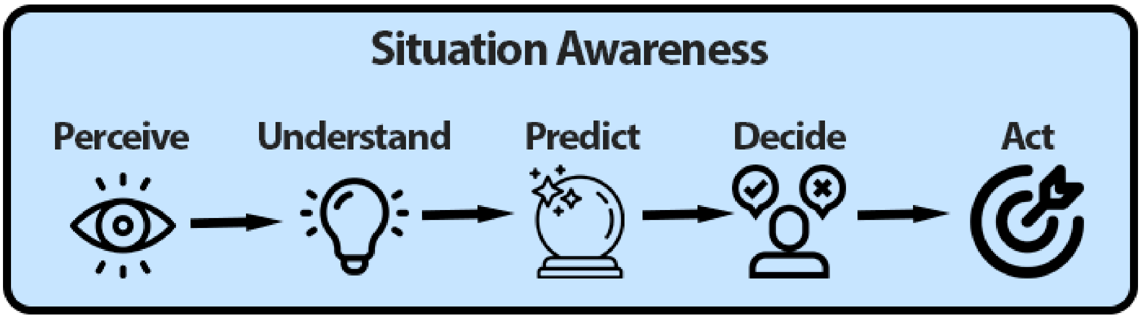

Figure 2.3 – Steps in situation-aware systems, as defined by Endsley (1988)

The **perception** in situation awareness encompasses collecting information about the relevant entities so that a situation can be subsequently understood. It comprehends time and space, i.e., gathering information about the context in two different moments may refer to two different situations. The **time** can be split into four dimensions (Cimino et al., 2012): bounds, position, proximity, and inclusion. The bounds refer to duration, with starting and ending moments. The position places perceptions and actions in order, such as before or after. Proximity refers to being close or far. The inclusion indicates interception of time intervals. **Activity recognition** is a temporal classification problem where activities are predicted depending on previous and future states (Vail et al., 2007).

It refers to knowing the current activity of users. Several studies in the medical context apply this approach.

IoT enables the development of situation-aware software systems. Both the layered IoT architecture and situation awareness begin their processes with perceptions. IoT applications perceive the context through data collected from sensors, which are communicated and processed. The constant data collection over time enables the IoT software system to understand what is happening in the context. In other words, it is possible to integrate the dynamics of situation awareness into IoT software systems so that the comprehension of sensor data can be used to predict potential impacts and decide whether actions should be taken or services should be provided. In the context of IoT software systems for managing the location and use of medical equipment, which is the focus of the research, the collected data will result in future predictions, such as determining which patients will need which medical equipment.

### 2.1.4 Metamodels

Metamodels define a high-level abstraction to be followed by other models. They define entities, properties, and associations represented with tools such as MOF (Meta-Object Facility) (De Farias et al., 2007; Saripalle, 2016) and UML (Unified Modeling Language) (Gruschko et al., 2007; Hebig et al., 2017; Motti & Vanderdonckt, 2013). By instantiating a metamodel, other models are created for specific software systems. Metamodels are intended to be instantiated in various contexts; hence, they must be flexible. They should provide options for choices, allow multiple levels of detail, implement reusable components, and permit their structure to be extended or reduced as necessary (Ceret et al., 2013).

## 2.2 Related Works

Several technologies and methodologies are used in the development and deployment of IoT software systems. This section reviews contributions from the literature, focusing on protocols, identification technologies, situation awareness, activity recognition, and metamodels.

### 2.2.1 Protocols for IoT Communication

Messaging protocols enable data transmission in IoT systems, and studies have evaluated their suitability for different contexts. A comparative analysis of MQTT and CoAP concluded that MQTT is better suited for critical tasks due to its reliability, while CoAP is ideal for resource-constrained scenarios (Thantharate et al., 2019). Another study compared MQTT, CoAP, HTTP, and XMPP regarding complexity, energy consumption, and performance. It found MQTT to have the best energy efficiency, CoAP to enable faster communication, and HTTP to be less suitable for IoT applications due to its high energy consumption and limited options (Nikolov, 2020).

Applications illustrate the practical use of these protocols. MQTT was employed in an IoT application to control temperature and aid fire prevention via Wi-Fi (Kang et al., 2017). Another study explored MQTT's latencies across different QoS levels and broker configurations, showing its efficiency for data transmission (G. Wang, 2021). In a medical context, CoAP was used to monitor neonatal incubators, collecting critical data such as temperature and heart rate (Nachabe et al., 2015). Efforts to enhance CoAP for IoMT applications have focused on reducing latency and data loss, making it more reliable (Sreekumar et al., 2023).

### 2.2.2 Identification Technologies

*Things* in IoT must be uniquely identifiable so that applications can receive data through messaging protocols and appropriately know which thing has been published. Examples of technologies that provide unique identification include RFID and NFC through EPC codes or UID, respectively (Brock, 2001), 6LoWPAN through IPv6 (Bkheet & Agbinya, 2021), BLE through UUID (Hoddie & Prader, 2020), and QR Code or barcode through line-of-sight visualization (Bkheet & Agbinya, 2021; Karia et al., 2019).

Suppose an IoT software system does not adopt these technologies. In that case, there will often be a way to uniquely identify devices, at least within the network, such as MAC addresses, IP addresses, or hostnames. In a study that uses NFC in smartphones, a mobile application reads tagged drugs to verify if patients are allergic. The smartphone is a reader capable of understanding the unique identifier in the tag (Alabdulhafith et al., 2013). Intelligent shopping follows a similar strategy to RFID, using an application to read tagged products on shelves (Chen et al., 2014). RFID is also used in airports to identify and track the position of passengers (Luis et al., 2018). BLE is used in museums to support visitors’ smartphones in identifying the devices and discovering their positions (Spachos & Plataniotis, 2020).

### 2.2.3 Situation Awareness Assessment

Situation awareness (SA) plays a critical role in high-risk environments, enabling systems to perceive, understand, and predict events in dynamic contexts. The **Situation Awareness Global Assessment Technique (SAGAT)** (Endsley, 1988b) is a tool for assessing user’s situational awareness in high-risk contexts. With it, users are interrupted to answer questions that measure their awareness about what is happening in the environment. This method is applied in a variety of risky situations. In a maritime context (Nisizaki, 2019), SAGAT was used to measure the situational awareness of navigators both in simulators and on board. Navigators were interrupted and asked critical questions, such as assessing collision risks. In submarine monitoring (Loft et al., 2015), SAGAT was used to question operators at random moments about emergency tasks while controllers and displays were disabled. In the medical context, for anesthetic nursing (Dishman et al., 2020), SAGAT was adapted to be used in simulations where participants were questioned at predetermined moments about events related to the induction of general anesthesia. It was also applied to evaluate the situational awareness of blind individuals in indoor environments (Alkhanifer & Ludi, 2015). This study paused user activities at predetermined moments to question participants' perceptions and understanding of the environment.

Situation-aware applications profit from the recognition of activities. For instance, sensors are used to detect the different actions in an operating room and their order to detect the specific phase of a particular type of surgery. Actions can co-occur, and several users in collaboration can execute each (Bardram et al., 2011). RFID is used to predict the occurrence of trauma resuscitations using tagged objects related to this specific activity (Y. Gu et al., 2017; Li et al., 2016). RFID is used to predict the occurrence of trauma resuscitations using tagged objects related to this specific activity (Y. Gu et al., 2017; Li et al., 2016).

### 2.2.4 Metamodels in IoT and Context-Aware Systems

Metamodels provide a high-level abstraction for defining software systems, and their use in IoT has been explored in several studies. An IoT metamodel is proposed to unify different patterns and architectures while modeling continuous integration and delivery (El Khalyly et al., 2020). A metamodel is provided to support simulating IoT environments without writing code (Barriga et al., 2021). Another concentrates on developing ESP microcontrollers (Karaduman & Challenger, 2021). A study contributes by proposing a modeling on the monitoring of IoT systems, encompassing all IoT layers and defining a domain-specific language (Erazo-Garzon et al., 2022). An interoperability metamodel is also proposed, focused on IoT devices (Amjad et al., 2022).

Studies also address the conception of metamodels for context-aware systems. A metamodel is proposed describing an ontology to integrate different levels of context abstraction in software, promoting the reuse of context information (Erfani et al., 2014). A metamodel is also proposed to encourage context-aware mobile applications' reuse, adaptability, and interoperability (Lajili et al., 2009). An extension of UML is proposed through a metamodel for developing applications in ubiquitous computing environments (Benselim & Seridi-Bouchelaghem, 2017). However, to our knowledge, studies have yet to focus on metamodels for creating IoT software systems for managing the location and use of medical supplies, emphasizing context and situation modeling.

### 2.2.5 Software Systems in Health Centers

According to the **World Health Organization (WHO)**, **health centers** are the entry point into the health system, providing person-centered, comprehensive, and integrated care with continuity across the life course. They ensure preventive and curative care for a defined population. These facilities provide healthcare to patients across hospitals, specialized services, and community organizations (Lerberghe et al., 2008).

Software systems are extensively developed for health centers, especially considering patient care; however, not all health centers have the resources to acquire them. WHO points out that health systems rely heavily on out-of-pocket payments, contributing to significant inequities in care access and leading to catastrophic health expenditures. The literature describes applications for monitoring patients, treating specific conditions, improving the use of particular equipment, and managing medical equipment. Commercially, Computerized Maintenance Management Systems (CMMS) provide maintenance assistance, while Real-Time Location Systems (RTLS) track assets in real-time.

In general, software systems described in the technical literature are intended to aid patient care. An application was developed to help patients with cervical cancer (Song et al., 2024). Another application monitored patients with diabetes (Souza et al., 2015). Mobile applications for assisting reproductive health were evaluated in terms of quality (Moumane et al., 2024). For home care, an application was developed for managing all family members' medical documents, appointments, and medication reminders (M. Wang et al., 2023). As previously mentioned, an IoT software system was developed to monitor premature babies (Nachabe et al., 2015).

Employing NFC-enabled smartphones, nurses may read both a tagged drug and a tagged patient to check if the patient is allergic to the drug (Alabdulhafith et al., 2013). NFC was also used by the visually impaired to read tags stuck in several rooms on a floor as part of an accessibility solution to assist in navigation in unfamiliar buildings (Ivanov, 2010). IoT and context awareness are integrated to propose an architecture connecting biometric sensors (Michalakis & Caridakis, 2017). A similar study developed an IoT application that collects and interprets patient biometric sensor data (Kumar & Rajasekaran, 2016). IoT applications collecting and processing patient parameters are typical in the literature (Merrad et al., 2020; Rahman et al., 2021; Rajesh, 2013; Vecchia et al., 2012; Yadav et al., 2017).

Studies focused on medical equipment development are rare. As ventilators became scarce during the COVID-19 pandemic, researchers developed an IoT ventilator that can be 3D printed (Koch et al., 2023). An application manages equipment using temperature and humidity sensors and tracks their location with Wi-Fi (Yao et al., 2018). A comprehensive study described the use of DevOps to manage the development and maintenance of software focused on devices (Martina et al., 2024). One study proposes developing a medical equipment management system that handles inventory, failure reporting, calibrations, and maintenance scheduling, among other tasks (Akar et al., 2019). The closest study to this research proposal develops a medical equipment management software system that locates equipment using RFID technology and indicates whether they are in the warehouse. It also manages preventive maintenance based on user inputs (Z. Zhou, 2022). This research proposal is different because the previously presented study describes a single application, not a metamodel for developing multiple applications. Also, their maintenance management relies on explicit inputs in the software system, like a CMMS.

Some commercial software offers functionalities resembling the proposal. CMMS is designed to assist in maintenance management. They optimize the organization's maintenance procedures and schedule preventive maintenance. RTLS tracks assets and people using radio-frequency technologies such as Wi-Fi and RFID, provides services like patient monitoring and generates alerts based on movements. RTLS are context-aware, as they understand how monitored assets and people interact within the environment. They are situation-aware, as they can generate alerts and predict maintenance needs. Examples of CMMS are Dimo Maint[4] and eMaint[5].

AeroScout[6] is an RTLS that uses Wi-Fi to locate medical equipment, staff, and patients throughout a hospital environment and collect environmental parameters such as temperature. Location and sensor data are presented on a dashboard with a map of the whole facility. CenTrak[7] is an RTLS that uses a mix of RFID, Wi-Fi, and BLE. It provides a dashboard displaying statuses for equipment based on inputs from professionals. Teletracking[8] is another RTLS solution for tracking equipment, patients, and staff. It offers patient visualization on a map and a centralized view of equipment location. Numerous CMMS and RTLS systems are available on the market in addition to those mentioned. CMMS solutions typically charge monthly per user, while RTLS installations can range from $1,000 to $50,000 (Sullivan et al., 2023). Small health centers and field hospitals often need help to afford those costs.

## 2.3 Conclusion

The research proposes developing a generic and specialized metamodel to support the creation of IoT software systems for managing the location and use of medical equipment in health centers. The metamodel can be instantiated from specific requirements and then serve as a foundation for creating various applications for different health centers. This proposal is based on the capability of IoT software systems to be context-aware and situation-aware.

Context-aware systems encompass the interaction between users and technologies in an environment, which helps the system manage the location and use of medical equipment. Situation-aware systems use historical data perceived over time to comprehend actions, recognize activities, and predict the future. A system with these capabilities enables objects to communicate with each other so that health professionals are provided services to improve their workflows.

This chapter presented the theoretical background and related works. The topics covered were IoT, situation awareness, context awareness, metamodels, and software systems in health centers, essential concepts for understanding the proposal.

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[4] https://www.dimomaint.com/

[5] https://www.emaint.com/

[6] https://www.securitashealthcare.com/aeroscout-rtls

[7] https://centrak.com/

[8] https://www.teletracking.com/resources/real-time-locating-system-rtls-data-sheet/

# 3 Investigating Location Technologies: A Systematic Mapping on RFID and a Literature Review on Indoors Localization

Preliminary research on location technologies used in IoT spotted **Radio Frequency Identification (RFID)** as a feasible, cost-effective, and low-energy option for identifying and locating objects in indoor environments. This finding led to a **systematic literature mapping**, published in ACM on Human-Computer Interaction Journal (V. C. Maia, de Oliveira, Kolski, et al., 2023), which analyzed software projects adopting RFID in interactive systems. Subsequently, another literature review addressed other ways of locating indoors and using radio-frequency technologies. This chapter presents the planning, execution, and analysis for a systematic mapping of RFID, followed by the results of the literature review about indoor localization.

## 3.1 Why RFID technology?

***Locating*** in the context of this research refers to *understanding where a target is within a restricted area with a small margin of error*. To enable this functionality, it is necessary to adopt a technology that allows:

- the **identification** of medical equipment,
- the estimation of a **location**, and
- the **communication** of location data to a middleware through a network protocol.

A brief literature review was conducted to find and compare technologies capable of performing these functionalities. The goal was to identify an option that could be adopted as the primary technology in any IoT software system developed from the metamodel.

The following options were spotted: the **passive ultra-high frequency RFID** was considered a location technology because it can find tags around 5m from a reader. It works well indoors, is low-cost, and does not demand power (Anandhi et al., 2019; Lemey et al., 2017). **GPS** is reliable and accurate for outdoor applications, while **RTK-GPS** can provide more precise positioning to GPS (Oguntala et al., 2018; Um et al., 2019). **Ultra-wideband (UWB)** may be used to track the position of objects indoors in real-time. Stations can detect nearby tagged objects and calculate their distance, ranging around 20 meters (Y. Zhou et al., 2012). **Bluetooth Low Energy (BLE)** is present in smartphones; it is discoverable and can be located up to 30 meters, considering obstacles (Jeon et al., 2018). **Wi-Fi** can also be used for locating indoors, based on the signal strength of connected devices, just like UWB and BLE (Sharp & Yu, 2019).

The chosen technology needs to function well in indoor areas for adoption in health centers, so GPS was discarded. Wi-Fi, BLE, and UWB require devices attached to objects to enable location tracking. In contrast, RFID only requires a tag, which is small, nearly invisible, and does not depend on a battery, thus promoting the implementation of more ubiquitous systems. The tags are inexpensive, often costing just a few cents, another advantage over the other radio technologies. RFID allows tags to be identified via a unique code and can determine location through signal strength, similar to other radio frequency technologies. The only disadvantage identified is that it cannot communicate data directly to middleware—the readers must be connected to devices with Wi-Fi or BLE. However, the benefits offered by RFID tags outweigh this issue, as the tags communicate directly with the readers.

Table 3.1 summarizes these characteristics and compares the technologies. The potential of **RFID** as a primary technology in metamodeling was initially considered because it covered various IoT requirements. This discovery instilled a sense of optimism and led to a **systematic literature mapping** on RFID in interactive systems to delve deeply into the subject.

Table 3.1 – Location technologies and their features

| Feature | RFID | GPS | RTK | UWB | BLE | Wi-Fi |
|---|---|---|---|---|---|---|
| Indoors Localization | ▨ | | | ▨ | ▨ | ▨ |
| Outdoors Localization | | ▨ | ▨ | | | |
| Unique Identification | ▨ | | | | | |
| Non-Unique Identification | | | | ▨ | ▨ | ▨ |
| Ranging around 5m | ▨ | | | | | |
| Ranging around 20m | | | | ▨ | ▨ | ▨ |
| Satellite | | ▨ | ▨ | | | |
| Present in smartphones | | ▨ | | | ▨ | ▨ |
| Inexpensive | ▨ | ▨ | | | ▨ | |
| Without battery | ▨ | | | | | |
| Low energy | ▨ | | | ▨ | ▨ | |
| External data communication | | | | | ▨ | ▨ |

The characteristics of RFID contribute to the composition of **implicit interactions** in such systems, mainly the passive ultra-high frequency (UHF), with tags that can be automatically read from around five meters. Tagged targets do not need to be near the reader. On the other hand, low-frequency (LF) and high-frequency (HF) RFID demands the approximation of a tag to a reader, consequently implementing explicit interactions in most cases.

Calculating proximity through UHF and approximation through LF/HF motivated RFID implementation in interactive software systems for identifying and tracking. The practical applications of RFID technology are inspiring. For example, it is applied in a system for safety management in industrial working sites with cargo cranes, in which tags are placed inside workers' helmets, and readers are installed inside the cranes. Distances are estimated to prevent workers from entering dangerous zones (K. Kim & Kim, 2012). A study describes a solution for monitoring tagged elders at home. RFID readers spread through the house to detect where the elder is and how long the elder is not moving, so a monitoring system may send emergency alerts (S.-C. Kim et al., 2013). Another study describes an innovative shopping application in which RFID tags are placed on each product on shelves. The customers walk through the store with an intelligent shopping assistant equipped with an RFID reader. The products are bought by approximating the reader to the desired product's tag (Chen et al., 2014). In a retail shop, a system monitors tags given to customers as soon as they arrive so algorithms can analyze their shopping behavior (S. H. Choi et al., 2015).

Some reviews of RFID in specific contexts can be found in the literature. One study reviewed the literature to explore RFID and Near-Field Communication (NFC) in Ambient Assisted Living. Among the most common application types were indoor position tracking and medical-related systems (De la Torre Díez et al., 2018). A review discussed Surface Acoustic Wave (SAW) tags: design approaches, utilization strategies, and characteristics (Plessky & Reindl, 2010). RFID and its characteristics are explored in smart agriculture (Rayhana et al., 2021). Using RFID and sensors, research tackles biomonitoring systems in green spaces to monitor trees and others (Luvisi et al., 2016). A review focuses on RFID on wireless sensors for IoT devices, from their architecture to application in various domains (Jamshed et al., 2022).

The systematic mapping follows a comprehensive process (Biolchini et al., 2007) composed of four phases: planning, execution, analysis, and packaging. The planning phase defines the research goal, the research questions, the search string, the inclusion and exclusion criteria, the selection procedure, the extraction form, and the quality assessment criteria. The execution phase executes the search string in the selected search engine to obtain a preliminary set of papers, followed by the selection procedure, reading of articles, extraction of information to the extraction form, and application of the quality assessment process. The analysis phase assembles and interprets the contents of the extractions to answer the research questions. The packaging phase manages the process's documentation, decisions, and history of changes. This comprehensive process reassures the audience about the thoroughness of the research. We will refer to actors (Motta et al., 2018) as those relevant to interaction with the system regardless of whether they are human.

## 3.2 Systematic Mapping: Planning and Execution

The research goal for the systematic mapping follows the Goal-Question-Metric (GQM) structure (Basili et al., 1994). The protocol, which comprises the goal, research questions, search string, strategy, and inclusion and exclusion criteria, is provided in Table 3.2 (V. C. Maia, de Oliveira, Kolski, et al., 2023).

An **extraction form** was elaborated with one field for each question, to be filled by each paper during the execution phase (*Annex B – Systematic Mapping Extraction Form*). The search string was elaborated following the PICOC (Population – Intervention – Comparison – Outcome – Context) structure (Petticrew & Roberts, 2006). The search string was executed in Scopus, a comprehensive abstract and citation database that indexes materials from journals and conferences, a standard in computer science. This research aims to characterize the use of RFID technology across various application domains. For this reason, we did not use databases specific to any particular domain, such as the medical or industrial fields.

The execution of the search string was followed by snowballing, a systematic literature review method that permits the selection of additional papers through a reference list of works or citations (Wohlin, 2014). It may be forward or backward. Backward snowballing refers to selecting new documents from the reference list in the paper. Forward snowballing refers to selecting recent articles that cited the paper. This combination of searches allows adequate coverage for secondary studies (Mourão et al., 2020; Wohlin et al., 2022).

After full reading, each paper receives a **quality assessment** score based on its content, which represents the accordance of the paper given the research goal (Y. Zhou et al., 2015). The criteria should be evaluated with a three-level Likert scale, meaning Totally/Yes (2), Partially (1), or No (0). The sum of each criterion's score is the paper's quality score. The first quartile (25%) is calculated for a dataset containing every paper's quality score, and the document with a score below it is excluded (EXC4). The search string was first executed in Scopus in July 2021 and then again in February 2023 for updates. In the first execution, the whole procedure described in the protocol in Table 3.2

was applied. Scopus returns papers with any search string terms in the title, abstract, or keywords that may result in documents out of scope. Therefore, the initial results include several papers unrelated to the topic. In addition, several results relate to conference proceedings, not papers.

Table 3.2 – Protocol Summary

| | | |
|---|---|---|
| Goal (GQM) | | **Analyze** RFID technology<br>**With the purpose of** characterizing<br>**With respect to** its usage issues, such as application domains, the reason for adoption, interaction, restrictions, and quality features<br>**From the point of view of** software developers and designers<br>**In the context of** interactive software systems using RFID technology described in the technical literature |
| Research Questions | | **RQ1** – Which **application domains** are addressed by RFID technology?<br>**RQ2** – **Why** is RFID technology used in interactive software systems?<br>**RQ3** – **Who** interacts through RFID technology, and **how** does the interaction occur?<br>**RQ4** – What are the **restrictions** related to RFID technology?<br>**RQ5** – What **quality characteristics** and measures are related to RFID technology? |
| Search String | Population | (“contemporary software systems” OR “ambient intelligence” OR “internet of things” OR “iot” OR “smart*” OR “Industry 4” OR “fourth industrial revolution” OR “context-awareness systems” OR “pervasive systems” OR “ubiquitous systems” OR “cyber physical systems” OR “micro-electro-mechanical systems” OR “machine-to-machine interaction” OR “internet of computer” OR “internet of object*” OR “network of things” OR “social IoT” OR “Internet of people” OR “internet of everything” OR “human-computer interaction*” OR “web of things” OR “automotive system” OR “tangible” OR “assisted living” OR “multiagent systems” OR “systems of systems” OR “autonomous systems” OR “autonomic computing” OR “multi-agent systems” OR “pervasive computing” OR “mobile computing” OR “distributed systems” OR “cooperative robotics” OR “adaptive systems” OR “smart manufacturing” OR “digitalization” OR “digitization” OR “digital transformation” OR “smart cit*” OR “smart building” OR “smart health” OR “smart environment”) |
| | Intervention | (“RFID” OR “radio-frequency identification” OR “radio frequency identification” OR “tabletop*”) |
| | Comparison | *(not used since there is no other study like ours)* |
| | Outcome | (“quality features” OR “quality characteristic” OR “quality measure” OR “metrics” OR “conditions” OR “prerequisite”) |
| | Context | (“campus” OR “home” OR “hospital” OR “city” OR “building” OR “health” OR “mobility” OR “environment” OR “parking” OR “kitchen” OR “education” OR “school” OR “classroom” OR “real-time” OR “interactive” OR “industry” OR “industrial setting”) |
| Search Strategy | | SCOPUS + Backward and Forward Snowballing + Updates |
| Inclusion Criteria | | **INC1** – The paper must discuss interactive software systems that use implicit and explicit user interactions, such as software for IoT systems, ubiquitous systems, Industry 4.0, and others.<br>**INC2** – The paper must address the use of RFID technology in a project.<br>**INC3** – The paper must be in English.<br>**INC4** – The paper must be available for download. |
| Exclusion Criteria | | **EXC1** – The paper focuses on the circuits and electronics of tags or readers.<br>**EXC2** – The paper only reviews the literature on an RFID-related topic.<br>**EXC3** – The paper does not use RFID technology in the solution.<br>**EXC4** – The paper's quality score is below the first quartile.<br>**EXC5** – Only for Snowballing: The paper’s content resembles the article from which it was retrieved. |
| Quality Assessment | Reporting | - Is the interactive software system well described?<br>- Is there a clear statement (definition) of the project's aims (goals, purposes, problems, motivations, objectives, questions)?<br>- Is there an adequate description of the context in which the project was carried out?<br>- Do the authors address quality characteristics? |
| | Rigor | - Are the metrics (methods, design, measures) used in the project clearly (fully) defined (description)?<br>- Are the variables/metrics/methods/design used in the project adequately measured and validated (justified)?<br>- Was the data analysis (collected) sufficiently rigorous?<br>- Are the data collection methods adequately described (defined)? |
| | Credibility | - Is there a clear statement of findings (data) relating to the project's aims?<br>- Do the authors discuss any problems (limitations, threats) with their results' validity (reliability)?<br>- Is RFID technology available?<br>- Is the project replicable?<br>- Do references and observations confirm the claims? |
| | Relevance | - Are conclusions, implications for practice, and future research suitable for its audience?<br>- Has the approach been validated on a particular scale (either in academia or/and industry)?<br>- Does the paper correctly answer the research questions? |

A title analysis allowed for reducing noise by verifying if a paper could be in the scope of this research, i.e., if it discussed the use of RFID in interactive systems. In our case, a preliminary title analysis removed 214 papers. Most of the remaining papers described studies taking place in expected domains. However, they did not describe an implemented project, and RFID did not seem to be an essential part of the study, so an abstract analysis removed an additional 159 papers. Among the remaining, fourteen papers were unavailable, and all were in English.

Full-text reading was performed with 85 papers. By applying the exclusion criteria and scoring documents with the quality assessment, an additional 32 papers were removed, resulting in 53 papers. This procedure followed backward and forwarded snowballing. Twenty-two papers were added, seven were removed by abstract analysis, two by unavailability, and seven by full-text reading, resulting in 59 papers. During full reading, nine papers were excluded because their focus was on the electronics of tags (EXC1); eight papers were excluded because they presented literature reviews, not focusing on a specific interactive system (EXC2); one paper was excluded because it was not about RFID (EXC3); eighteen papers were removed. After all, their quality scores were below the first quartile (EXC4), and three papers were excluded because their content was nearly the same as the papers from which they were retrieved (EXC5).

In the second up-to-date search execution, the publication period was set after August 2021 to look for terms in the titles or abstracts to avoid noise. It returned 71 papers, from which 43 were removed directly by title and abstract analysis. Four papers were unreachable, resulting in 24 papers for a full reading. During full reading, three papers were excluded because their focus was on the electronics of tags (EXC1); one paper was excluded because it presented a review, not focusing on a specific interactive system (EXC2); four papers were removed because their quality scores were below the first quartile (EXC4); and four papers were excluded because RFID was not an essential part of the project (INC2). The whole procedure took two weeks. The remaining 12 papers were added to the original set, producing 71 papers (*Annex C – Systematic Mapping Selected Papers*). The extractions were assembled, interpreted, and analyzed, concentrating on identifying excerpts that answered the research questions, subsequently interpreting information not explicitly written in papers (e.g., for the quality characteristics).

### 3.2.1 Analysis for RQ1: Application Domains

The central focus of RQ1 is to identify the specific domains where RFID technology has been integrated into applications. Understanding these domains, where interactive software systems can be effectively implemented with RFID, is crucial for practitioners seeking to develop similar systems. Most papers, 64 out of 71 (90.1%), have addressed this research question. Our classification is based on a taxonomy (Kotonya et al., 2003) that is a foundational tool for identifying application domains. This taxonomy synthesizes others from IBM, Reifer, and Object Management Group. We are also keen on categorizing the domains in which the presented applications are situated. For instance, a supply chain system for monitoring products during transportation may fall under the transportation domain, as this taxonomy outlines.

The taxonomy is a comprehensive compilation of the following items: Avionics (e.g., air traffic control), Command and control (e.g., satellites), Embedded systems (e.g., I/O controllers), Electronic commerce (e.g., online stores), Enterprise computing (e.g., cloud for companies), Finance (e.g., banks), Healthcare (e.g., home care), Real-time (e.g., sensor readings), Manufacturing (e.g., markets), Software engineering (e.g., for building software), Scientific (e.g., for research), Simulation (e.g., environmental simulators), Telecommunications (e.g., network management), Transportation (e.g., supply chain), Utilities (e.g., electric, water, gas) and General (e.g., do not specify the context). Furthermore, based on the papers, we recognized the need to expand the taxonomy by adding new items: Means of transportation (e.g., for cars and roads), Home Automation (e.g., for improving activities at home), and Crowd management (e.g., for managing groups of actors at once).

Each paper was assigned a specific domain. Figure 3.1 illustrates the distribution of application domains and their correlation with the types of interaction they facilitate (implicit and explicit). Applications where tagged things (e.g., objects, buildings, plants) are perceived by the system illustrate thing-thing interactions (TTI), even if humans are not directly involved. For instance, a system that monitors product parameters during transportation may automatically perform readings. However, a driver carrying the products and a manager verifying the data later also contribute to the interaction, albeit indirectly. We interpret this as an implicit TTI with RFID. TTI typically promotes implicit interactions, but these can also be made explicit by attaching an RFID reader to a moving robot (J. Zhang et al., 2016).

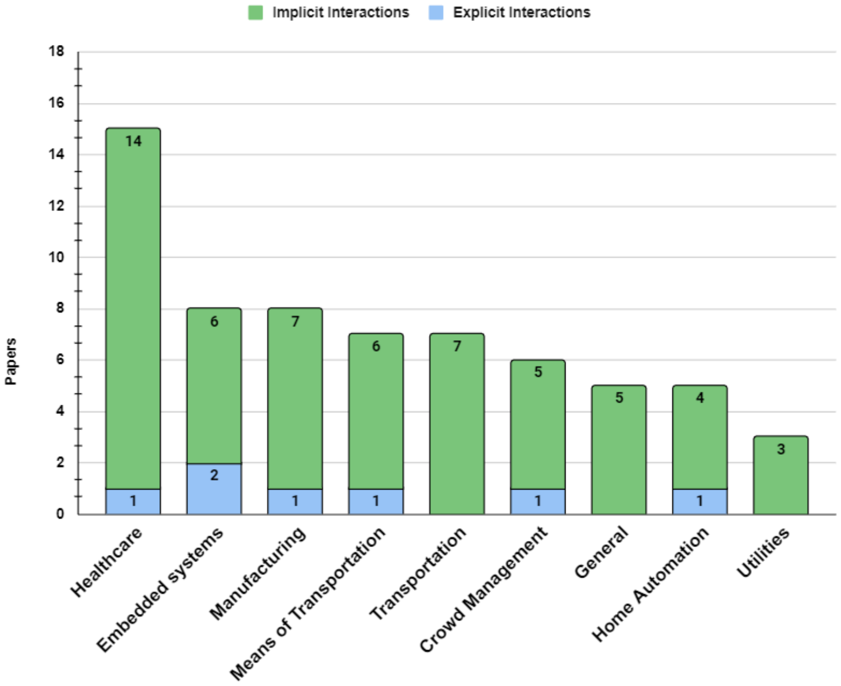

Figure 3.1 – Application domains and interaction types

Healthcare was the most recurring domain in 15 papers. Applications were assigned to it when they were somehow related to tracking medical-related things, treating patients, or collecting biometrical parameters with sensors, even outside health centers. A study implanted biometric RFID tags in patients (Y. Kim et al., 2016), while another described a system for monitoring sleepwalkers at home (Kaur et al., 2015). Five papers (Rahman et al., 2021; Rajesh, 2013; Rodrigues et al., 2012; Vecchia et al., 2012; Yadav et al., 2017) focused on invisible tracking or sensing patient parameters. A study tackled tracking patients and monitoring when certain drugs are opened (Zappia et al., 2014). The health of athletes was also monitored (Huang et al., 2019). Two papers (S.-C. Kim et al., 2013; F. Xiao et al., 2018) monitored elders at home, which were not categorized in the Home Automation domain because their primary objective was to ensure health. Pharmaceutical products were identified and monitored to guarantee good environmental conditions (D’Uva et al., 2021). RFID and GPS were mixed to detect patients intending to leave a quarantine area and pass through the entrance door (Chin et al., 2022). NB-IoT, GPS, and RFID were mixed to identify and locate specimens collected for testing while taking them to another lab (Chit et al., 2021). All the previous solutions implement implicit interactions, while in another study, patients' parameters were monitored, demanding the explicit approximation of a card (Alias et al., 2021).

The Embedded Systems domain was present in eight papers. Papers were classified based on whether RFID was used to create another hardware or if RFID was embedded in a particular structure or object. Two studies used Tabletops, whose architecture comprised a matrix of LF RFID reader antennas for use in schools and kitchens, respectively (Kubicki et al., 2015; Lebrun et al., 2014). Two papers embedded UHF tags in clothes (Jankowski-Mihułowicz et al., 2021; Lemey et al., 2017), one paper embedded UHF tags and moisture sensors in diapers (Tajin et al., 2021), while three papers (Strangfeld et al., 2019; J. Zhang et al., 2017; Zhao et al., 2022) embedded UHF sensor tags inside walls for monitoring structural health. As for tabletop applications, the interaction is explicit because users intentionally use them. The other solutions implemented implicit interactions since information is automatically collected from clothes or buildings. The type of interaction may vary with the tag's frequency.

The Manufacturing domain was present in eight papers. It refers to the manufacturing or management of products. Two studies (Chaves et al., 2008; Farhat et al., 2018) detected products on shelves to facilitate their management. A study investigated the information excess collected from products (Feng et al., 2020), while another investigated customers' behavior in retailers by reading about products left in the fitting rooms (Landmark & Sjøbakk, 2017). A paper presented a solution to monitor assets in supply-chain processes, which could detect theft or incorrect storage (Hayward et al., 2021). In the automotive industries, RFID and sensors were used for producing car tires (Nappi et al., 2017), and RFID and sensors were also used to monitor the temperature of vehicles during painting procedures (Melia-Segui et al., 2022). In the Manufacturing domain, many solutions apply to producing or managing products, frequently many at once, resulting in implicit interactions in most cases. However, one paper implemented a robot that performed inventory in a warehouse, interpreted as an implicit interaction (J. Zhang et al., 2016).

The domain of Means of Transportation was present in seven papers. It differs from the Transportation domain because the foci are the vehicles or the environment where they are inserted, not the actors being transported. A paper discussed the privacy of RFID technology integrated into vehicles (Fan et al., 2019), another paper used RFID to detect and prioritize ambulances and fire brigade vehicles during a traffic jam (Javaid et al., 2018), and yet another paper detected traffic violations (Wong et al., 2017). Two papers (Bazzi et al., 2017; Dwiputra et al., 2018) developed solutions for car parks. A study collected data from gas sensors to monitor pollution rates (Manna et al., 2014). Vehicles were equipped with RFID Readers to receive road conditions from tags embedded in the asphalt (Walvekar & Burkholder, 2018). It was not categorized as an

Embedded system because its objective was to provide information to vehicles, which also had a portion of the RFID implementation. Except for one solution in car parks, where the driver should approximate a tagged card for authentication, all other papers implement implicit interactions.

The Transportation domain was present in seven papers. It refers to applications in which actors are monitored or sensed while taken somewhere. A study explored the delivery of health-related products in the supply chain (W. Zhou & Piramuthu, 2018). Almost every paper involves supply chain processes for tracking products, guaranteeing that they are not violated, or checking if they are in good condition, especially food (Abad et al., 2009; Anandhi et al., 2019; Hsueh & Chang, 2010; W. Wang et al., 2020; S. Zhu et al., 2018). A study addressed automatically detecting passengers entering public transportation (Oberli et al., 2010). For product transportation, interactions occur implicitly at checkpoints or inside the vehicle. For humans, interactions may vary with the tag frequency.

Crowd Management was present in six papers and referred to applications intended to make decisions based on several RFID readings simultaneously in the same environment. The possibility of reading many tags simultaneously with active UHF readers makes it a suitable technology for this application. Two papers (Luis et al., 2018; Vastianos et al., 2014) detected crowds of people in airports. A study simulated identifying accident victims before taking them to a hospital (Ingrassia et al., 2012). A study detected traffic congestion by reading vehicle RFID tags (L. Zheng et al., 2018). Another study monitors everyone inside a prison (H.-C. Xiao & Xiong, 2013). All these examples implement implicit interactions. Meanwhile, a system developed a system to be used by several people evacuating a fire building only implements explicit interactions (Atila et al., 2018). In general, the use of RFID to detect the presence of several actors at once will occur implicitly.

Even though several papers address smart homes, only five were classified in the Home Automation domain because they focus on improving the house itself. Other papers, for instance, implemented solutions at home with healthcare intentions (S.-C. Kim et al., 2013; F. Xiao et al., 2018). Three papers (Azghandi et al., 2015; Hussain et al., 2009; T. Zhang et al., 2009) focused on optimizing tag readings or integrating them with other technologies. A study sensed the presence of babies while at home and detected their presence when passing through the house's entrance (Sundarajoo et al., 2022). Another study implemented an authentication system for entering the house with an HF reader (Kamelia et al., 2018), which is the only solution for implementing explicit interactions.

The general domain was attributed to five papers discussing the adoption of RFID without specifying where the solution could be implemented; however, it was general enough to apply to many domains. Three papers (Currie & Marina, 2008; Xiong et al., 2012; W. Zhu & Li, 2018) focused on optimizing tags or integrating RFID with other technologies. A study detected a method to identify gait rhythm using radio waves, which could be applied indoors (Jiang et al., 2022), while another study developed a solution to reduce distance ambiguity when RFID is deployed to many locations, a solution applied to many domains (Khalid et al., 2022). Finally, the utility domain is intended to describe applications that deliver services such as water, gas, electric, agricultural, and security. A paper monitored soil (Luvisi et al., 2016), while other monitored plants in agricultural solutions (J. Zhang et al., 2022). Finally, RFID and cameras were integrated for security (J. Kim et al., 2020). All General and Utility applications implemented implicit interactions. However, these categories are very generic and may permit any interaction.

### 3.2.2 Analysis for RQ2: Why using RFID

RQ2 aims to identify why RFID technology was selected as part of the described solution in the paper. 39/71 papers (54.9%) have clarified the reasoning. RFID was adopted for five main reasons: (1) because the communication is contactless, (2) because it works well indoors, (3) because tags have a low cost, (4) for complementing data originating from cameras, and (5) because it does not demand to power. Every paper that provided a reason for adopting RFID implemented implicit interactions. Figure 3.2 illustrates a link between the reason for adoption and the application domains.

The possibility of using RFID for tracking objects in a contactless way, reading tags in a wide range was a determinant characteristic in 20 papers (Abad et al., 2009; Currie & Marina, 2008; D’Uva et al., 2021; Fan et al., 2019; Hayward et al., 2021; Hsueh & Chang, 2010; Jiang et al., 2022; Khalid et al., 2022; Landmark & Sjøbakk, 2017; Rahman et al., 2021; Rajesh, 2013; Xu et al., 2017; Yadav et al., 2017; Yee-Loong Chong et al., 2015; Zdziechowski et al., 2020; J. Zhang et al., 2022; T. Zhang et al., 2009; Zhao et al., 2022; S. Zhu et al., 2018; W. Zhu & Li, 2018), from which the most recurring application domains were Healthcare, General, and Transportation. All papers implemented implicit interactions. For example, automatically reading tags in health centers for performing essential tasks prevents unnecessary actions from health workers, who can focus on their daily activities. The same applies to conductors during supply-chain processes, for instance. Barcode is a well-established option for identifying objects, but it demands a physical line-of-sight contact to be read (Abad et al., 2009; Currie & Marina, 2008; Hsueh & Chang, 2010; Rajesh, 2013; Yee-Loong Chong et al., 2015; Zdziechowski et al., 2020).

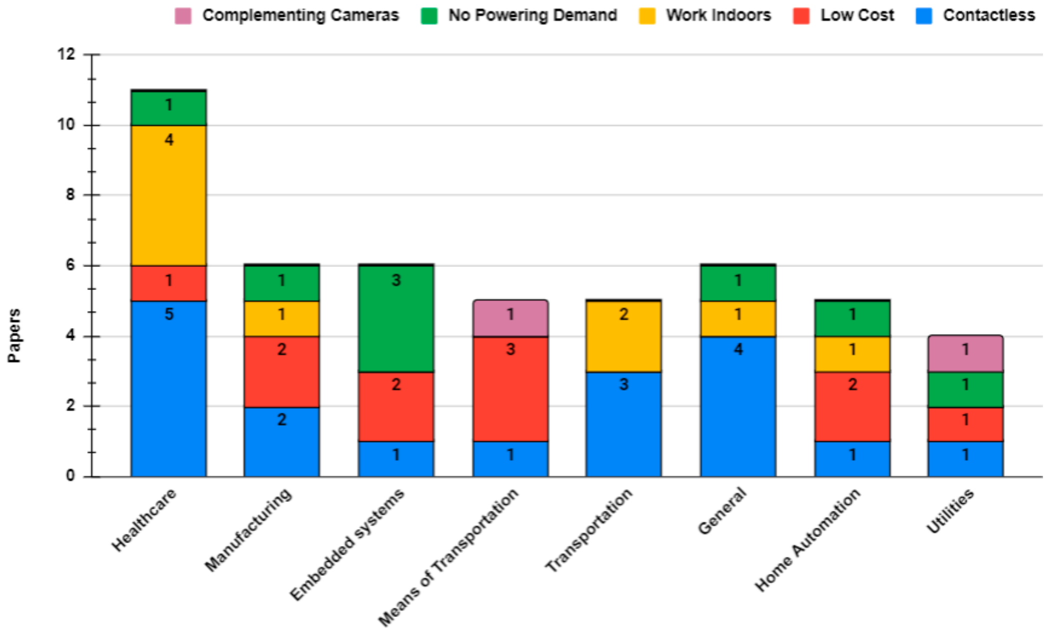

Figure 3.2 – Reasons for RFID adoption by application domains for explicit interactions

The cost of tags was a determinant factor in eleven papers (Bazzi et al., 2017; Fan et al., 2019; Hayward et al., 2021; Jankowski-Mihułowicz et al., 2021; Manna et al., 2014; Melia-Segui et al., 2022; Rahman et al., 2021; Sundarajoo et al., 2022; J. Zhang et al., 2017, 2022; T. Zhang et al., 2009), independently of the adopted type. Even though the cost is not a characteristic directly related to human-computer interaction, it allows the tagging of more actors, making the system more interconnected than other high-cost options. Notice, in Figure 3.1, that this reason was well distributed among several application domains, not applying to specific ones.

Appropriately tracking actors indoors was a determinant characteristic in nine papers (Anandhi et al., 2019; Hayward et al., 2021; Hsueh & Chang, 2010; S.-C. Kim et al., 2013; Rodrigues et al., 2012; Vecchia et al., 2012; F. Xiao et al., 2018; Xiong et al., 2012; T. Zhang et al., 2009), from which the most recurring application domains were, again, Healthcare and Transportation. All papers implemented implicit interactions. For example, health centers are usually indoors, as are supply-chain warehouses. Vehicles performing transportation can also benefit from attaching an RFID reader to check the parameters of objects being transported constantly. Wi-fi is highlighted as a possible solution for the indoor location of connected devices. However, it is less accurate and would not be suitable for tracking non-connected objects and objects in transit (Anandhi et al., 2019). Although GPS is an appropriate solution for monitoring vehicles, it is not ideal for indoor locations because walls or other fixed structures obstruct Global Navigation Satellite Systems (GNSS) signals, preventing triangulation techniques from working properly (Anandhi et al., 2019; Hayward et al., 2021; Hsueh & Chang, 2010; S.-C. Kim et al., 2013; Xiong et al., 2012; T. Zhang et al., 2009).

Another characteristic of passive tags, the lack of batteries, was determinant in 8 papers (D’Uva et al., 2021; Khalid et al., 2022; Lemey et al., 2017; Melia-Segui et al., 2022; Strangfeld et al., 2019; Sundarajoo et al., 2022; J. Zhang et al., 2022; Zhao et al., 2022), all implementing implicit interactions. Its combination with the low cost makes UHF passive tags a versatile option for implementing ubiquitous systems because many tags may be deployed without needing battery maintenance. This characteristic was specially addressed in studies about structural health (Embedded Systems domain), in which exchanging or recharging batteries would be incredibly demanding.

Finally, two papers described solutions in which RFID technology complemented image processing. One described a solution in which cameras detect vehicles on roads. However, the images were eventually inaccurate or ambiguous. Therefore, the system detected available vehicle RFID tags to complement the data (Wong et al., 2017). Another study used cameras for surveillance in a building. However, facial recognition was inaccurate in many situations. Therefore, RFID technology detected possible RFID support in the person's mobile device (J. Kim et al., 2020). In both cases, just as the cameras alone would implicitly perceive vehicles or people, the addition of RFID maintains the ubiquity of these systems and provides extra perceptions that the cameras cannot do alone.

### 3.2.3 Analysis for RQ3: Who Interacts and How

RQ3 aims to understand which actors directly interact with the RFID technology within a system and how these interactions occur. 64/71 papers (90.1%) provided an actor (who) and a type of interaction (how). We looked for actors directly involved in actions involving RFID technology, i.e., it was not identified who the software system users were but who were directly involved with the RFID features within the system. First, actors were only classified as humans or things. The actors were humans in 30/64 papers

(46.9%), things in 29/64 papers (45.3%), and both in 5/64 papers (7.8%). Actors interacting with RFID and carrying a tag or reader, or in some cases, those who do not hold them but interact with things that keep them, have been classified. Regarding actors' roles, the most common were patients, home residents, drivers for humans, and products and vehicles for things. These roles align with the application domains, such as Healthcare, Transportation, and Home Automation.

Concerning how the actors interact, we searched for interaction patterns between actors and RFID in the interactive system. It was possible to characterize the interaction as implicit or explicit in terms of the actor's actions. The actions triggering interactions are (1) just being inside a monitored environment that constantly searches for tags, (2) passing through a portal or entering an environment, (3) approximating or touching a card, (4) changing the state of an object, or (5) using a user interface somehow related to RFID. These actions are illustrated in Figure 3.3. Figure 3.4 illustrates the link between the type of actor, the kind of interaction, and the actor's actions.

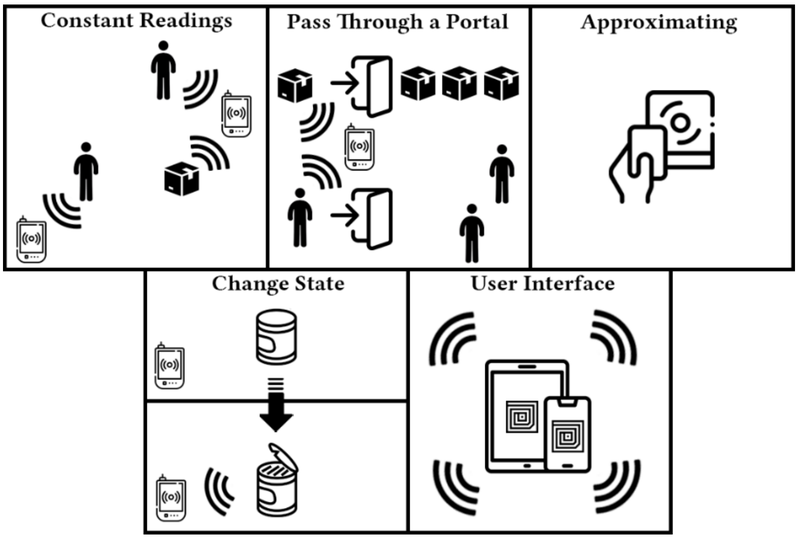

Figure 3.3 – Actions triggering interactions with RFID

Explicit interactions with RFID are a minority, occurring in just seven papers. In four papers, actors read tags by touching or approximation. A study provides an authentication system for smart homes, which demands that residents (humans) touch a tagged card to open the door (Kamelia et al., 2018). A study describes a robot (thing) that carried an RFID reader and walked through a warehouse to perform inventory (J. Zhang et al., 2016). An authentication system was implemented for a car park where the driver (human) used a tagged card to gain access (Bazzi et al., 2017). Health data about patients were stored by approximating RFID tags to readers (Alias et al., 2021). In three papers, a human actor used a UI related to an RFID implementation. One developed a mobile system to be used by evacuees in a fire building (Atila et al., 2018). The other studies developed interactive systems deployed in tabletops internally built with RFID antennas (Kubicki et al., 2015; Lebrun et al., 2014).

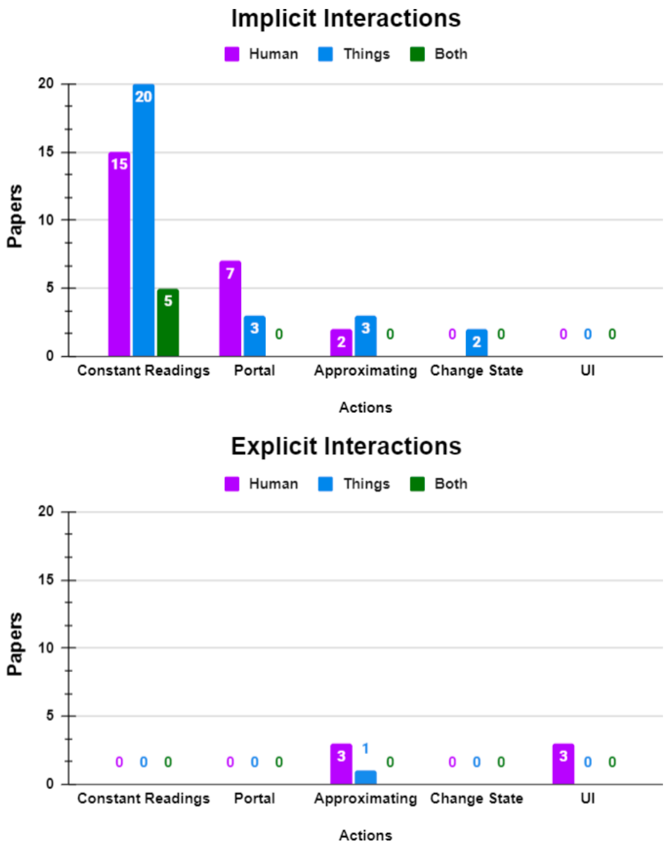

Figure 3.4 – Types of actors, interaction types, and actions triggering interactions

In 40 papers, the solution described interactive systems constantly monitoring tagged actors. In every case, the interaction was implicit because the tag readings occurred without the intervention of these actors. In 15 studies, the actors were humans. Two studies constantly located patients' presence or absence (Rodrigues et al., 2012; Vecchia et al., 2012). Two studies (Rahman et al., 2021; Rajesh, 2013) constantly monitored patients' health parameters. A study tracked patients' positions and sensed their heartbeats (Yadav et al., 2017). An RFID tag was also integrated into a baby diaper to detect moisture constantly (Tajin et al., 2021). A study monitored people in prisons with tagged wristbands (H.-C. Xiao & Xiong, 2013). Two studies (S.-C. Kim et al., 2013; F. Xiao et al., 2018) monitored elders' movements to prevent falls, while two (Hussain et al., 2009; Lemey et al., 2017) monitored residents. A study was interested in minimizing the quantity of RFID readers in smart homes with multiple residents (Azghandi et al., 2015).

RFID readers were placed in fitting rooms to constantly detect tagged products brought by customers (Landmark & Sjøbakk, 2017). One study collected the health status of tagged athletes (Huang et al., 2019), while another aimed to detect crowds by giving every passenger an RFID tag (Luis et al., 2018).

Similarly, 20 papers addressed things being constantly and implicitly monitored. Three studies (Strangfeld et al., 2019; J. Zhang et al., 2017; Zhao et al., 2022) constantly monitored sensor data about the structure of buildings. One study collected factory car tire data during the production phase (Nappi et al., 2017), while another constantly monitored the vehicle's painting temperature (Melia-Segui et al., 2022). RFID readers were placed on roads to collect data from cars with gas sensors (Manna et al., 2014). Two studies (Chaves et al., 2008; Farhat et al., 2018) constantly read products on shelves. RFID tags are read from vehicles to deduce traffic violations (Wong et al., 2017). A study developed an algorithm for detecting objects indoors with active tags (T. Zhang et al., 2009). Other studies proposed strategies for monitoring objects moving in predictable patterns (W. Zhu & Li, 2018). Two studies (Abad et al., 2009; Anandhi et al., 2019) monitored products during transportation. A study used RFID to detect priority vehicles within dense traffic (Javaid et al., 2018). Vehicle tags were monitored to predict traffic congestion (L. Zheng et al., 2018). A study explored big data to reduce the inefficiency of a product's data glut (Feng et al., 2020). Environmental conditions surrounding medications were constantly monitored (D'Uva et al., 2021). A study discussed privacy problems of RFID technology integrated into vehicles (Fan et al., 2019). Two studies (Luvisi et al., 2016; J. Zhang et al., 2022) monitored soil and plants, and both were interpreted as things.

Five other studies follow the same strategy, but the solution applies to humans and things. The first study developed a distance disambiguation technique applicable to any actor (Khalid et al., 2022). The second study described the integration of RFID with cloth, which could be applied, e.g., in people's clothes or on a table cover (Jankowski-Mihułowicz et al., 2021). Two studies (Currie & Marina, 2008; Xiong et al., 2012) discussed tracking people or objects equipped with tags. Finally, a study monitored people and luggage inside airports (Vastianos et al., 2014). This vast list of 40 (out of 64) examples represents 62.5% of the results, suggesting that, most times, RFID intends to facilitate the implicit readings of many tags at once or to provide many readings on a few tags.

Ten papers presented solutions in which humans or things were eventually read when passing through a portal or entering a specific environment. Two studies (Chin et al., 2022; Sundarajoo et al., 2022) detected humans when passing through the environment's entrance. A study identified people by their gait if they passed right between an RFID reader and an array of tags (Jiang et al., 2022). Accident victims were given tags to detect their hospital arrival (Ingrassia et al., 2012). People were identified with video surveillance integrated with RFID when entering a building (J. Kim et al., 2020). Biometric RFID tags were implanted in the patient's body to identify their health information before entering the hospital (Y. Kim et al., 2016). Bus passengers' cards are detected while passing through a bus portal (Oberli et al., 2010). Two studies (Hsueh & Chang, 2010; S. Zhu et al., 2018) considered when products arrive at transportation checkpoints. Finally, a study (W. Zhou & Piramuthu, 2018) investigated electromagnetic interferences with RFID when products come into a hospital. This kind of action differs from the constant readings because once the actors pass through the portal, they will not be monitored anymore.

Two studies integrated RFID in objects to trigger an event when these objects reach a specific state of interest: One used RFID tags to monitor the opening of drug tins in a hospital (Zappia et al., 2014), and the other developed a solution for detecting violated products by intentionally positioning an RFID tag antenna so that it would break when the package was opened (W. Wang et al., 2020). Finally, the tags are read by approximation in five studies, but this action is implicit (not intentional). A study described a solution in which assets are moved with RFID readers through a warehouse until reaching their correct storage. Tags in walls are read for locating when assets got close (Hayward et al., 2021). A study verified that the presence of cars in parking places is detected so that the system can provide information about empty places (Dwiputra et al., 2018). Vehicles have an RFID reader that reads information about road conditions from tags embedded in the asphalt (Walvekar & Burkholder, 2018). Sleepwalkers are monitored at home by giving them a reader and placing tags throughout the house (Kaur et al., 2015). Finally, saved patients' information is stored in tags after blood testing (Chit et al., 2021).

### 3.2.4 Analysis for RQ4: Restrictions

RQ4 aims to find possible restrictions related to the usage of RFID. Based on the extracted content, we needed to decompose the understanding of restriction into three classifications: Characteristics, Requirements, and Limitations, present in 63/71 papers (88.7%). Characteristics are the intrinsic restrictions that characterize the RFID's basic properties. Requirements are the restrictions imposed on the RFID in a specific context or domain. Limitations describe a disadvantage or adverse condition that prevents the RFID from reaching particular goals. A good understanding of these three dimensions would supply designers of interactive software systems with invaluable prior knowledge and insights about the technology.

As for the characteristics, the architecture of RFID-based systems consists of tags, readers, and a back-end (Abad et al., 2009; Chit et al., 2021; J. Choi, 2018; Fan et al., 2019; Farhat et al., 2018; Hsueh & Chang, 2010; Jiang et al., 2022; Khalid et al., 2022; S.-C. Kim et al., 2013; Luis et al., 2018; Rajesh, 2013; Rodrigues et al., 2012; Sundarajoo et al., 2022; H.-C. Xiao & Xiong, 2013; Xu et al., 2017; Yee-Loong Chong et al., 2015; J. Zhang et al., 2022; Zhao et al., 2022). Tags are identified through a globally unique identifier, which connects and identifies tagged things on the internet (Chaves et al., 2008; Hayward et al., 2021; J. Zhang et al., 2017). They also have a user memory for allowing writing from an RFID reader (Rahman et al., 2021; Vastianos et al., 2014). Readers can communicate with multiple tags within their range for reading and writing (Abad et al., 2009; Chaves et al., 2008; S.-C. Kim et al., 2013; Wong et al., 2017; T. Zhang et al., 2009). The data obtained by readers is transferred to a back-end for storage or computing (Fan et al., 2019; S.-C. Kim et al., 2013). Tags can be passive, active, or semi-passive. Passive UHF tags are battery-free (Currie & Marina, 2008; Lemey et al., 2017; Tajin et al., 2021; J. Zhang et al., 2022) and are powered by the reader (Oberli et al., 2010; J. Zhang et al., 2016, 2017), while active has a power source (Hayward et al., 2021; Rajesh, 2013; W. Wang et al., 2020; Zdziechowski et al., 2020). The communication distance depends on the frequency. Low-frequency (LF) and high-frequency (HF) reach a few centimeters. Ultra-high-frequency (UHF) ranges up to five meters, and microwave ranges up to 100 meters. Active UHF tags also go up to 100 meters. The longer the range, the greater the possibility of identifying far objects and integrating them into implicit interactions.

The requirements related to RFID may be classified in three ways: (1) the use of RFID by humans, (2) the periodicity of readings, or (3) the decisions due to a particular domain. Regarding the use of RFID, human users may carry a tag using necklaces (Vastianos et al., 2014), bracelets (Rodrigues et al., 2012; H.-C. Xiao & Xiong, 2013), or even implanted (Y. Kim et al., 2016); they may carry the reader instead of the tags

(Hayward et al., 2021; Kaur et al., 2015); or they may not carry tags nor readers, but interact with tagged things (Kubicki et al., 2015; Lebrun et al., 2014; Rekik et al., 2019). Regarding periodicity, the readings may be constant or periodic. As illustrated in Figure 3.4, constant readings are the most recurring frequency and apply to interactive systems that need to verify parameters of one-to-many targets constantly. As opposed, readings may occasionally be necessary, as illustrated in Figure 3.4, by touching/approximating (Alias et al., 2021; Bazzi et al., 2017; Chit et al., 2021; Dwiputra et al., 2018; Hayward et al., 2021; Kamelia et al., 2018; Kaur et al., 2015; Walvekar & Burkholder, 2018; J. Zhang et al., 2016) or passing through a portal (Chin et al., 2022; Hsueh & Chang, 2010; Ingrassia et al., 2012; Jiang et al., 2022; J. Kim et al., 2020; Y. Kim et al., 2016; Oberli et al., 2010; Sundarajoo et al., 2022; W. Zhou & Piramuthu, 2018; S. Zhu et al., 2018).

The interactive system designer must define which user actions will trigger them in specific readings. Very few studies outlined requirements for implementing RFID in a particular domain. For example, an embedded RFID antenna should fulfill aesthetical requirements for intelligent clothes, such as being invisible to users and comfortable. Therefore, the antennas should be fabricated with yarns, threads, or paints (Jankowski-Mihułowicz et al., 2021). In the traffic context (Walvekar & Burkholder, 2018), it is recommended that applications that read tags from vehicles use more than one reader to ensure that the tag is read due to the high speed of vehicles. Two studies (Melia-Segui et al., 2022; Zhao et al., 2022) indicated that temperature sensor tags could stand around 140 degrees. A study used RFID for detecting gait rhythm, which is unique for each person (Jiang et al., 2022). Tabletops (Kubicki et al., 2015; Lebrun et al., 2014; Rekik et al., 2019; Vispi et al., 2021) take advantage of LF by arranging a matrix or reader antennas on a surface capable of reading tagged objects placed on top of it. The same strategy may be used for composing other structures, such as smart shelves, which can comprehend what objects are on them.

A few studies spotted limitations and restrictions that may prevent RFID technology from reaching specific goals. The limitations are illustrated in Figure 3.5. First, radiofrequency propagation does not work correctly in metal environments (Hayward et al., 2021; Zdziechowski et al., 2020), i.e., RFID technology may not be a reliable option if the interactions happen within a place with metallic walls. Second, some characteristics of RFID tags are also interpreted as current challenges: low data rate, reduced area coverage, and insufficient ranging (J. Zhang et al., 2017). Third, natural conditions such as rain and snow affect the read range (Walvekar & Burkholder, 2018), i.e., RFID tags may not be adequately read during lousy weather. Fourth, RFID readers do not randomly distribute their reading spatially, so tagged objects near the reader are probably read more often than farther away (Chaves et al., 2008; Currie & Marina, 2008). Fifth, UHF RFID devices may impact the functioning of medical equipment, such as ventilation rates, syringe pumps, pacemakers, and renal devices (W. Zhou & Piramuthu, 2018), i.e., interactive medical systems should avoid UHF RFID or use it in areas where these equipment are not present. Finally, RFID data may be unreliable (Landmark & Sjøbakk, 2017; Xu et al., 2017), given that exists (1) false positives, tags that a reader should not have recognized but were for some reason; (2) false negatives, tags that a reader should have recognized but were not; and (3) dirty data, tags that a reader has recognized, but the data contains errors.

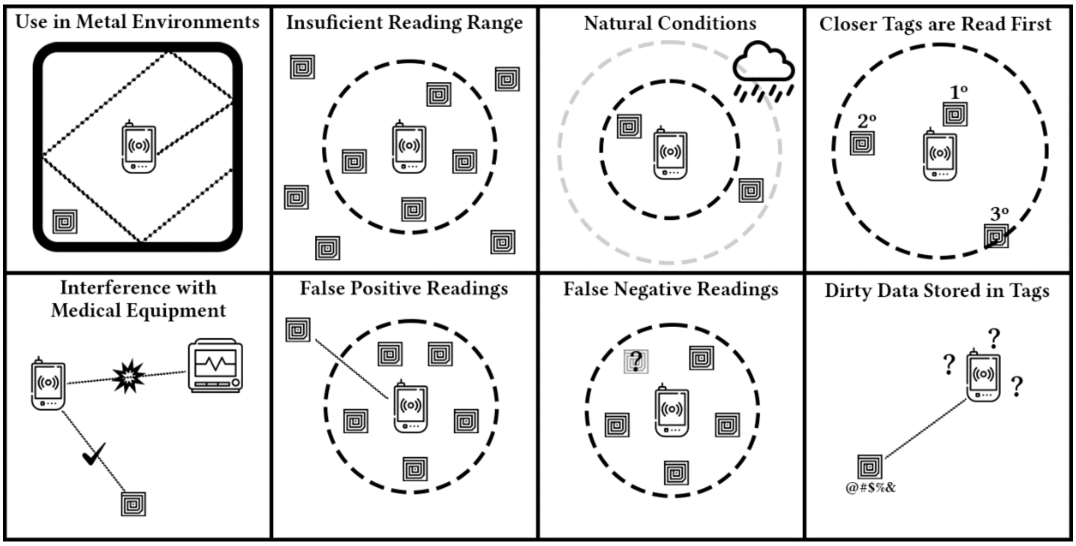

Figure 3.5 – Limitations of the RFID technology

### 3.2.5 Analysis for RQ5: Quality Characteristics

The main goal of this research question is to identify if papers define quality characteristics to evaluate the use of RFID in interactive software systems, as well as measures for these characteristics. This identification is relevant because it impacts how users perceive application quality. Furthermore, traditional software product evaluation may be insufficient because of the new sensing possibilities and different types of user interfaces in interactive systems. For this reason, we based our search on the quality characteristics of the traditional software standard (ISO/IEC, 2010) and a set of ubiquity-related quality characteristics (Carvalho et al., 2017).

ISO/IEC 25000 standards provide quality models and measures applicable to software, but none are related to IoT and ubiquitous systems. However, it still addresses general concerns such as reliability and performance, which we may consider independently of the kind of software. As a complement, a study (Carvalho et al., 2017) performed invaluable research on quality characteristics impacting the quality of interaction in ubiquitous systems: context awareness, mobility, transparency, attention, and calmness. None of the papers formally addressed software quality approaching standards or other quality-related materials. However, several concerns were implicitly present even though they were not explicitly mentioned. Therefore, it was necessary to face the risk of bias by reading and interpreting the papers' contents to answer this research question, intending to relate what the authors said with definitions of characteristics from previously mentioned literature. This approach presented quality characteristics in 52/71 papers (73.2%). However, measures were only found for performance efficiency and reliability in 13/71 papers (18.3%).

ISO/IEC 25010 defines software quality as *the degree to which a software product satisfies stated and implied needs when used under specific conditions*. In contrast, a quality characteristic is *an attribute that bears on software quality*. Finally, a quality measure is *a degree to which a set of static attributes of a software product satisfies stated and implied needs for the product to be used under specific conditions*. Figure 3.6 illustrates which quality characteristics were found, the number of papers where they were present, and the implicit or explicit interaction types in each case.

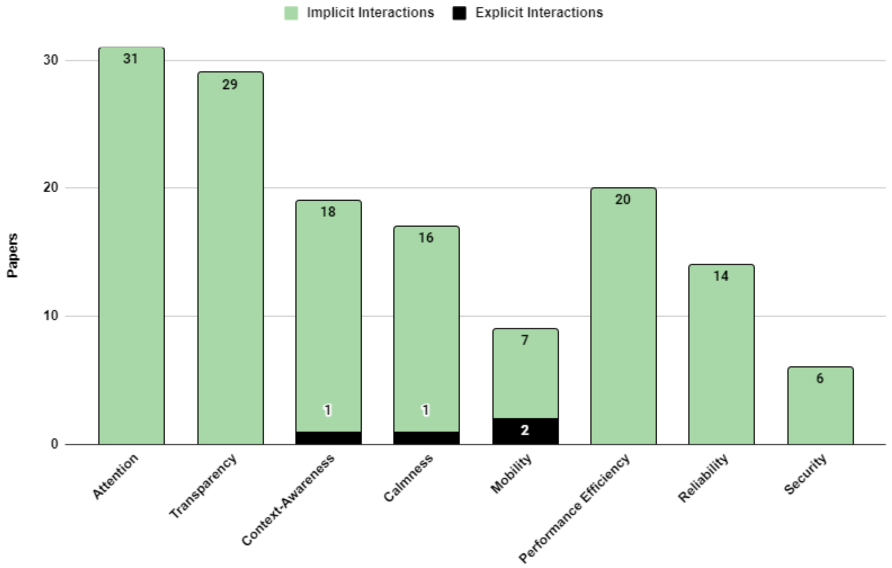

Figure 3.6 – Quantity of papers addressing each quality characteristic and interaction type

Only **Performance Efficiency**, **Reliability**, and **Security** were addressed among the traditional quality characteristics. Notice that **Usability** was not precisely identified in the papers. ISO/IEC 25010 defines usability as *the degree to which specified users can use a product or system to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context*. Actors do not usually know they interact with RFID, which invisibly identifies objects or collects information as part of a higher-level software system. Therefore, we understand that the additional quality characteristics (Carvalho et al., 2017) cover the usability of ubiquitous systems.

Twenty papers showed concerns with the performance (Chaves et al., 2008; Chit et al., 2021; Currie & Marina, 2008; D’Uva et al., 2021; Fan et al., 2019; Jiang et al., 2022; Khalid et al., 2022; J. Kim et al., 2020; Y. Kim et al., 2016; Landmark & Sjøbakk, 2017; Lemey et al., 2017; Luis et al., 2018; Rahman et al., 2021; Strangfeld et al., 2019; Vastianos et al., 2014; Walvekar & Burkholder, 2018; Xu et al., 2017; J. Zhang et al., 2017; T. Zhang et al., 2009; Zhao et al., 2022). **Performance efficiency** is relative to the number of resources used under stated conditions. It refers to properly using the available resources, e.g., suppose a tagged patient should be detected when entering a hospital. In that case, the patient would not be identified in case of delay. It was a concern in papers due to limits such as maximum reads in a limited time, reading range, and transmission power. Table 3.3 presents the related measures and their definitions.

Table 3.3 – Measures for Performance Efficiency

| Measure | Definition |
|---|---|
| Reading Range | Maximum distance between the reader and the tag at which the radiation field from the reader is strong enough to power up the tag (Currie & Marina, 2008; D’Uva et al., 2021; Lemey et al., 2017; Strangfeld et al., 2019; Vastianos et al., 2014; Walvekar & Burkholder, 2018; Xu et al., 2017; J. Zhang et al., 2017). |
| Delay Time | The time a reader takes to read data from a tag (Y. Kim et al., 2016; Landmark & Sjøbakk, 2017; Walvekar & Burkholder, 2018). |
| Transmit Power | The transmission power transmitted by readers is measured in dBm. This parameter can be modified and affects the reading range (Strangfeld et al., 2019; Vastianos et al., 2014). |
| Reads per Tag | The average number of successful reads per tag in multiple close-them scenarios (Currie & Marina, 2008). |
| Tag Distance | The distance between a tag and the nearest reader. Not the same as the Reading Range (Vastianos et al., 2014). |

Fourteen papers showed concerns with data reliability (Chaves et al., 2008; Hayward et al., 2021; Jiang et al., 2022; Landmark & Sjøbakk, 2017; Luvisi et al., 2016; Oberli et al., 2010; Rahman et al., 2021; Strangfeld et al., 2019; Sundarajoo et al., 2022; Vecchia et al., 2012; Xiong et al., 2012; Xu et al., 2017; Zdziechowski et al., 2020; J. Zhang et al., 2017). False positives/negatives and dirty data may make an interactive system unreliable (Figure 3.5). **Reliability** is *the degree to which a system performs* *specified functions under specified conditions for a specified period*. The unreliability may result in wrong conclusions about the actor or the environment, e.g., a humidity sensor reading may be incorrectly stored in a tag, causing an erroneous interpretation of a bridge's structural health. Table 3.4 presents the related measures. Tag distance (performance) and reading frequency (reliability) are considered quality measures because RFID readers may read the nearest tags first, so distance and frequency of reading attempts may affect performance and reliability. Performance measures are usually related to the speed of readings and resource utilization of readers. Reliability measures are associated with the effectiveness of the readings, regardless of the time it takes.

Table 3.4 – Measures for Reliability

| **Measure** | **Definition** |
|---|---|
| Error Rate | Readings with error data are divided by the total number of readings (Chaves et al., 2008; Xu et al., 2017). |
| Accuracy Rate | Checksum-verified read data is divided by the total readings (Zdziechowski et al., 2020). |
| Recognition Rate | Failure tag reading attempts are divided by the total number of tag readings (Oberli et al., 2010). |
| Reading Frequency | Frequency in which tag data are queried by readers (Xu et al., 2017). |

Six studies (Anandhi et al., 2019; Fan et al., 2019; S.-C. Kim et al., 2013; Y. Kim et al., 2016; Landmark & Sjøbakk, 2017; J. Zhang et al., 2017) showed concerns about data security in systems using RFID for identifying actors or collecting data. It is defined as the degree to which a system protects information and data so that persons or systems have the degree of data access appropriate to their types and levels of authorization. The concern refers to data availability in RFID tags for third parties, e.g., data saved in a tag could be decoded by a reader outside the system, which may demand extra effort to encrypt the content (S.-C. Kim et al., 2013). In addition, the UHF reading range may cause the tags to be accessible outside buildings (J. Zhang et al., 2017).

Ubiquitous computing represents the concept of computing everywhere, making computing and communication essentially transparent to the users (Yau et al., 2002). RFID technology permits the invisible tracking of things, making it suitable for ubiquitous computing (S.-C. Kim et al., 2013). Several studies used RFID due to its contactless and non-line-of-sight characteristics. Furthermore, tags are manufactured in many shapes, such as coins, cards, and labels (Jankowski-Mihułowicz et al., 2021), so the best format may be selected without influencing the appearance of the physical object. Most interactions between actors and RFID technology are implicit, reinforcing ubiquity's relevance for these software systems. Implementing this kind of system has been discussed in many papers. Ubiquity will be further discussed regarding context-awareness, mobility, transparency, attention, and calmness (Carvalho et al., 2017).

**Attention** in a ubiquitous environment refers to *the system's ability to keep the user's focus on real-world interactions rather than on technology*. This characteristic is present in systems where the users do not lose focus on their daily activities because of a software system in the environment. **Transparency** is *the system's ability to hide its computing infrastructure in the environment so the user does not realize it interacts with a set of computational devices*. The tags' size and the possibility of producing them in several shapes permit their implementation with RFID technology. Transparency differs from Attention because users may focus on their activities even if the structure is not invisible. Attention was present in 31 papers, and Transparency in 29 and 21 addressed both.

In all the following examples, all implicit, the actors are not necessarily aware of their participation in an interactive system while using an invisible RFID structure. We interpreted that tagged necklaces and bracelets are not transparent. Six studies (Fan et al., 2019; Javaid et al., 2018; Manna et al., 2014; Walvekar & Burkholder, 2018; Wong et al., 2017; L. Zheng et al., 2018) present TTI between tagged vehicles and the software system, while a driver is an indirect use of the system. In these studies, the tag is hidden, and the driver is unaware of the vehicle's participation. A study hid the heartbeat sensor and tag in the patient's clothes to monitor ECG (Rahman et al., 2021). Two studies (S.-C. Kim et al., 2013; F. Xiao et al., 2018) tagged elders' clothes at home. Two other studies (Jankowski-Mihułowicz et al., 2021; Lemey et al., 2017) also embed clothing tags. A study identified people using radio waves without attaching infrastructure to their bodies (Jiang et al., 2022). Passenger cards were automatically read in public transport (Oberli et al., 2010). A study hid tags in retailers' products and readers in fitting rooms (Landmark & Sjøbakk, 2017). Tagged cards were provided to everyone entering an airport, not affecting the user's activities (Luis et al., 2018). Three studies (Y. Kim et al., 2016; Rodrigues et al., 2012; Vecchia et al., 2012) invisibly tag patients. Without intervention, RFID support was detected in users' phones (J. Kim et al., 2020). Two studies (Chaves et al., 2008; Farhat et al., 2018) monitored products based on the customer's expected activities while they visit the markets.

Eight implicit thing-thing solutions implement Transparency but not Attention. In most cases, the infrastructure is well hidden, but the system's objective constantly provides parameters to a human user not involved with the interaction. A study put tags inside product packages, but the user notices the tag when opened and is now aware of the system (W. Wang et al., 2020). Three papers (Strangfeld et al., 2019; J. Zhang et al., 2017; Zhao et al., 2022) hid tags inside the structure of buildings, but the users responsible for performing maintenance are always aware of their deployment. A study places tags inside packages, but the responsible for checking the parameters knows the patient when opening the package (D'Uva et al., 2021). Two studies (Luvisi et al., 2016; J. Zhang et al., 2022) hid tags in plants or soil to monitor parameters. However, human users frequently check these parameters. A study hid tags and sensors inside vehicles with a rubber encapsulation, but the temperature readings are constantly monitored (Melia-Segui et al., 2022).

Ten implicit solutions implemented Attention but not Transparency. These studies permitted involved humans to focus on their activities but did not hide the system's infrastructure well. A study intended to minimize readers in smart homes but did not specify the format of tags (Azghandi et al., 2015). Two studies (Hussain et al., 2009; Lemey et al., 2017) monitored residents in general but did not specify the format of tags, as well. A study monitored patients with a complex device. However, patients did not need attention to it (Yadav et al., 2017). A study monitored the health of athletes using a wristband (Huang et al., 2019). Another study monitored the opening of a drug tin linked to a patient using a wristband (Zappia et al., 2014). Patients were monitored using a chest strap (Rajesh, 2013). Sleepwalkers were monitored as well and were not bothered unless necessary. However, the RFID structure was not hidden (Kaur et al., 2015). A study monitored warehouse assets, and the involved workers were not affected by the system, but RFID tags were visible on the walls (Hayward et al., 2021). A study unconsciously saved patients' information in tags during a blood test, but the infrastructure was not hidden (Chit et al., 2021).

As a quality characteristic, **context awareness** is *the system's capability of monitoring contextual information regarding the user, the system, and the environment*. With this information, the system dynamically and proactively adapts its functions accordingly. Even though the analyzed papers describe several solutions automatically perceiving actors, only the following exemplified functions triggered according to context variations. It was present in 19 papers, from which only one implemented explicit interaction. Four studies (Fan et al., 2019; Javaid et al., 2018; Wong et al., 2017; L. Zheng et al., 2018) presented solutions in which decisions are taken based on the perception of the environment around vehicles. A study demonstrated a solution aware of where assets were placed inside warehouses so that the system could deduce theft or misplacing (Hayward et al., 2021), while another study monitored environmental parameters around medications to guarantee good conditions (D'Uva et al., 2021). Patients' information was collected during blood testing, and the system was also aware of the location of the test tubes while taking them to another lab (Chit et al., 2021). Alerts were sent to the system if products were violated (W. Wang et al., 2020). A study optimized stock based on the information of products on shelves (Chaves et al., 2008). Empty parking slots were monitored to manage a car park (Dwiputra et al., 2018). The state of sleepwalkers was observed to prevent accidents (Kaur et al., 2015). Two studies (Luis et al., 2018; Vastianos et al., 2014) detected people or luggage in airports to make security decisions. Two studies (Rajesh, 2013; Rodrigues et al., 2012; Vecchia et al., 2012) sent alerts depending on the patient's presence or health parameters. The context was sensed to detect falls of elders (S.-C. Kim et al., 2013). A system was alerted based on the soil parameters (Luvisi et al., 2016). One study implemented explicit interactions by assisting people evacuating a firing building (Atila et al., 2018).

**Calmness** is *the system's capability to interact with the user at the right time and in the right situation, presenting only relevant information*. Given that this characteristic refers to the presentation of information, it applies to systems where humans are involved. It was present in 17 papers, with only one presenting explicit interaction. The only information provided by the system in a hospital reception was the victim's identification (Ingrassia et al., 2012). Two studies (Rodrigues et al., 2012; Vecchia et al., 2012) provided information about patients who went to the hospital in case of an unusual situation. A study also provided patient information when they entered the hospital (Y. Kim et al., 2016). Another study provided information only in case of something odd in the state of assets (Hayward et al., 2021). Alerts were set if the vehicle's temperatures exceeded the required interval (Melia-Segui et al., 2022). A study only tried identifying people passing between reader and tags (Jiang et al., 2022). A system once requested the patient's information after blood testing (Chit et al., 2021). Two studies (Chin et al., 2022; Sundarajoo et al., 2022) only triggered RFID readings when the actors of interest passed through the door. A study provided drivers with information about empty or filled parking slots (Dwiputra et al., 2018). Another study stored product data in the cloud to be accessed by users where necessary (Anandhi et al., 2019). The system administrator was alerted in case of elder falls or health problems (S.-C. Kim et al., 2013). Another system was only alerted if drug tins were incorrectly opened (Zappia et al., 2014). A system provides drivers with traffic information when required (L. Zheng et al., 2018). Sleepwalkers were woken up just in case of danger (Kaur et al., 2015). Implementing explicit interactions, a study provided users with a large amount of information, although necessary because it refers to escaping from a fire building (Atila et al., 2018).

**Mobility** in ubiquitous computing refers to *the continuous or uninterrupted use of the systems while the user moves across several devices*. This characteristic applies to interactive systems where actors navigate different areas while still using the system. It was present in nine papers, two of which implemented explicit interactions. Additional studies might also address mobility, but descriptions were unclear. A study collected products' data regardless of their location (Anandhi et al., 2019). Another study monitored patients in several areas (Vecchia et al., 2012). Assets were moved through several warehouses (Hayward et al., 2021). A system covered testing labs and the outdoor ways among them (Chit et al., 2021). People and luggage were monitored in airports no matter where they were (Vastianos et al., 2014). A system collected the vehicle's location on any covered road (L. Zheng et al., 2018). Sleepwalkers were expected to be anywhere inside the house (Kaur et al., 2015). Concerning explicit interactions, a whole building was covered during the escape (Atila et al., 2018), and a study integrated a door authentication system into sensors throughout the house (Kamelia et al., 2018).

### 3.2.6 Discussion

The systematic mapping investigated the usage issues of RFID technology implemented in interactive software systems. The results allowed the discovery of typical actors and how they interact, the common application domains, the requirements, the reasons for adopting the RFID technology, and the most relevant general or ubiquity quality characteristics addressed in the paper. However, we also spotted several limitations which should be further investigated.

Most of the discussed interactive systems were composed of RFID infrastructure distributed through an environment of interest and actors, making up IoT software systems instead of traditional ones. By and large, all research questions headed in this direction and reached results due to the same features of RFID or due to the same system's design requirements. The application domains, such as healthcare, transportation, means of transportation, and manufacturing, have contexts or needs that demand the simultaneous perception of several targets for carrying out analysis and providing value. The most common reason for adopting RFID in interactive systems was the possibility of locating objects around in a long range, which allowed the implementation of almost exclusively implicit interactions. Long-range RFID readers enable these interactions, which cover a wide area of interest, performing constant readings. In some cases, readers perceive when actors enter an environment, yet implicitly. Humans and *things* represent nearly half of the actors, who usually carry tags, transparently or not.

Figure 3.7 – Link between interaction types, tag types, and user actions.

Even though papers were unclear about implicit interactions being a requirement, their recurrency suggests that using long-range RFID was a design decision for implementing ubiquitous systems. The tag type is directly related to the interaction type and the periodicity of readings, as illustrated in Figure 3.7. The figure suggests that interactive system designers select UHF RFID to locate tagged actors and constantly verify tags implicitly. Data is collected simultaneously in these systems, and users are not disturbed during their activities. Even papers addressing TTI (i.e., the system communicates with tagged *things*) present a human user, such as the driver in Transportation applications. System designers may not be aware of the several dimensions of ubiquity, such as the related quality characteristics (Carvalho et al., 2017).

While most of the systems we analyzed were in some way ubiquitous, only four papers briefly touched on this aspect (Jankowski-Mihułowicz et al., 2021; Vecchia et al., 2012; J. Zhang et al., 2017; T. Zhang et al., 2009). Of all the studies that addressed software quality, we could only discern that two (Vecchia et al., 2012; L. Zheng et al., 2018) managed to present all ubiquity-related characteristics. Some presented fewer characteristics due to the provided functionalities, such as a system not offering mobility because patients would not be monitored after leaving the room (Rodrigues et al., 2012)—however, most papers presented at most three ubiquity characteristics. In addition, reliability, performance, and general software qualities were addressed more than mobility. This observation suggests that despite the traits of these systems, some were not intentionally engineered to be ubiquitous. For instance, a study monitored patients but did not conceal the infrastructure nor provide evidence of functions being adapted based on collected data to make it context-aware (Rajesh, 2013).

Even though many interactive systems were implemented in the healthcare domain, they were often implemented in a controlled manner, such as monitoring the entrance of a hospital or a patient's room. This could be attributed to electromagnetic interference (EMI), which can occur with some medical equipment (Censi et al., 2012). Among the affected devices are ventilators (Iadanza et al., 2013; van der Togt et al., 2008), defibrillators (Iadanza et al., 2013; Seidman & Guag, 2013), syringe pumps (Seidman & Guag, 2013; van der Togt et al., 2008), and infusion pumps (Seidman & Guag, 2013; van der Togt et al., 2008). IEC 60601-1-2 (International Electrotechnical Commission, 2014) defines requirements for electromagnetic compatibility in medical devices to work satisfactorily in an electromagnetic environment without introducing intolerable disturbances. Nine solutions used passive UHF RFID. Two used active tags, two used LF or HF tags, one used both, and one did not specify. A study that opted for passive UHF reported EMI occurring in the transmission of biometrics (Y. Kim et al., 2016). Others did not report EMI. Designers of interactive medical systems should carefully consider the project's financial feasibility for using active tags and thoroughly understand if the hospital's medical devices could be affected. The correct application of IEC 60601-1-2 would greatly benefit the development of safe and ubiquitous software systems in these domains.

Among the conventional quality characteristics, the performance of RFID infrastructure was specially addressed. The hardware's simplicity brings limitations intrinsic to the technology, such as the maximum reading distance and the time taken for a reader to read nearby tags. These features may be very limited in some cases and are linked to the selected radio frequency and the passiveness of the tags. Zhang et al. (J. Zhang et al., 2017) point out a trade-off between sensing capabilities and RF communication, so the interactive software systems that collect parameters from actors should be especially wary. These limitations should be handled as a future challenge for the technology (J. Zhang et al., 2017). The reliability of the communication between RFID tags and readers is also a concern due to technology limitations, e.g., expected data may not be delivered or read with errors.

Furthermore, communication depends on the physical health of a fragile piece of hardware, which must not be trusted blindly. Data stored in tags might be dirty if damaged, or the sensor may have collected them without further refinements. As a result, sensors may be broken, and their single readings do not necessarily represent the environment well. On the other hand, data fusion may increase sensing quality (Okafor et al., 2020). Tag data may also be affected by security problems. RFID readers can collect the tag's data outside the interactive software system. For example, if a tagged patient is near a hospital's entrance, an RFID reader in the building in front might collect or rewrite the tag's contents. Likewise, if tagged food is in transit during a logistic process, a reader in a nearby vehicle can read it. Papers addressing this concern proposed algorithms to mitigate the problem, although it is still an open issue.

Considering all the previously described RFID features and limitations, we can provide general recommendations, such as avoiding RFID in metal environments, minimizing RFID readers due to their high price, avoiding RFID in large areas due to the need for many readers, and, where applicable, using RSSI (Received Signal Strength Indicator) to estimate the distance of tags and to implement multilateration with several readers. Since tags have a unique identifier, an interactive software system should also register tags beforehand in a database to relate them to a specific actor.

Moreover, some recommendations can be set for designers and developers of IoT software systems. Two guidelines to support IoT application development were analyzed: (1) The first presents an evidence-based *roadmap for IoT* composed of eight facets or perspectives (*Things, Problem Domain, Behavior, Interactivity, Data, Environment, Connectivity, and Smartness*) (Motta et al., 2023) and (2) the second offers the *Thing*

*Commandments*, a list of eight guiding principles for stakeholders involved in IoT projects, focused on ownership and usage of *things* (Oriwoh et al., 2013). The roadmap and the commandments apply to adopting RFID in interactive systems.

Recommendations can be considered for each facet of the roadmap. Notice that all covered points apply to RFID or any other radio-frequency technology. The ***Things*** facet represents the physical realm, comprising the definition of necessary components and their attributes, besides strategies for protection and identification. RFID tags are associated with actors, so they must not be transferred or reused; otherwise, the interactive system could make incorrect deductions about who is interacting. Also, the environment must not contain devices that suffer electromagnetic interference. The recommendations apply to radio-frequency technologies in general.

The **Problem Domain** facet defines objectives, motivation, stakeholders, and other project decisions. RFID or other UHF radio-frequency technology should be primarily adopted to identify and locate actors. System designers must investigate the system's stakeholders and direct users' roles and characteristics to determine whether they will correctly use the technology.

The **Behavior** facet comprises selecting technologies for identification, sensing, and actuation where applicable and defining a monitoring strategy and interaction rules. Apart from verifying the occurrence of electromagnetic interference, the monitoring strategy must be chosen between selected constantly or eventually. Even for constant monitoring of the environment, the system designer must define the interval between readings to optimize performance efficiency and data reliability.

The **Interaction** facet comprises the characterization of actors and their interaction methods. Any object directly or indirectly interacting with RFID must be identified, and possible incompatibilities must be investigated. Passive UHF RFID permits the implementation of implicit interactions while promoting the transparency of ubiquitous systems. The same applies to other technologies, such as Wi-Fi and BLE, except for a loss in Transparency due to the size of sensing devices.

The **Data** facet concerns capturing and treating data from the environment and other devices, comprising data models, privacy issues, and temporality. The system designer must plan which data will be captured (e.g., an object's location, a user's biometric data), the frequency at which the data will be collected for updates, and the *thing*'s data lifecycle.

The **Environment** facet defines relevant information about the place holding *things*, actions, events, and people. Sensors should be set strategically inside the environment to collect location data about the actors in the best way. Readers should be set at a suitable distance from each other to reduce ambiguity in tag readings. The distance depends on the frequency of the selected radio frequency technology.

The **Connectivity** facet refers to the connection among *things* themselves. In addition to the connection between tags and readers, communication and transport protocols must be selected considering the specific requirements of the interactive system. If the system designer adopts Wi-Fi or BLE, it can locate and communicate.

The **Smartness** facet refers to the orchestration associated with *things* and the level of intelligence. We argue that the reasoning behind adopting RFID is profiting from its simplicity and ubiquity, intending to transform conventional interactions towards human-centric ones by implementing implicit interactions (Stephanidis et al., 2019). Therefore, the system should be engineered to implement further smartness, such as context awareness (Abowd et al., 1999) and situation awareness (Endsley, 1988a).

The *Thing Commandments* (Oriwoh et al., 2013) provide principles applicable to RFID. *Things* must only respond to owner commands; otherwise, it would configure illegal access. This concern applies to explicit interactions. Therefore, a security strategy may be adopted to verify if the users are themselves. The humans involved in the interactions reserve the right to decide whether they will be part of the system. e.g., they can refuse to have an implanted tag or even to carry other *things*. Once users accept to be identified by RFID, they may decide to dispose of it at any time, and the disposition procedure should be easy. *Things* sharing some relationship, such as tagged objects of the same type, should belong to the same network, identify each other, and communicate among themselves. For example, using this functionality, one object could recommend using another object of the same type in better condition.

This systematic mapping did not adopt the PRISMA standard, a framework for ensuring quality in systematic literature reviews (Page et al., 2021), due to its technological nature. However, future replications should consider incorporating PRISMA to enhance the transparency and rigor of the research process.

## 3.3 Investigating Other Indoor Technologies

A systematic mapping was previously conducted to delve into the use of RFID technology in interactive systems. Although the analyzed papers focused on RFID, the results extend beyond this technology. The studies described various projects where RFID was applied as an identification and localization solution. Among these projects, most implemented implicit interactions through constant readings between readers and tags (Figure 3.3 and Figure 3.7). The readings are based, in some cases, on the fact that the tag was detected by the reader, and in other cases, they rely on RSSI to estimate a distance.

The limitations (Figure 3.5) of RFID technology in these software systems are, in fact, limitations of radio-frequency technologies, such as issues with metallic environments, insufficient reading range, and occurrence of false positives and negatives. Characteristics such as not requiring batteries or low cost are attractive for RFID specifically. Still, they work well indoors, do not rely on contact, and can complement other sensor data (Figure 3.2), referring to radio-frequency technologies in general.

The systematic mapping showed that many systems did not rely solely on RFID to perform their functionalities. Some integrated with cameras, while many others used RFID tags with embedded sensors. RFID cannot communicate with middleware and needs network protocols like Wi-Fi and BLE, which use messaging protocols like MQTT or CoAP. RFID systems can be expensive depending on the number of readers, and although tags are cheap, readers are costly. Infrastructure can be more affordable if it uses devices with Wi-Fi, which supports RSSI for location and allows network communication. Using Wi-Fi, BLE, and UWB, among others, instead of UHF RFID does not significantly change the positioning functionalities, except for identification, due to the absence of a unique identifier.

In other words, the study focused on RFID made us realize that the primary reason for adopting it in interactive systems is due to its radio frequency characteristics. Since our proposal involves developing a metamodel that allows the generic implementation of IoT systems for the location and use of medical equipment, limiting it to RFID would be detrimental to the design of the IoT systems. The metamodel should represent not only RFID but any other UHF radio-frequency technology. Additionally, cameras and sensors should be included in the modeling.

Therefore, we conducted an ad-hoc review in search of secondary studies on technologies and techniques for indoor localization. This research is not intended to be as extensive and detailed as the systematic mapping previously conducted. It was decided to search for secondary studies as they analyze various primary studies and provide well-founded conclusions on the possible methods. In other words, this review aims to discover what techniques and types of data can be collected to determine where objects are within the environment based on robust research on the available subject. Five studies reached similar classifications (Basri & Elkhadimi, 2020; Farahsari et al., 2022; F. Gu et al., 2020; Hayward et al., 2022; Khan et al., 2021). The selected studies will be briefly summarized as follows.

- **(Basri & Elkhadimi, 2020)**: This study reviews indoor localization technologies in IoT software systems. The technologies discussed include Wi-Fi, inertial sensors, infrared, RFID, ultrasound, ultra-large band, and hybrid systems. Even though the study does provide a classification, those technologies encompass radio-frequency systems, light systems, inertial systems, and sound-based systems. It highlights relevant characteristics of indoor localization, such as precision, accuracy, complexity, scalability, cost, and privacy. The study cites proximity, triangulation, multilateration, dead reckoning, and fingerprinting as location methods.
- **(Hayward et al., 2022)**: This study reviews indoor positioning systems (IPS) and indoor location-based services (ILBS) applied in the industry of cyber-physical systems (CPS). It compares location technologies and classifies them as inertial systems (e.g., accelerometer, gyroscope, and magnetometer), *network systems* (e.g., Wi-Fi, Bluetooth, RFID, UWB), *acoustic systems*, and *computer vision systems* (e.g., cameras, barcodes, infrared). Different techniques can be applied for each classification, such as dead reckoning for inertial systems, proximity based on RSSI for network systems, time of flight for acoustic systems, and scanning for vision systems.
- **(Farahsari et al., 2022)**: This study reviews Indoor Positioning Systems (IPS) in IoT. It provides a classification of location technologies encompassing *radio-frequency* (e.g., Wi-Fi, BLE, RFID), *light/optic* (e.g., VLC, cameras), or *sound-based* (e.g., ultrasonic sensors), in addition to classifying them as short-range or long-range. Each analyzes characteristics such as accuracy, precision, availability, cost, coverage, and energy efficiency. They briefly considered using gyroscopes, magnetometers, and accelerometers for positioning. It highlights that the Global Positioning System (GPS) is inefficient for indoor localization. GPS is not recommended as an indoor location technology because satellite triangulation does not work well indoors (Xiong et al., 2012).

- **(F. Gu et al., 2020)**: This study provides a review of indoor localization methods. It overviews proximity, triangulation, dead reckoning, and hybrid localization techniques. Among the possible location technologies that may apply these techniques are cameras, radio-frequency technologies (e.g., Wi-Fi, Bluetooth, Zigbee, UWB), inertial sensors (e.g., magnetometer, gyroscope, accelerometer, barometer), light sensors (e.g., infrared) and sound-bases sensors.
- **(Khan et al., 2021)**: This study presents a systematic review of localization schemes in IoT. It analyzes the localization techniques based on performance features such as localization accuracy, energy efficiency, target prediction, target recovery, and security. The study does not classify location technologies but indirectly discusses radio-frequency (e.g., Wi-Fi, Bluetooth, Zigbee), acoustic sensors, and infrared.

Although the five studies explore the same topic from different perspectives, they refer in some way to the same four classifications for indoor location technologies: *inertial systems*, *radio-frequency systems*, *acoustic systems*, and *vision systems*. *Inertial systems* measure the movement of a target and use it to estimate a specific direction. *Radio-frequency systems* calculate distance and proximity based on the signal strength of radio waves. *Acoustic systems* emit and capture sound waves and use the time between emissions to estimate distances from obstacles. *Vision systems* use cameras to identify objects or light emissions to detect objects or transmit data. In other words, if we can use these four possibilities to locate objects in indoor areas, such as health centers, they must be well represented in the proposed metamodel.

### 3.3.1 Inertial Systems

Inertial systems combine accelerometers, gyroscopes, and magnetic compasses, among others, to measure movement (Basri & Elkhadimi, 2020). Together, these sensors calculate direction, orientation, and rotation and use these measures to track a target in an environment over time. Dead *reckoning* uses direction and speed to determine the following position (Basri & Elkhadimi, 2020; Farahsari et al., 2022; F. Gu et al., 2020; Hayward et al., 2022). The *strap-down method applies inertial sensors onto a tracked object* while aligning the object’s three orthogonal axes. This setup captures the object's motion. Another method is the *step and heading*, which uses acceleration data to detect steps and determine the heading direction (Hayward et al., 2022). All these methods can be used altogether. Those methods are usable but complex for calculating precise positioning alone in an environment. Hybrid architectures (Basri & Elkhadimi, 2020; Hayward et al., 2022) may be composed by combining inertial systems with other strategies, such as cameras (F. Gu et al., 2020).

### 3.3.2 Radio-Frequency Systems

The location of a target can be estimated by using radio-frequency technologies (Basri & Elkhadimi, 2020; Farahsari et al., 2022; F. Gu et al., 2020; Hayward et al., 2022; Khan et al., 2021). They are also called wireless or network systems, given that the adopted technologies are usually ultra-high-frequency and compose a network for localization, such as Wi-Fi, Bluetooth Low Energy (BLE), Ultra-Wide Band (UWB), and RFID. All studies consider Wi-Fi a robust option, relying on existing public or private networks. Even though Wi-Fi is a network protocol, the same infrastructure can be used to enable positioning.

These technologies use the *Received Signal Strength Indication* (RSSI) to detect the proximity between a radio emitter and a radio receiver. Two techniques may use RSSI: *Proximity* and *Multilateration*. *Triangulation* is another technique that can be used, but it interprets distances based on the angles from reference points (F. Gu et al., 2020). *The proximity* method in radio-frequency systems determines a device's location by sensing whether the object is close to a known location. Wi-Fi station devices scan Wi-Fi access points (AP) in their range for ultra-high radio-frequency systems. The same method applies to low or high-frequency systems where readers touch NFC or RFID-enabled devices. (F. Gu et al., 2020). Multiple scanning devices may record RSSI from the same access point; in this case, the highest RSSI determines the closest device (Hayward et al., 2022). *The multilateration* method uses RSSI to estimate the distance from an object to at least three reader devices, from which the distances are used to calculate the exact location in the environment (Hayward et al., 2022). As the number of readers increases, the accuracy and reliability will also increase (Farahsari et al., 2022).

### 3.3.3 Acoustic Systems

*Acoustic systems,* usually composed of *ultrasonic sensors,* emit, receive, or reflect sound waves. This strategy is limited to small distances, and the detected objects or obstacles depend on the line of sight, i.e., the object must be in front of the sensor. Their slow propagation speed permits the implementation of the *Time-of-Flight* method, which calculates the round-trip time of a signal between emitter and received, ranging up to 15 meters. The *Time of Arrival* method is similar but measures the arrival time of a signal from the emitter to the receiver (Basri & Elkhadimi, 2020; Farahsari et al., 2022; F. Gu et al., 2020; Hayward et al., 2022; Khan et al., 2021).

Acoustic systems enable localization in specific situations. E.g., an ultrasonic sensor can be placed facing the commonplace of a particular object. If the sensor does not detect this obstacle, it deduces that someone has taken it. Ultrasonic sensors can be used in hybrid systems, where data is combined with others, such as radio-frequency devices or inertial sensors. Ultrasonic sensors may detect movements in and out through a door, while radio-frequency devices detect that a particular piece of equipment is no longer in the room. This way, an IoT system can infer that someone took and left the object.

### 3.3.4 Vision Systems

Vision systems rely on visual/optical strategies for locating objects, frequently using cameras and infrared (IR) or visible light communication (VLC). *Cameras* capture scenes, subsequently compared with data in a known database for analysis. Simultaneous Localization and Mapping (SLAM) algorithms may be applied to create environmental maps of what is being captured (Hayward et al., 2022). Cameras can be a solution in cases where radio-frequency systems are not allowed; however, they require high-resolution and heavy processing.

*Infrared (IR)* is applied in home automation and robotics for remote controls and obstacle detection using invisible light to the human eye. LEDs emit IR signals decoded by sensors or IR cameras to provide location information. IR systems are limited to a ten-meter line-of-sight like acoustic systems (Basri & Elkhadimi, 2020). *On the other hand, visible light communication (VLC) uses visible light to transmit data by flickering, which, in turn,* is detected by cameras. This method is accurate, low-cost, and may be applied by attaching LEDs to objects (Farahsari et al., 2022).

Computer vision algorithms can perceive the kind of object in a video but not necessarily which instance of the object. For example, it may not be possible to identify which wheelchair is being filmed if all look the same. Therefore, cameras must be used with other sensors in hybrid systems to locate objects accurately. They might also face resistance from users unsure if the cameras monitor them instead of the objects. Infrared (IR) and Visible Light Communication (VLC) are limited strategies that can only accurately locate objects when combined with other sensors. IR is applied similarly to ultrasonic sensors. Both cameras and VLC may fail to detect the presence of an object if there are obstacles in the way.

## 3.4 Threats to Validity

Several threats may affect the validity of the results in the systematic literature mapping. A classification was followed, which considers the importance of descriptive validity, theoretical validity, interpretative validity, and generalizability (Petersen et al., 2015). This classification applies to secondary studies, such as systematic mappings.

**Descriptive validity** is the extent to which observations are described accurately and objectively. In some cases, the information extracted by papers might not have been adequately interpreted due to the lack of definitions, especially for the restrictions and quality characteristics. Therefore, the contents were interpreted to relate to descriptions of quality characteristics to mitigate this threat. In addition, the data extracted from papers were classified together to cluster recurring information.

**Theoretical validity** is determined by our ability to capture what we intend to capture. For example, the search string might not have captured several important papers due to the lack of additional vital terms. Therefore, the search string was revisited several times before the first execution. The papers were verified until researchers and advisors considered them suitable and comprehensive for mitigating this threat. Snowballing is intended to minimize this risk.

**Interpretive validity** is achieved when the conclusions are drawn reasonably given the data, hence mapping to conclusion validity. RQs 2, 3, 4, and 5 might have been too subjective, leading to biased analysis. In addition, traditional quality characteristics, ubiquity-related quality characteristics, and measures have been interpreted based on the author's background and the descriptions provided by the analyzed papers. Furthermore, the researcher performed the procedure, possibly leading to a biased initial set, extractions, and quality assessment scoring. Therefore, the advisors accompanied and constantly reviewed the whole procedure to mitigate this threat.

**Generalizability** applies to the mapping results considering the research questions, both internal (within the population) and external (between different populations). The results were not too general, given that only two papers addressed agriculture, and none addressed animal monitoring. The decision not to use specific-domain databases may have limited the inclusion of relevant studies, potentially excluding high-quality research. This choice aimed to focus on a broader characterization of RFID technology across application domains but inherently impacts the generalizability. The second execution did not perform snowballing, which may have led to the loss of additional studies. However, we mitigate that since it updates the results with papers till February 2023. In any case, a comprehensive search engine was selected (Scopus), and snowballing was applied in the first execution, bringing a great variety of other topics to mitigate this threat.

## 3.5 Conclusion

The systematic mapping on the use of RFID in interactive systems looked for studies with projects where RFID was used as a means of interaction. Our focus on RFID was due to its ability to **identify** and **locate** objects and **communicate** data, which meets the research proposal and IoT requirements. The systematic mapping sought to determine (1) application domains implementing RFID, (2) the reason for adopting RFID in projects, (3) who interacts with RFID in the project and **how** the interaction occurs, (4) its **characteristics** and **limitations**, and (5) the related **quality characteristics**. In most cases, UHF RFID was adopted to implement **implicit interactions** where tagged objects were detected near RFID readers for localization and monitoring purposes. Similar results could be achieved with other technologies like Wi-Fi and BLE. Some projects integrated RFID with cameras and sensors, showing that RFID alone cannot always satisfy all system requirements, leading to the need for hybrid systems.

The ad-hoc research on indoor localization aimed to extend the systematic mapping on the use of RFID in interactive systems, considering that RFID is just one of the possible radio technologies that allow inferring location. As we propose a metamodel enabling the construction of IoT applications for managing location, it is crucial to provide the necessary tools for system designers to implement localization as they prefer, according to the health center's requirements. This research analyzed five secondary studies on indoor localization, which had already investigated several primary studies and reached well-founded conclusions. The analysis of the five studies altogether showed that this type of localization can be implemented through (1) **inertial** sensors, (2) **radio-frequency** technologies, (3) **acoustic** sensors, or (4) **cameras** and light sensors. Among these, the most common, simple, and accurate is through radio-frequency technologies.

# 4 Design and Evolution of a Metamodel to Support the Creation of Applications for the Management of Location and Use of Medical Equipment

This chapter presents the **Metamodel Conception** (Figure 4.1), which encompasses its creation and iterative evolution, gradually including fundamental concepts previously researched in the literature investigation. First, before starting the design, we interviewed health professionals to understand better how the medical equipment is used in daily activities. The literature investigation did not address such a point of view concerning the medical context. Research on IoT and context awareness resulted in a first representation, research on indoor localization resulted in a second representation, and research on situation awareness, plus results of the interviews, resulted in a third representation. Two proofs of concept were developed to evaluate the first and third representations.

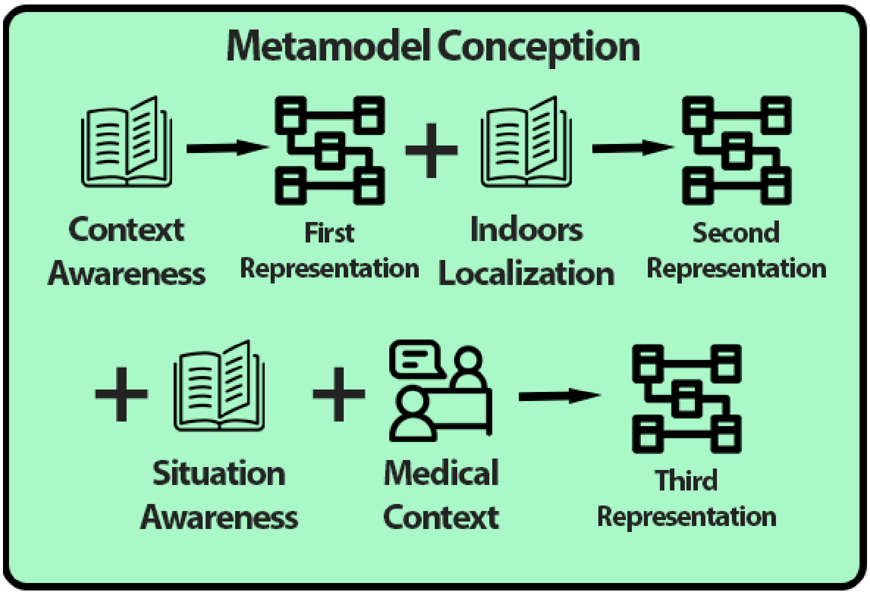

Figure 4.1 – Studies that contributed to the design of each representation of the metamodel

## 4.1 Interviews with Health Professionals

So far, research on technical concepts has been conducted based on literature, but not yet about the medical context. It is crucial to understand which types of equipment are used in health centers, their characteristics, how they are used, the procedures such as maintenance and cleaning, and the problems professionals commonly encounter with them. These aspects need to be represented in the modeling to ensure that the generated IoT systems meet the expectations of the health center. While another literature review could provide these answers, we obtained them more vividly through **interviews** with health professionals.

This approach allows us to gather real-life accounts of their daily work, with actual and practical examples of problems that could later be used to instantiate the metamodel. Such interviews allow us to understand the receptiveness when introducing new technologies in a health center. Listening to medical professionals is crucial for understanding how digital transformation could be applied to their working routines (Frisinger & Papachristou, 2023). Health centers may vary in size, types of professionals and their activities, the existence of patients, types of equipment, and working rules, among other *things*. Our interviews explored the use of medical equipment, specifically in hospitals. Other health centers may have different characteristics from hospitals, leading to the need for additional future research in various contexts.

In interviews, the researcher asks a series of questions to subjects about the areas of interest (Wohlin et al., 2012). It is a data collection method for eliciting a vivid picture of a participant's perspective on the research topic (Wohlin & Aurum, 2015). We opted to prepare semi-structured interviews (Wohlin et al., 2012; Wohlin & Aurum, 2015) as our method because they are interpersonal and permit improvisation based on the planned questions. i.e., during the interview, the interviewees may be more open to discussing sensitive topics, the interviewer may ask unplanned questions, and it is possible to paraphrase queries or provide further explanations until the interviewee understands the focal point of each question. The interviews were descriptive, i.e., intended to understand and describe the problem through the reported experiences. A set of 20 questions (provided below) was prepared to be applied to every interviewee, regardless of their specialties. A research question was composed for the interviews: **How can the location and management of medical equipment be supported to facilitate their utilization in hospitals?**

### 4.1.1 Planning and Execution

The interviews occurred in December 2022 and January 2023. The interviewees were health professionals working in a French hospital comprising nearly 4500 health professionals. The participation invitations were based on their experiences and due to occupying a chief position. Those who accepted were (1) a geriatric nurse, (2) a diagnostic radiologist, (3) two device pharmacists (interviewed together), and (4) a biomedical engineer. These specialties are very distinct, so their experience reports would probably provide different points of view on the use of medical equipment. Participation was based on the invitees' available schedule. Their details are summarized in Table 4.1.

Table 4.1 – Interviewee’s details

| Interviewee’s specialty | Years of Experience | Position |
|---|---|---|
| Geriatric Nurse | 16 years | Head of the geriatrics |
| Diagnostic Radiologist | 15 years | - |
| Device Pharmacist (1) | 20 years | Head of the device pharmacy |
| Device pharmacist (2) | 13 years | - |
| Biomedical Engineer | 19 years | Head of the biomedical services |

The interviews were conducted face-to-face with the nurse, the radiologist, and the biomedical engineer in their rooms. The interview was a videoconference with the pharmacists due to difficulty finding a time slot. The interviews lasted around one hour each. In addition, the audio was recorded for further analysis. A non-disclosure agreement was signed by each interviewee and by the interviewer to guarantee anonymity and to ensure that recordings would be deleted after one year. Due to the interviewees' job positions and experience, the anonymity guarantee, and the actual content of their answers, it seems unlikely they did not answer potentially sensitive questions correctly.

The interviews begin with introductory questions, including the interviewee's years of experience, previous experience with software systems inside the hospital, and a general inquiry about the difficulty of locating medical equipment. Amidst this introduction, the interviewer explains the research proposal in a non-technical manner: the aim is to develop software capable of providing real-time information on the location of equipment and other details, such as whether they are in working condition. Once the interviewee understands the proposal, the main questions begin. Their focus is on the equipment commonly used by their specialty, the specificities of using them, and any negative experiences. Depending on the flow of the conversation, the main questions are asked in different orders. The interview questions are listed below.

- **Introductory questions:**
    1. How many years of experience do you have?
    2. What other experts work with you, and how many?
    3. Which activities does your specialty perform daily?
    4. (Yes/No) Do you have problems finding medical equipment inside the hospital?

5. Do you use any software that helps you in your everyday work? (If yes...) Which ones?

- **At this point, the interviewer details the proposition.**

6. Do you believe our proposition would be helpful in your work? Why?

- **Main questions:**

7. What equipment do you usually use daily? I mean any work-related object, including computers.
8. How is the equipment cleaning procedure done?
9. (Yes/No) When you find one of the equipment you mentioned, is it always guaranteed that the person who used it before properly cleaned it?
10. Could you describe a situation where you found dirty equipment and cleaned yourself? Does this type of situation often happen?
11. Which is the longest unavailable equipment due to being in use by patients?
12. Is there any medical equipment so widely used in the hospital that none is available when there are many patients? (If yes...) Which ones?
13. What happens when medical equipment breaks down or burns out? What is the maintenance procedure?
14. Could you describe any particularly negative experiences from losing medical equipment?
15. Is it possible for objects to be permanently lost? (If yes...) How?
16. Is any medical equipment frequently damaged? If so, what is the reason for this damage?
17. Are there restrictions on using specific medical equipment or even everyday objects such as mobile phones in certain rooms?
18. How is the management of medicines?
19. How do you know where the hospital staff is?
20. Do you have any comments or suggestions?

The interviewer avoided making notes and focused on the conversation to extract as much information as possible and detect the possibilities of improvising questions. The audio recordings were subsequently transcribed into text files for further analysis. The transcribed texts were interpreted together to obtain the following:

- occurrences of **activities**, **equipment**, and **software**,

- descriptions of **cleaning** and **maintenance** procedures,
- description of **medicines** management,
- **characteristics**, **restrictions**, and **patterns** related to equipment,
- information on the location of **people**: staff and patients,
- interviewees' opinions and suggestions.

The interviews were conducted in French. They were audio-recorded, transcribed in French, and later translated into English for analysis. This translation was carefully done to ensure that the essence of the responses was not lost. Information that could potentially be important for composing the metamodel or permitting its future instantiation was collected from the transcribed English texts.

### 4.1.2 Analysis of the Interviews

The interviews with the nurse and the radiologist provided information about the **physical environment**: the hospital comprises different **sectors**, each with various **rooms**. Specialized medical equipment is expected to not move from one industry to another. However, a single sector can be spread across multiple floors, making it challenging to locate specific equipment. After the interview, the nurse showed us the bladder scan equipment for checking urinary retention, used numerous times daily with various patients. It is costly, so the hospital has only one. Due to the large size of the geriatrics sector, nurses often need to search across multiple floors to find it.

Depending on the **rules of an environment**, some equipment may be restricted. The nurse says that in the context of infections, when patients are in isolation, personal belongings must not be taken to the room. Potentially dangerous tools must not be left near patients with extreme agitation. The radiologist states that metallic objects must not be used in imaging rooms. The biomedical engineer says ventilators and gas cylinders must also not be taken to imaging rooms. In other words, the **type of material** used for equipment is a vital characteristic to consider before moving it into a room.

For ethical reasons, staff and patients cannot be in this hospital. All interviewees stated that badges could identify staff entering and leaving the building. However, knowing where they are while inside the hospital is impossible. The same restriction applies to patients.

The nurse also presented the patient-lifter, which helps lift patients who cannot quickly move to a wheelchair. It comprises harnesses attached to fixed lanes on the ceiling. This means that equipment may consist of multiple parts or **depend on other**

**equipment**. Considering lanes as separate, equipment may be **fixed** or **mobile**. Similarly, equipment like magnetic resonance imaging (MRI) is fixed in a single room, not requiring location management, only usage management. The radiologist emphasized that managing MRI usage data would be valuable for hospital administration. The types of objects mentioned by the interviewees include:

- Common **medical equipment** such as oximeters and MRI,
- **General-use equipment** such as carriages that transport other devices,
- **Resources** like clothing,
- **Notebooks** used to record performed tasks,
- **Biomedical materials** such as ultrasound gel and disinfectants,
- **Medicines**.

Some characteristics impact how an object is used. As mentioned, fixed equipment does not need tracking and will never be lost. The **size** may also be necessary: Oximeters are small and easily lost. The nurse and the radiologist reported cases in which small equipment was stolen. The radiologist stated that biomedical materials are not often lacking, but requests are made to the pharmacy when they are. The device pharmacists claim that they do not suffer from the loss of equipment; therefore, the proposed solution is irrelevant. However, they state that it would be very relevant in emergencies, where health professionals struggle to find pumps, mobile beds, and wheelchairs when a new patient arrives.

All interviewees stated that the pharmacy manages and produces medicines and biomedical materials. Materials are requested in significant quantities from time to time. Medicines are ordered for inpatients by the physician, who makes the prescription and sends it to the pharmacy. Pharmacists verify the prescriptions and submit them to a robot that produces the medications, separates them into boxes for each patient, and sends them to the hospital.

Concerning **cleaning procedures**, the nurse states that clothes are taken to the laundry while other objects are always disinfected after use. The radiologist also disinfects the MRI after each use. Items like injections are used and then discarded. The nurse mentioned that sometimes clothes are lost during the washing.

Among the **activities** practiced by health professionals, we may cite that geriatric nurses perform blood testing and check urinary retention. Radiologists perform mammograms and biopsies. Device pharmacists produce prostheses and implants.

Biomedical engineers purchase and manage medical equipment. Medical equipment may be involved in each type of activity. Depending on the kind of staff using equipment in a particular room, a software system may infer possible activities being performed. This aligns with Activity Recognition (Vail et al., 2007).

Notebooks are used throughout geriatrics for nurses to report the status of inpatients, such as recording if a medication was taken. The hospital's use of them is essential because it indicates that professionals are already familiar with other software systems. The same notebook could be used to display information about the location of equipment in the future. However, the nurse reported that the hospital's Wi-Fi network is weak, hindering the real-time updating of patient’s data. The presence of Wi-Fi is positive, suggesting that it does not interfere with medical equipment. However, its weak signal indicates that Wi-Fi may not be a localization technology, leaving room for other solutions such as BLE or RFID.

The interviewees use several software systems to assist their work, such as image-related software in radiology. Among those related to equipment management, the nurse showed us DIMO Maint, a CMMS for opening tickets in case of malfunctioning equipment. It is only used by nurses. The radiologist says that the technician is directly contacted by phone in case of malfunction or a request is made to nurses. The biomedical engineer who knew about IoT technologies highlights that locating is already the case for some medical equipment. Those considered critical are augmented with third-party BLE, Wi-Fi, or RFID tags. These technologies are currently used for easy recovery, not for real-time tracking. Again, this claim suggests that it is possible to implement these three technologies to some extent in this hospital. The biomedical manager adds that RFID has never caused electromagnetic interference in this hospital.

Although locating objects is not a novelty, the biomedical engineer says that managing their states and using collected information to predict the future would be helpful in preventive maintenance. Besides financial gain, annual maintenance is expensive and could be gradually replaced by the system's predictions. The nurse also sees financial gain because the system would reduce purchasing new equipment when an object is not found. The radiologist and the biomedical engineer indicate that the hospital would profit from understanding which equipment is underused or overused.

The interviews provided valuable insights into the practical aspects of using medical equipment in a hospital setting. They highlighted difficulties in finding some kinds of equipment, such as the bladder scan that is unique for all the geriatric, the oximeters that are frequently lost due to being small, and mobile beds that are unavailable when a new patient arrives in emergencies. Managing the use of equipment would benefit this hospital by understanding usage patterns, detecting underused or overused equipment, and assisting in preventive maintenance. Integrating IoT technologies such as RFID, BLE, and Wi-Fi proved feasible based on software already in use in the hospital.

## 4.2 Metamodel Evolution

When the domain is complex, the realization of a meta-model usually involves several representations. It evolves progressively, with changes guided by various criteria linked to the domain's characteristics. This section provides a concrete and representative case of meta-model evolution, aiming to support the creation of IoT software systems for managing medical equipment's location and use while reducing user interventions.

Metamodel evolution is incremental and occurs as we gain a deeper understanding of the domain. New representations emerge based on **fundamental concepts** and validations that lead to structural changes or the realization of **new functionalities**.

- **Fundamental Concepts**: During evolution, we may identify that the metamodel still lacks certain fundamental concepts that must exist in the target software system. When such gaps are identified, the essential concepts must be researched, and their elements should be integrated with existing entities. For instance, a newly researched concept involving users should be merged with an existing User entity.
- **Validations**: When a metamodel undergoes new iterations, it is essential to validate it. Validations may reveal previously unnoticed issues. They may be theoretical, such as proof of concept, or involve complete software development. Validations can uncover conceptual flaws such as incorrect associations or missing behaviors and entities.
- **New Functionalities**: Even if a metamodel has been validated and appears complete, it may still lack the support of certain important functionalities that were not yet considered. For instance, literature may later identify a new data security algorithm not yet represented in the entities but essential for improving IoT system security. In such cases, even a seemingly robust metamodel must evolve to incorporate these new possibilities.

A metamodel was created and evolved using UML (Unified Modeling Language), grounded in its widespread adoption in software engineering. UML provides a standard and well-documented notation for representing entities, properties, and associations, making it accessible to a broad audience of researchers and practitioners. Given the authors’ experience with UML in prior projects, its adoption facilitated a more efficient modeling process.

The metamodel underwent three representations based on fundamental concepts. The **first representation** was built upon **context awareness** concepts applied to the **Internet of Things** while including **radio-frequency technologies** as localization strategies. A hypothetical **proof of concept** validated this preliminary representation.

The **second representation** extended the metamodel with additional indoor localization strategies besides radio frequencies. Approaches such as using cameras or sensors could improve indoor location possibilities. Only the technology-related classes were changed, and no validation was performed.

The **third representation** was built upon the specificities of the **medical context** and **situation awareness**, leading to a more comprehensive metamodel. First, a hypothetical **proof of concept** validated this representation. Later, it was tested by creating an IoT software system based on the metamodel as part of an **experimental study** (Section 5.3).

### 4.2.1 First Representation of the Metamodel: Internet of Things and Context Awareness

The first representation of the metamodel was built with UML after the systematic mapping of RFID use in interactive systems and before the review of indoor localization. The metamodel to be developed aims to support the creation of IoT software systems for managing medical equipment in health centers. New concepts were gradually incorporated into each representation. The first representation consists of IoT, context awareness, and radio-frequency concepts. Understanding the **meta-requirements** that guided the decisions leading to this initial representation is essential.

To represent **IoT**, it is necessary to consider that these systems identify, sense, collect, communicate, and interpret data about things. The modeling must account for **uniquely identifying** these *things* within the system. Sensing in these systems refers to the perceptions that lead to **deductions about location**. Communication for subsequent data interpretation should be done through protocols **capable of transmitting the data** to a middleware.

The metamodel must include characteristics of users, environment, and technology to represent **context awareness**. **Users** are responsible for **moving objects**, which alters their **locations and states**. The **environment** is where all interactions occur. Since the systems are being developed for health centers, this environment is **indoors**, **consisting of rooms** containing **rules** that vary depending on each user and equipment involved. The **technologies** should encompass both **software** and **hardware** that enable the implementation of IoT functionalities.

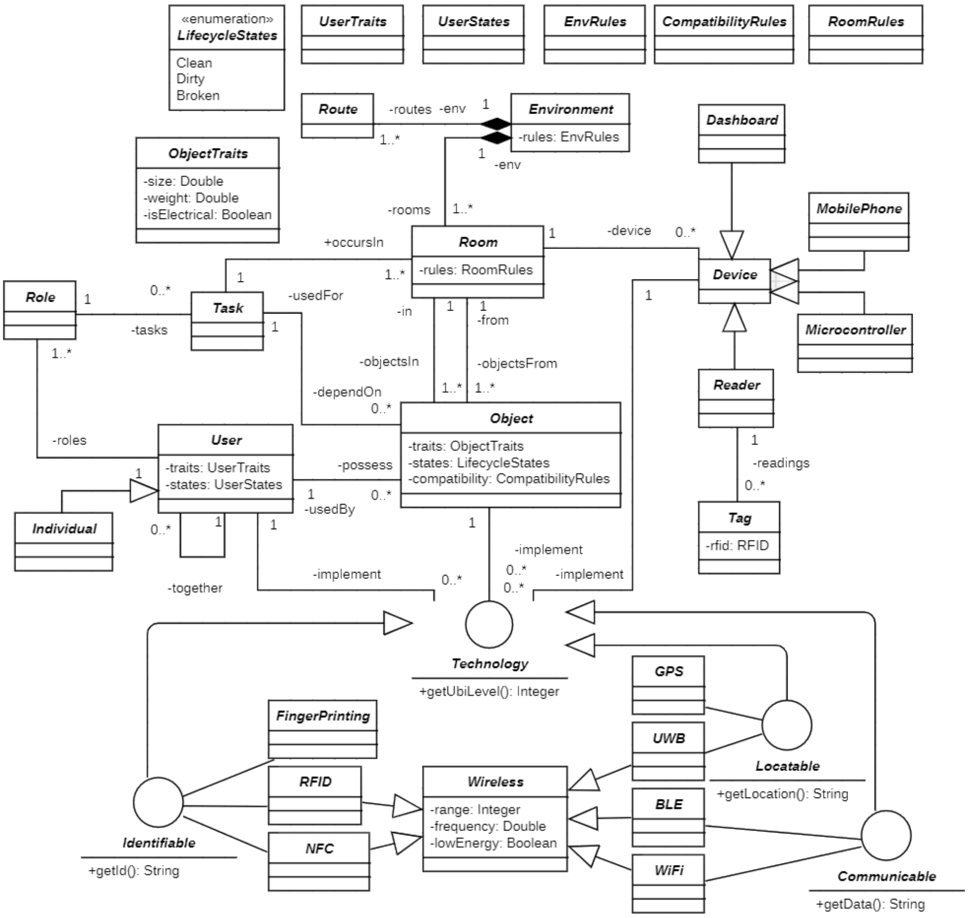

Figure 4.2 – First representation of the metamodel

The IoT software systems manage **objects**, so these must be represented as ***things***. They should implement the appropriate IoT functionalities for **identification**, **location**, and **communication**. It is necessary to know which **room** they are in and their **current state**. This information should **be made available** to users through output devices such as dashboards.

The modeling considers requirements from prior research on RFID adopted in interactive systems. All objects and their types should be known before the radio technology is adopted to ensure **no interference occurs**. RF is used to implement identification and location and should be a wireless technology to **enable implicit interactions**. The use of **Wi-Fi or BLE** is anticipated as a communication protocol. Other decisions, such as sensor reading frequency, depend on implementation rather than metamodeling. The first representation is presented in Figure 4.2. A metamodel is meant to be instantiated; therefore, all classes are **abstract**.

At the center of the metamodel is the **Object** class, which represents the objects to be managed. At this stage, medical context concepts have not yet been integrated to apply the metamodel generically for any object. The objects can implement technologies that enable **identification**, **localization**, and **communication**, as expected in IoT applications for location management. i.e., the objects can have a unique identifier, sensors can be implemented to allow localization, and protocols can be implemented to communicate data to a middleware.

**The technology** class represents the software in the **context**'s computational platform. It is modeled as an interface to allow the same courses to provide more than one functionality where necessary. Among those that enable **identification**, the modeling includes **RFID** (which uses the EPC code), **NFC** (which uses the UID code), and **Fingerprinting** (F. Gu et al., 2020). This technique uses predefined data for both identification and localization. Among those that enable **localization**, the modeling includes **GPS** and **UWB**. At this stage, GPS was not still disregarded. The modeling consists of **BLE** and **Wi-Fi**, among those allowing communication. These classes are just examples – they may be reorganized, and other technologies may be included according to system requirements. For instance, Wi-Fi alone could simultaneously implement all three functionalities. **The technology** consists of a behavior called **ubiquity level**, which aims to represent how ubiquitous a technology is compared to others. For instance, UHF RFID would have a higher ubiquity level than LF RFID. The adopted radio-frequency technologies enable the system to implement implicit interactions, such as automatically reading the parameters of objects while users keep working.

The **Device** class represents the hardware in the context's computational platform. As this representation considers only radio-frequency technologies, a **Reader** is included as a device capable of reading **Tags**. Other technologies besides RFID follow this architecture, such as Wi-Fi and BLE. Depending on the type of reader, it may need to be connected to a **Microcontroller**. Information about the location and use of objects must be made available to users, achieved through visualization devices such as a **Mobile Phone** or a **Dashboard**.

The **User** class represents the humans interacting with the software system within the **context**. A user is allowed to possess objects, affecting their usage parameters. Users have a **Role**, representing the parts they play in the context. For instance, users could assume the roles of a nurse or a physician in a medical software system. The User is formed by interindividual and intraindividual differences, respectively, traits (culture, preferences, personality) and states (psychological, cognitive, and emotional) (Braun & Alt, 2019). Both concepts are represented as properties. Users may also affect the behavior of other users (Poslad, 2009; Tesoriero & Vanderdonckt, 2010), represented by a self-association. Depending on the user's role, tasks can be performed, represented by the **Task** class. For example, a physician may consult while a nurse conducts a follow-up. The tasks may depend on objects to be correctly performed, such as a stethoscope during a consultation and an oximeter during a follow-up.

The Environment, Room, and Route classes represent the physical environment in the context. The environment is defined by the location, the infrastructure, and the physical conditions (Poslad, 2009; Tesoriero & Vanderdonckt, 2010), in addition to the rules contained in it (Trist, 1981). Technologies, users, and objects must satisfy the environment's rules. For instance, if a specific rule defines loud sounds as not allowed after 10 PM, this must apply to the whole infrastructure, including all rooms. Rooms can have their own rules as well. Routes refer to a path or rooms. The modeling sets the rooms as the smallest granularity for the location, i.e., an object can be in a room, but the system does not know where it is. Objects and rooms are associated twice: to represent where objects are in and where objects are from. Through these two associations, the software system can track the position of objects and inform whether they are in the correct location, such as a warehouse.

The **Object** has traits, such as its size, and a set of compatibility rules, such as requiring a specific temperature. In addition, the object may have states, such as being **Clean**, **Dirty,** or **Broken**. Implementing a lifecycle composed of these states enables the software system to manage the use of the object. For example, a particular object, such as an oximeter, is from a warehouse but is not there for one hour. So, the application understands the usage pattern and comprehends that it is not clean anymore. Movements between rooms and specific tasks can automatically change the states of objects to characterize how users use them.

A **proof of concept** illustrates the operation of an IoT software system implemented in a hospital based on the metamodel's first representation. Figure 4.3 presents the hypothetical hospital and summarizes the scenario. Every piece of equipment and every user contains an RFID tag. Equipment might be in Rooms A or B; therefore, these rooms contain RFID readers. Room C is a lobby with a dashboard that constantly displays the location of every object. RFID readers continually verify whether the equipment mapped to rooms A and B exists. RFID Readers are attached to microcontrollers that use Bluetooth (e.g., ESP32) to communicate the data to a broker. Figure 4.4 provides an instantiated model for this application, in which new or modified classes are highlighted in blue, and others were removed due to not being used in the example.

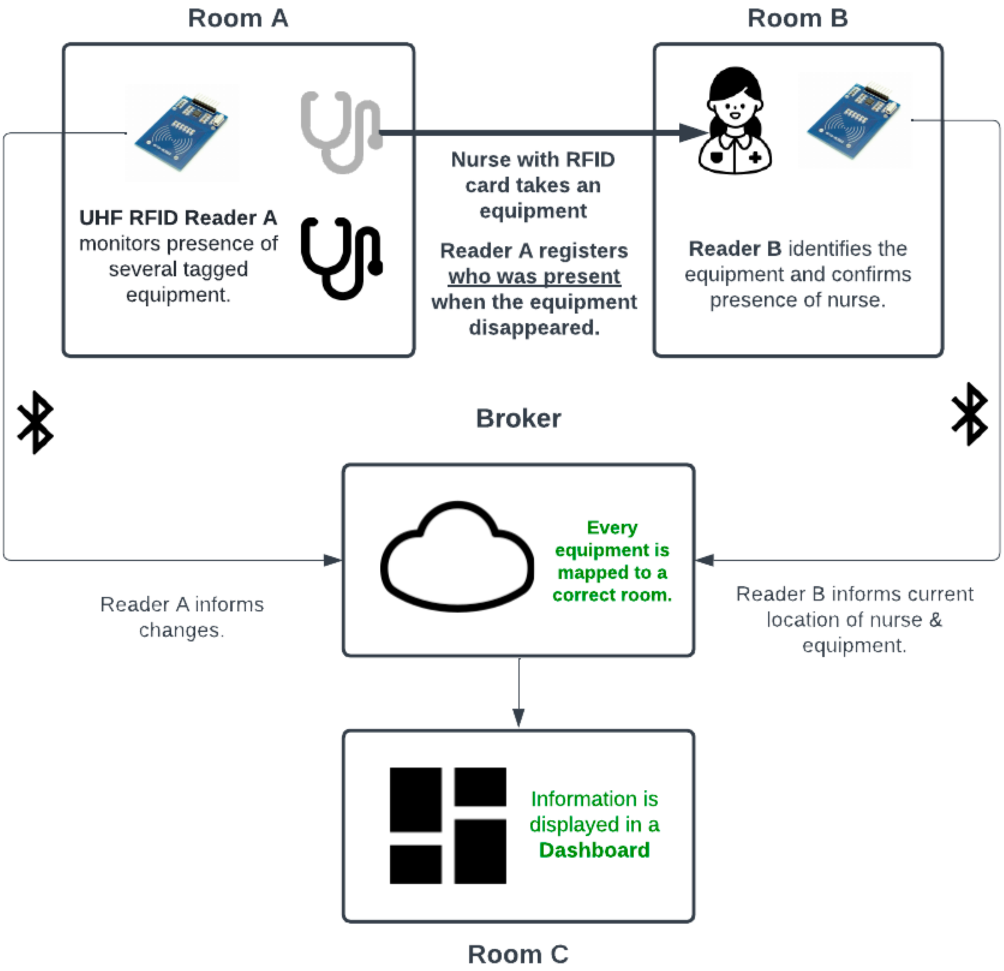

Figure 4.3 – Proof of Concept for the metamodel’s first representation

A nurse enters Room A, searching for a stethoscope. The nurse has an identification card with an RFID tag so the reader can detect who entered the room. The nurse takes the stethoscope and leaves for Room B. The reader in Room A notices that the stethoscope and the nurse who was there a little while ago have been displaced. The application processes this information and infers that the nurse may have left room A in possession of the stethoscope.

After a few minutes, the nurse enters Room B. The corresponding RFID reader identifies the nurse and the stethoscope. The application crosses both reports and deduces that the nurse took the stethoscope and left room A. The deduction may permit recognizing that a task such as a patient follow-up is in progress in Room B. However, who uses the stethoscope is simply a guess, given that countless coincidences might occur in an environment with many workers. The use may be attributed to different staff, for instance. The system is only sure about the current location of the stethoscope and knows that it is in use and is potentially dirty.

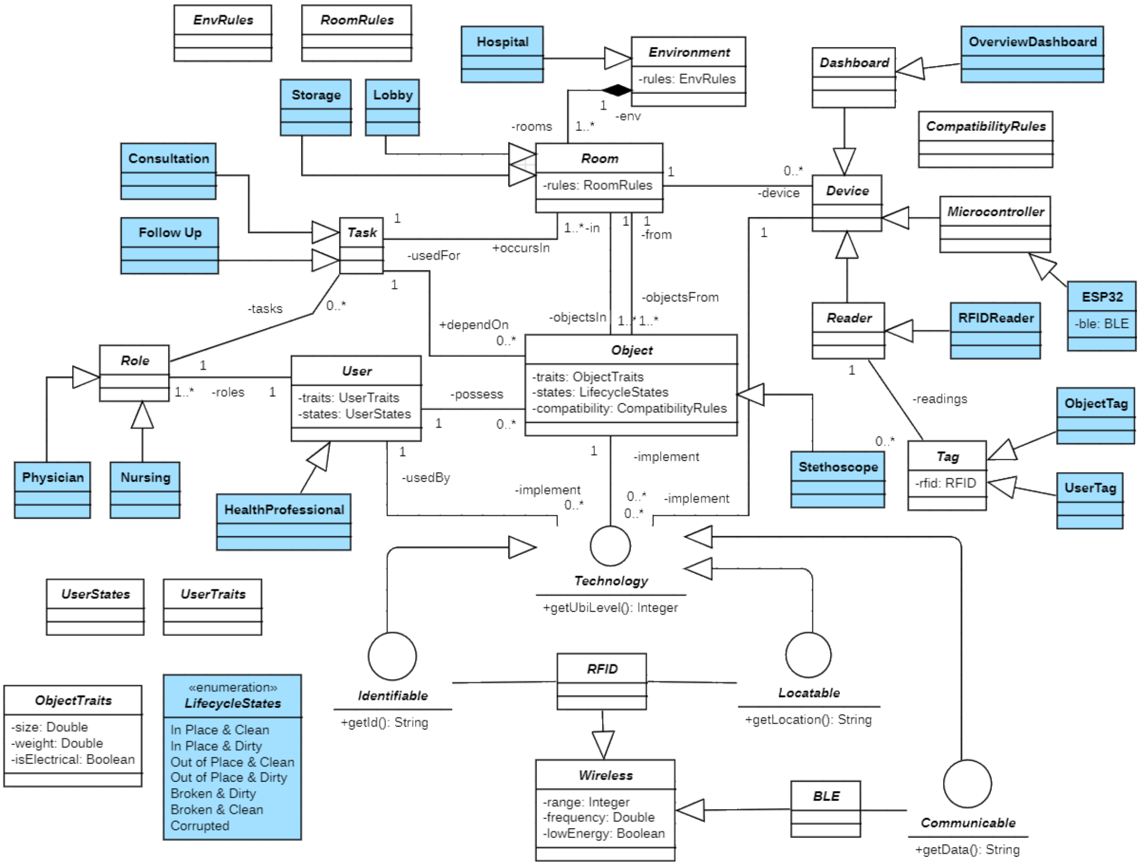

Figure 4.4 – An instantiated model for the first proof of concept

A physician arrives at the hospital and needs the stethoscope. The physician that it should be in Room A. Initially, the physician checks the dashboard in Room C to see if it is in use. Indeed, the dashboard shows that it is in Room B, possibly in use by the nurse. So, the physician goes there and asks if it could be borrowed. As a subsequent action, the system may detect that a different staff member is carrying the stethoscope and alert them that it might be used for a different task without following cleaning procedures.

Notice that the nurse acts as if there is no software system, simply taking the equipment and leaving. The work routine is not disturbed by explicit interactions. The system keeps track of users and equipment and performs the appropriate deductions to overcome the lack of user inputs. Ideally, querying the dashboard would be the only obligatory explicit interaction in this software system. An object diagram of this scenario, based on the first representation, is shown in Figure 4.5. The physician and the nurse are User instances. The nurse performs an attendance (Task) that needs a stethoscope (Object) and happens in Room B. Each room has a reader that is used to read the tag in the stethoscope. The physician is querying (Task) the Dashboard in the lobby (Room).

The scenario explores the software system's behavior when the location of the stethoscope is changed. The system can also manage the object's usage status based on users' actions. By maintaining a usage history, the system can comprehend the object's current situation through rules defined in a state diagram, shown in Figure 4.6, with values specified in the **Lifecycle States** enumeration.

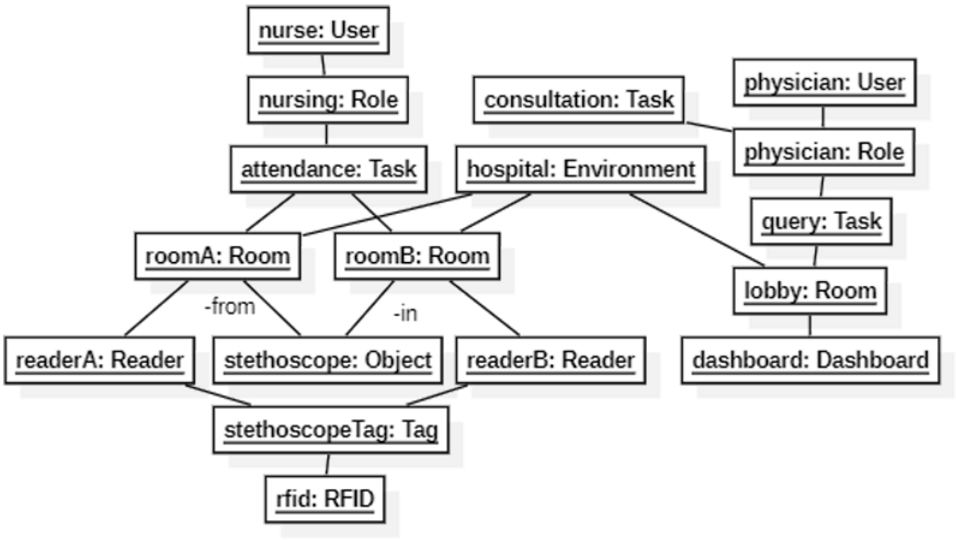

Figure 4.5 – Object diagram for the first proof of concept

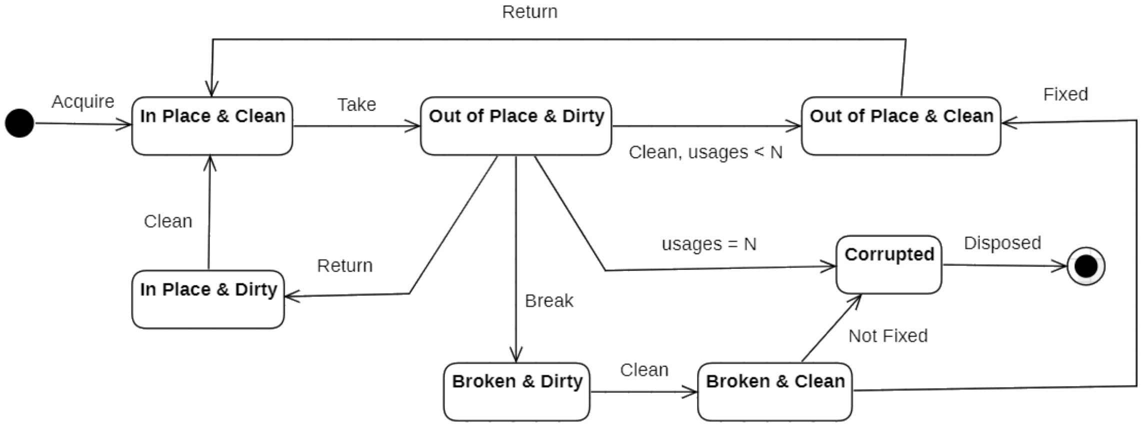

Figure 4.6 – Lifecycle states for the first proof of concept

Consider the stethoscope in Room A as an initial situation where the equipment is **In Place & Clean**. When the stethoscope is removed from Room A, it changes to **Out of Place & Dirty**, considered dirty since it has been used. If it were returned to Room A, it would enter the state **In Place & Dirty**. If the stethoscope underwent cleaning procedures but was not returned, it would enter **Out of Place & Clean**. It could also break, changing to the state **Broken & Dirty**. After cleaning, it would change to the state **Broken & Clean**. A technician could try to fix it, changing the state to **Out of Place & Clean** or **Corrupted** if the repair was unsuccessful. Based on preventive maintenance knowledge, the system could determine that the equipment is **Corrupted** after being used N times, so it can be discarded and replaced before any problems occur.

A state diagram like this should be defined for a software system to manage equipment usage effectively. It is important to note that, although we define a state diagram for the lifecycle of each object, it is not based on any generic state diagram. This is because the definition of relevant states depends on the application's **requirements**. For this proof of concept, we considered whether the object is in the correct location, clean, and functional. However, depending on the objectives of other proofs of concept, different information may be relevant. For the state diagram's definition, it is expected, at a minimum, that there is a default state indicating the object is available (e.g., **In Place & Clean**). Additionally, there should be a final state representing the conclusion of the object's use, either due to damage or reaching a certain usage time (e.g., **Corrupted**).

### 4.2.2 Second Representation of the Metamodel: Indoors Localization Technologies

The second representation incorporates improvements based on the results of the indoor localization review (Section 3.3). A thorough check was conducted, identifying flaws related to both software and hardware. The second representation incorporates new possibilities for how data is sensed in IoT. Previously, data sensing was only possible through radio-frequency technologies. However, other devices, such as cameras, inertial sensors, and acoustic sensors, can be used together to allow for data collection on location. As meta-requirements for the second representation, metamodeling must enable the developed IoT software systems to implement perception through various means beyond radio technologies, creating **hybrid localization systems**.

The differences between the first and second representations are highlighted in blue in Figure 4.7. All classes are **abstract**. First, interfaces were replaced by classes. While object-oriented programming languages typically do not support multiple inheritance, this concern should be addressed during the software creation process, not during the metamodeling stage. Identification, Location, and Communication Technology classes replaced the interfaces. New courses were added under Location Technology: **Radio Frequency**, **Vision**, **Inertial**, **Light**, and **Acoustic**, reflecting the findings from the review on indoor localization (Section 3.3). **GPS** was retained as a subclass of **Outdoor**. New classes were added under Devices: **Camera**, **Ultrasonic Sensor**, and **Motion Sensor**. The **Tabletop** class was included as a new type of visualization device. As this new representation merely extends the previous format, no proof of concept was developed. The new locating technologies, such as using sensors and cameras together with radio-frequency technologies, empower the possibilities of the software systems in implementing implicit interactions.

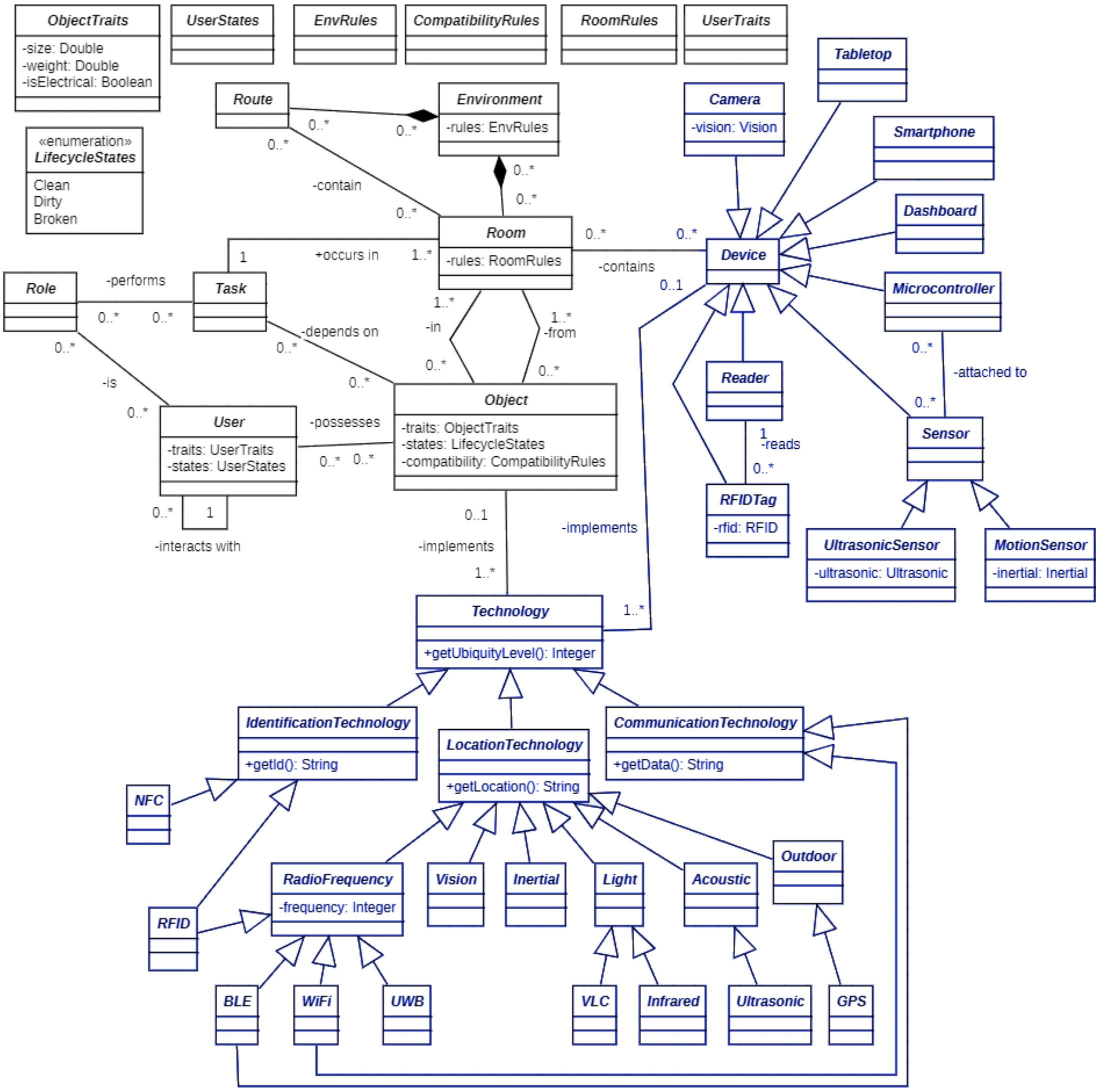

Figure 4.7 – Second representation of the metamodel

### 4.2.3 Third Representation: Situation Awareness and Medical Context

The third representation was enhanced with concepts of situation awareness and specificities of the medical context, learned during interviews with health professionals (Section 4.1). To represent **situation awareness**, the metamodel must consider that IoT software systems should be capable of **perceiving** what is happening and using this comprehension to **decide** if a particular **action** should be taken. The metamodel already includes various ways of perceiving objects in terms of location and state, and it also knows which activities users perform with these objects. Now, patterns must be comprehended to **provide functionalities**. Among the deductions, it should be possible to understand if users use an **object**, a **dashboard**, or **search** for an object.

The information obtained during interviews with health professionals can be partially used. Since hospitals are organized this way, the environment should include **sectors** composed of **rooms** among the meta-requirements. The **Sectors** refer to the thematic divisions within the hospital, such as administration, geriatrics, diagnostic support, and maintenance. Objects must explicitly indicate whether they are **metallic** and if they are **shared** between sectors. Other information obtained in the interviews applies only to instantiations, such as types of rooms and medical equipment, scenarios, and procedures.

The third representation is presented in Figure 4.8. All classes are **abstract**. A **situation** is a finite sequence of actions (Anagnostopoulos et al., 2007). Activity **Recognition** predicts activities depending on previous and future states (Vail et al., 2007), a concept strongly related to situation awareness. Due to this, the **Task** class was renamed to **Activity,** and a new **Situation** class was added. A situation is composed of a set of activities positioned in time. i.e., we may characterize a situation by a sequence of activities that happened in a time interval. The previous representations did not model temporal awareness, such as indicating the order of tasks, hindering software systems from storing historical data about objects. The **Activity** class is organized as a linked list, indicating the order of user activities. Furthermore, each **Activity** considered within the time interval of the **Situation** depends on the use of **Objects**, which contain information about their lists of **States** and locations. In this way, the **Situation** also captures detailed state information over time, supporting the analysis of ongoing events.

The **Event** class knows situations occurring over time and can trigger actions. e.g., two users may need the same medical supply. Based on urgency or priority, the software system may perceive this conflict and notify both users who should use the supply first.

Triggering events based on user activities, leading to relevant functionalities, is a significant improvement of this representation because implicit interactions are being reduced, and actions are being perceived and interpreted while users interact the least with the software system.

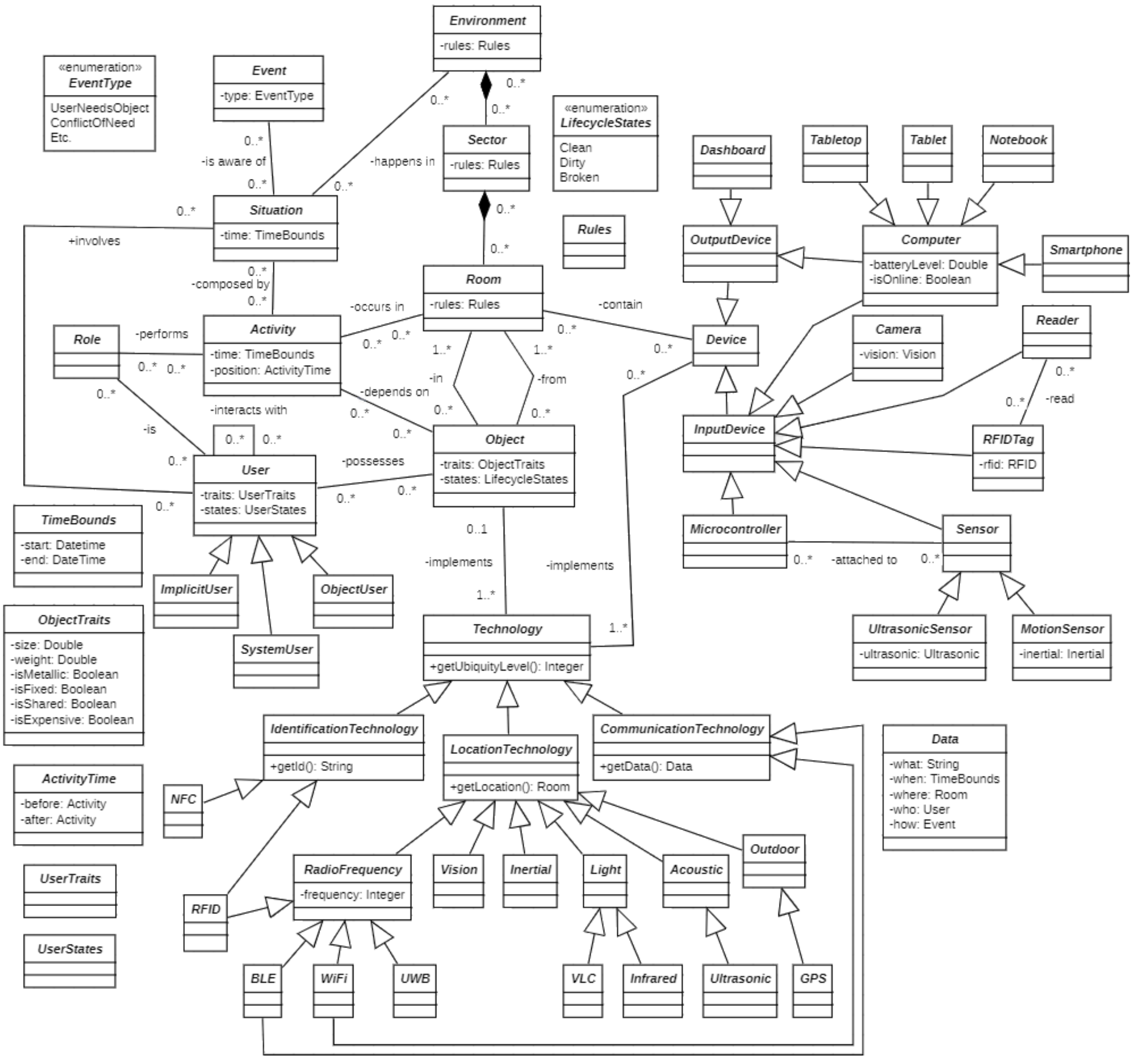

Figure 4.8 – Third representation of the metamodel

Complementing the patterns that events may perceive, the users were extended into three categories: (1) **users of objects** who are already possessing objects; (2) **users of the system** who are explicitly querying a user interface for finding objects or for checking their conditions; and (3) **implicit users**, who are not using an object nor a user interface but need an object. Even though implicit users are not explicitly interacting, their need configures them as users.

In the previous representations, communication technologies submitted a string without specifying the data format. The third representation defines a format for communication, contextually separating information into what, when, where, who, and how (Poslad, 2009). **What** information is being communicated, such as sensor data? **When** is the time or interval during which the data was collected? **Where** refers to the room from which the data was collected. **Who** refers to the user involved in the data collection, if any? **How** refers to an event related to the data, if any. This format allows for better characterization of the context during communication and a better understanding of the activities.

The remaining changes were due to the knowledge obtained during the interviews with health professionals (Section 4.1). Among the changes is the **Computer** class, created to encompass all devices with screens, including **tablets, notebooks, and Smartphones**. Computers include properties for battery level and connectivity status, addressing two issues identified during the interviews. The hierarchy of **Devices** has also been organized. The previous representations had no clear separation between input and output. Two new classifications have been included: **Input Devices** are those such as sensors, and **Output Devices** are those such as computers.

The interviews taught us that rooms are not direct parts of the environment. This realization led to a sector class between room and environment. The **Object Traits** class was extended with some properties: if the objects are shared, indicating the possibility of using them in many sectors; if they are fixed, suggesting that they never leave the same room; if they are metallic, meaning that they may not be allowed near radiology-related equipment; and if they are expensive, suggesting that only a few might be available in the hospital. The remaining knowledge applies to instantiations, not to metamodeling.

A **proof of concept** illustrates the operation of an IoT software system implemented in a hospital based on the metamodel’s third representation. In this application, objects contain **RFID tags,** and rooms contain **RFID readers**. The system can detect which objects are present in each room, and a dashboard is displayed on **mobile phones**. In this scenario, three **nurses** in the geriatric **sector** need the same **bladder scan** simultaneously. Due to the high price of this equipment, there is only one for the whole hospital. At first, the nurses search for it in the corridors. If it is in use, the nurses will have difficulty discovering which room it is in. Figure 4.9 provides an instantiated model for this application, in which new or modified classes are highlighted in blue, and others were removed due to not being used. An object diagram presents and summarizes the scenario in Figure 4.10.

In the hypothetical scenario, **RFID**, **Acoustic,** and **Wi-Fi** were retained as technologies. **RFID** enables the identification and location of objects, while Wi-Fi-enabled **microcontrollers** (e.g., ESP32) communicate collected data. **Ultrasonic Sensors** are used to support the area. Only the **Smartphone** class was kept as the **output device**, with which nurses will monitor the data on a **Dashboard**. All sensors and cameras were removed as they were not used. Only the event type **Conflict of Need** was retained, as in the scenario. The new classes related to the medical context are **Nurse** as a **Role**, **Follow** as an **Activity**, **Patient Room** as a **Room**, **Geriatric** as a **Sector**, **Hospital** as an **Environment**, and **Bladder Scan** as a subclass of **Medical Equipment**, which is a subclass of **Object**.

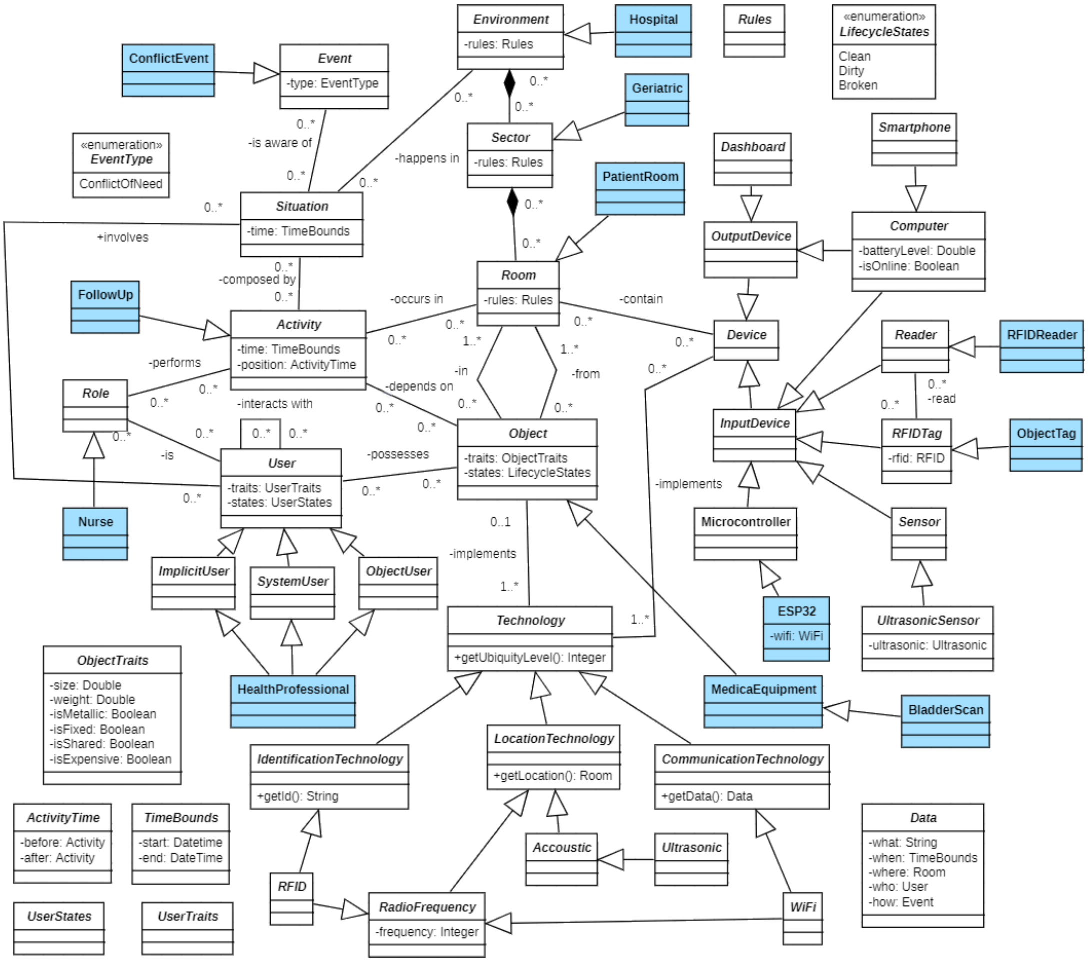

Figure 4.9 – The instantiated model for the second proof of concept

The nurses are referenced by numbers: 1, 2, and 3. **Nurse 2** is using the **bladder scan** in a specific **patient room**. This nurse is a **user of objects**. Meanwhile, two other nurses (1 and 3) need the bladder scan to perform **follow-ups** elsewhere. **Nurse 1** is querying for the bladder scan on a **mobile phone**. **Nurse 3** is looking for the equipment without resorting to the system. They are, respectively, a **system user** and an **implicit user**. Nurses must not be tracked inside the hospital for ethical reasons that differ from the previous proof of concept. The system knows someone needs the equipment by perceiving walking patterns with **ultrasonic sensors**.

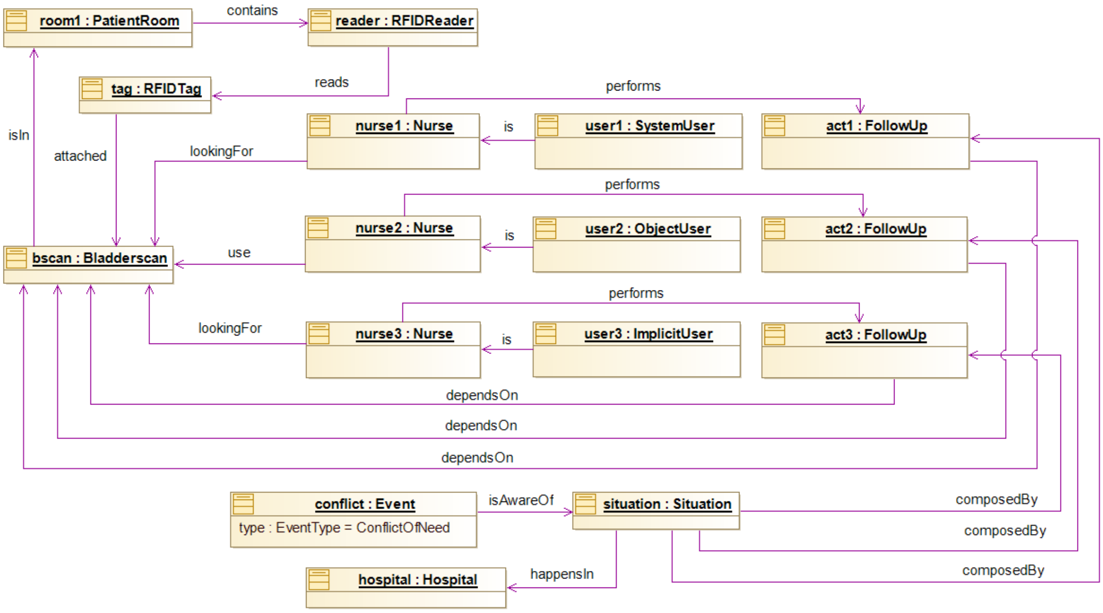

Figure 4.10 – Object diagram for the second proof of concept

**Nurse 1** quickly discovers the current location of the **bladder scan** and goes directly to the **patient's room**. This equipment, although necessary, is not used for more than five minutes, so **Nurse 2** might have finished using it. Meanwhile, **Nurse 1** is notified through the **mobile application** when reaching the **patient's room**. The software system detected an event of conflict: two staff members needing the same object. The notification proposes that **Nurse 1** checks who the other staff member needs the **bladder scan** because it might configure a priority **follow-up**. **Nurse 1** meets **Nurse 3** in the corridor and decides that **Nurse 3** should use the equipment first.

This hypothetical scenario presents a complex situation frequently occurring in the hospital where the interviews were conducted (Section 4.1). The application features a **hybrid system** that uses both **acoustic** and **radio-frequency** technologies. Without **ultrasonic sensors**, it would not be possible to identify the movement of **Nurse 3** in the corridor and trigger the **conflict event**. This scenario offers a more dynamic possibility for visualizing data, as each staff member can access the **dashboard** directly from their **smartphone**. Note that the nurses did not need to interact explicitly with the software system. **Nurse 2** was using the **bladder scan** in a daily activity. **Nurse 1** only accessed the **dashboard** and walked to the **patient's room**. Meanwhile, **Nurse 3** did not even access the **dashboard**; movement patterns were analyzed invisibly. By examining the available information, the application could perceive, comprehend, and act to trigger an event, as expected from a situation-aware software system.

The proof of concept covers concepts included in the second and third representations of the metamodel and suggests that the modeling aligns with the research objectives. The **third representation** considers all fundamental subjects of the research: **IoT**, **location technologies**, **situation awareness**, **context awareness**, and the **medical context**. Therefore, it is deemed complete and robust enough to be applied in creating a natural IoT software system. The subsequent evolutions will occur due to problems encountered while coding or using real applications. Section 5.1 presents the methodology for developing applications from the metamodel.

## 4.3 Conclusion

A metamodel for creating IoT applications for managing the location and use of medical equipment was conceived. This metamodel gradually evolved from the research conducted during the literature investigation. Three representations were drawn up, from which proofs of concept were created to test the first and third representations.

The **first representation** integrated IoT concepts, radio-frequency technologies, and context awareness. It was tested in a **proof of concept,** and the modeling resulted in a simple part of a hospital where a nurse moves a stethoscope between rooms while a physician views information on a dashboard. The **second representation** expanded the modeling of indoor localization, including more strategies beyond radio-frequency technologies, such as sensors and cameras. The **third representation** introduced specific details of the medical context and new classes related to situation awareness, allowing IoT software systems to understand situations and provide functionalities based on future predictions. A **proof of concept** test is one in which three nurses simultaneously need the same medical equipment. The **third representation**, which already models all the fundamental concepts, will have its **Feasibility** tested (Sections 5 and 6) by creating an actual application, subsequently applied in an experimental study.

# 5 First Experimental Study: Evaluating the Metamodel’s Third Representation

Two experimental studies have been conducted to verify the metamodel's **Feasibility** (Section 1.4) in supporting the creation of IoT software systems for managing the location and use of medical equipment in health centers. This chapter presents an **instantiation** of the metamodel’s third representation based on **requirements** used to **build** an IoT software system applied as part of an **experimental study**. The study's findings highlight problems in the representation, leading to the **tailoring** of the metamodel. The same procedure is then applied to a new, consolidated representation of the metamodel, described in Chapter 6.

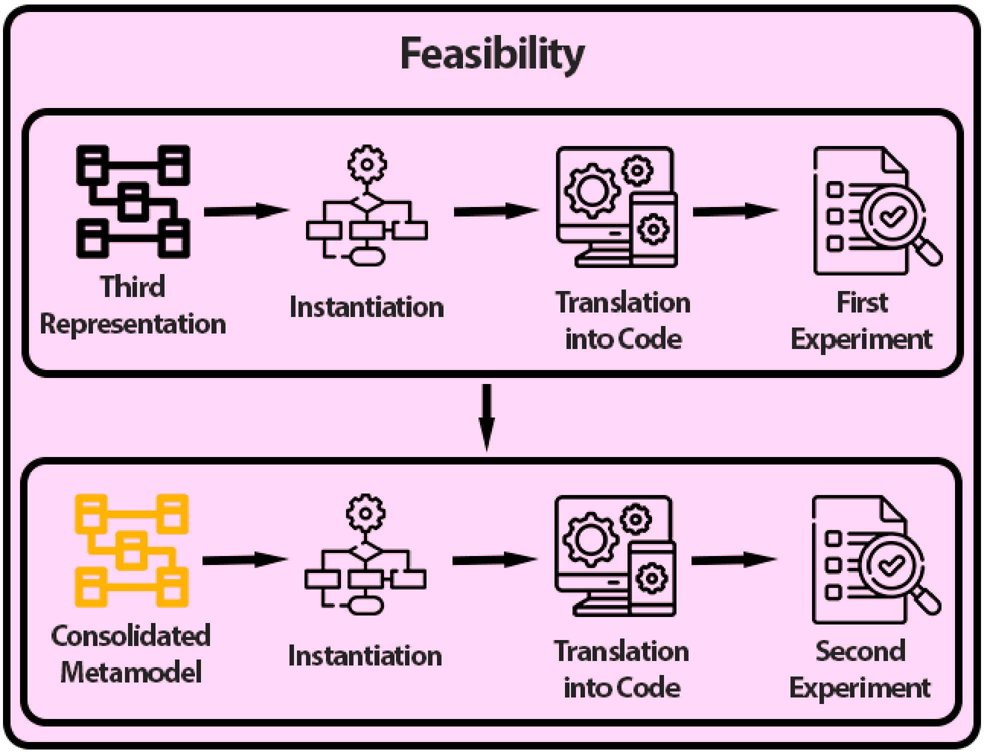

Figure 5.1 – Experimental studies conducted to verify the feasibility of the metamodel

## 5.1 Tailoring Methodology

A methodology was set to define and use metamodels, considering three levels of abstraction, as presented in Figure 5.2. It goes from the **conception** of the metamodel, its **instantiation**, and its **translation** into code to a specific application. Defining the metamodel captures the necessary information to create context-aware and situation-aware IoT applications intended to manage the location and use of medical equipment in health centers. Integrating context awareness allows the system to understand the context through users, environmental elements, and technologies. Integrating situation awareness enables the system to perceive what is happening in the context and provide services based on future predictions. The metamodel is generic and designed to serve as a foundation for creating many software systems. The metamodel is represented as a class diagram with abstract entities, and its usage follows the standard practice for class diagrams, where abstract classes are instantiated into concrete classes and then utilized in software development. However, a specific methodology has yet to be identified to guide the construction of metamodels.

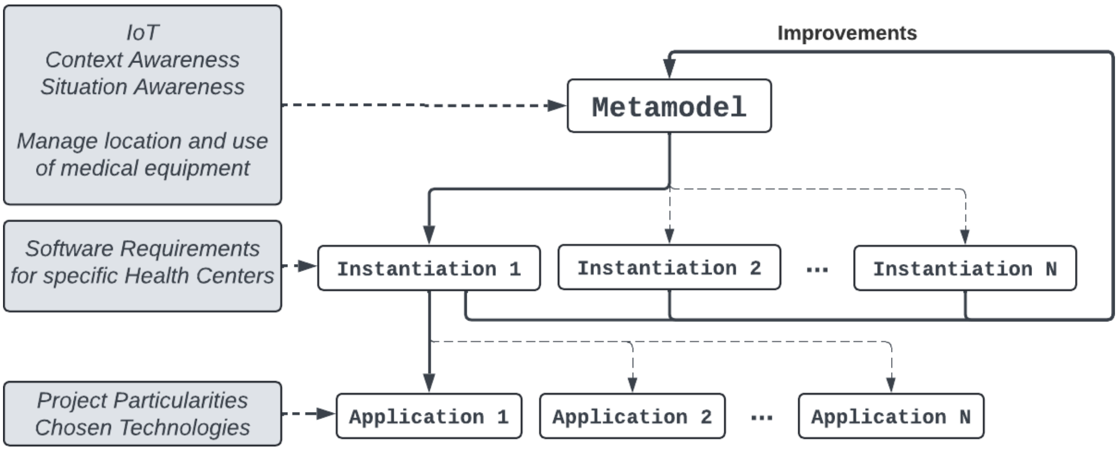

Figure 5.2 – Tailoring Methodology

To **instantiate** the metamodel, the requirements and functionalities of the software system to be developed must first be defined. The following steps should then be followed:

- **Identify Entity Types**: Identify the specific types of existing entities from the requirements. For instance, determine the specific **Objects**, **Roles**, **Tasks**, and **Rooms**. These will become subclasses of the respective entities. For the target software system to be functional, there must be at least one type of equipment, user, and room.
- **Define Lifecycle (if applicable)**: If the requirements include lifecycle management, create a state diagram, either global or specific to each type of equipment. These diagrams must include at least one initial “neutral” state and one final “disposal” state.
- **List Events**: The list of **Events** may include lifecycle states and references to functionalities. Events should be listed if their occurrences trigger an action. For

instance, cleaning equipment may produce an output, or the system might notify if two users require the same equipment.

- **Remove Unused Entities**: Abstract entities that do not have subclasses should be removed. For instance, if the requirements do not include the use of BLE, it should be excluded.
- **Check for Missing Requirements**: Verify if any requirement item could not be accommodated within the metamodel entities. Such a requirement might indicate the need for future evolution. If this need arises, **tailoring** occurs: the metamodel itself is **improved** to incorporate these fundamental changes.

Different requirements lead to different instantiations. For example, the requirements of a particular field hospital and the requirements of a specific clinic would result in the elaboration of different instantiated models, even though both come from the same metamodel. The two hypothetical proofs of concept were examples of instantiations, but they served as theoretical validations and did not improve the metamodel nor were translated into code.

Instantiated models can then be **translated** into code to create applications. The same instantiated model may lead to different applications depending on the adopted technologies, hardware, algorithms, and communication protocols. Although all resulting applications have different technical differences, they implement the exact requirements previewed in the corresponding instantiated model. The creation and execution of applications based on instantiated models may reveal flaws in the metamodel representation, leading to improvements, thereby continuing the evolution process.

The tailoring methodology was applied twice. The **third representation** of the metamodel (section 4.2.3) was **instantiated** from the requirements of a simple part of a hospital. The instantiated model was **translated** into code for an application. Through this application, the metamodel was evaluated in an experimental study. Subsequently, the metamodel was improved, resulting in a **fourth representation**. It underwent the same process: **instantiation** from the requirements of another simple part of a hospital and then **translation** into code for an application, which was applied in another experimental study. The details of both studies will be described as follows.

## 5.2 Third Representation: Instantiation and Coding

The metamodel’s third representation is robust as it models all the research’s fundamental concepts, so it was used as the basis for the **Tailoring Methodology**.

Requirements were elicited to simulate a simple part of a hospital, and an instantiated model was developed from the requirements. Finally, it was translated into code to create an IoT software system.

The IoT software system was then used in an experimental study to analyze the feasibility of using the metamodel in creating applications and verify how accurately the metamodel can develop applications that collect contextual data, allowing situation-aware functionalities. This section presents the requirements, an instantiation based on them, and the creation of an IoT software system. Subsequently, the IoT software system is applied in an experimental study.

### 5.2.1 Requirements for a Simple Part of a Hospital

Requirements were raised to simulate a simple part of a hospital. **Tracking** health professionals and objects is essential; the application will be aware of the current room where users and objects are. Moving objects is another crucial feature that will change their **states** accordingly. Some objects may be fixed in place; in this case, the users must be explicitly informed when using them.

The objects in the application may be **wheelchairs**, **ECGs** (electrocardiograms), **MRI** (magnetic resonance imaging), and hospital **clothes**. The rooms in the application can be **imaging rooms**, **cleaning rooms**, **storage,** or **patient rooms**. The application users can be **nurses** or **radiology manipulators**. If an **object** and a **user** share the same room, the system will suppose they are walking together. Therefore, the object is **in use**. They are considered in place if an object is detected in their original room. The original rooms for the MRIs are **imaging rooms**, while they are storage areas for all the others. **Wheelchairs** and **ECGs** are not allowed inside **imaging rooms** due to their metallic nature. An **LED** set inside imaging rooms lights up whenever a metallic object is detected.

The objects must be **cleaned** before being returned to their original room. This will be done by simply moving the object inside the **cleaning rooms**. The **cleaning procedures** would be performed in two different ways. **Assets** like clothes would be **washed**, while **medical equipment** such as **ECGs** would be **disinfected**.

Information about the objects is displayed in a **dashboard** so that the users can profit from the information. The **dashboard** must contain the following:

- **Equipment Overview**: It displays every supply's current room and state.
- **Preventive Maintenance**: Based on past data, it displays a list of equipment that needs maintenance.

- **Send Equipment to Maintenance**: The health professionals must explicitly inform when an object presents problems. In the scope of the simulation, objects sent to maintenance will not return to the system.

States are assigned based on how they are used to manage objects' usage. The states refer to three simultaneous conditions: ownership, cleaning, and maintenance. The ownership states indicate if the objects are in place, in use, or not in use. The cleaning states indicate if the objects are clean, dirty, or being cleaned. The maintenance states indicate if the objects are in good condition or not. They are summarized in Figure 5.3.

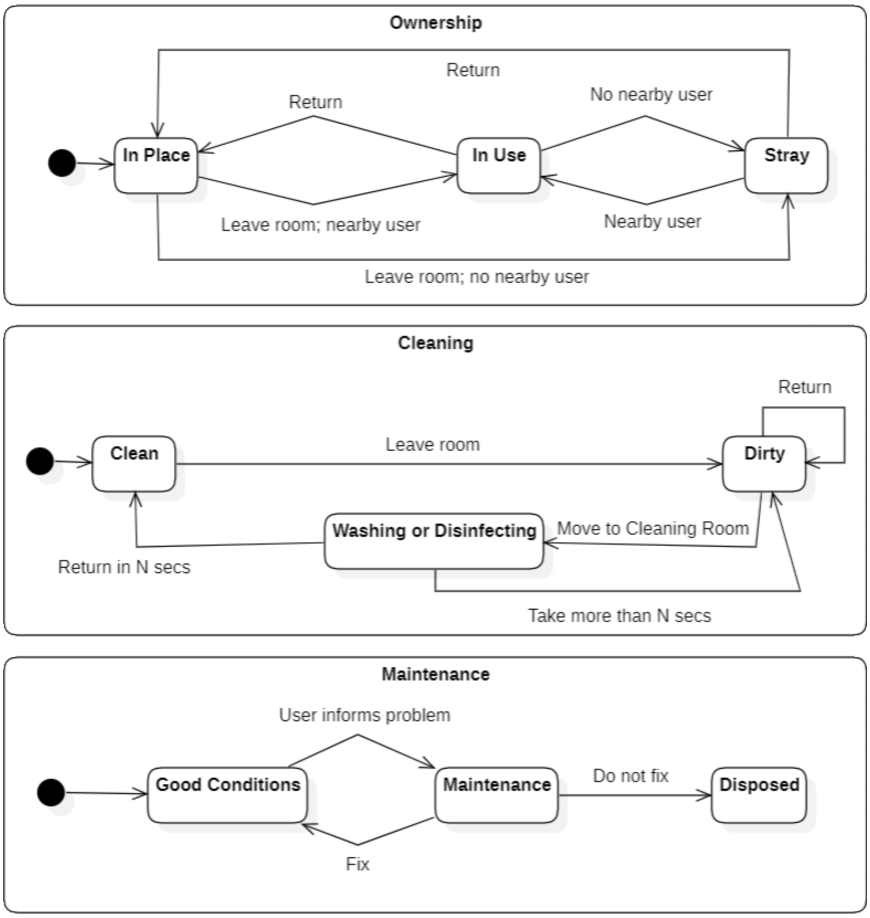

Figure 5.3 – Object States for the Experimental Study

Objects are in place, clean, and in good condition by default. As for the **Ownership** states, they will continue **in place while** inside the original room. The state will change to In Use when the object is detected outside and in the same room as some users. Then, if the object is detected outside but not in the presence of a user, the state will change to **Stray**. As for the **Cleaning** states, the object will be considered initially **Clean** but will change to **Dirty** if detected outside. When a dirty object is taken inside a cleaning room, they change to **Washing** or **Disinfecting**, depending on the object type.

When the object leaves the cleaning room, it must go directly to the original room within N seconds (configurable), which changes the state to **Clean**. Otherwise, the object will be altered to **Dirty** again. As for the **Maintenance** states, the object will be in **Good Condition** until a user sends it to maintenance through the dashboard, which changes to the **Maintenance** state. An object is Disposed if a technician cannot fix it. This state will not be implemented.

Wi-Fi devices implementing the Proximity strategy will manage objects. Stations constantly scan for nearby **access points** (AP) and estimate that the AP is getting near based on the RSSI (Received Signal Strength Indication) value. Mobile objects will be given an **AP**, while each room will contain a fixed **station**.

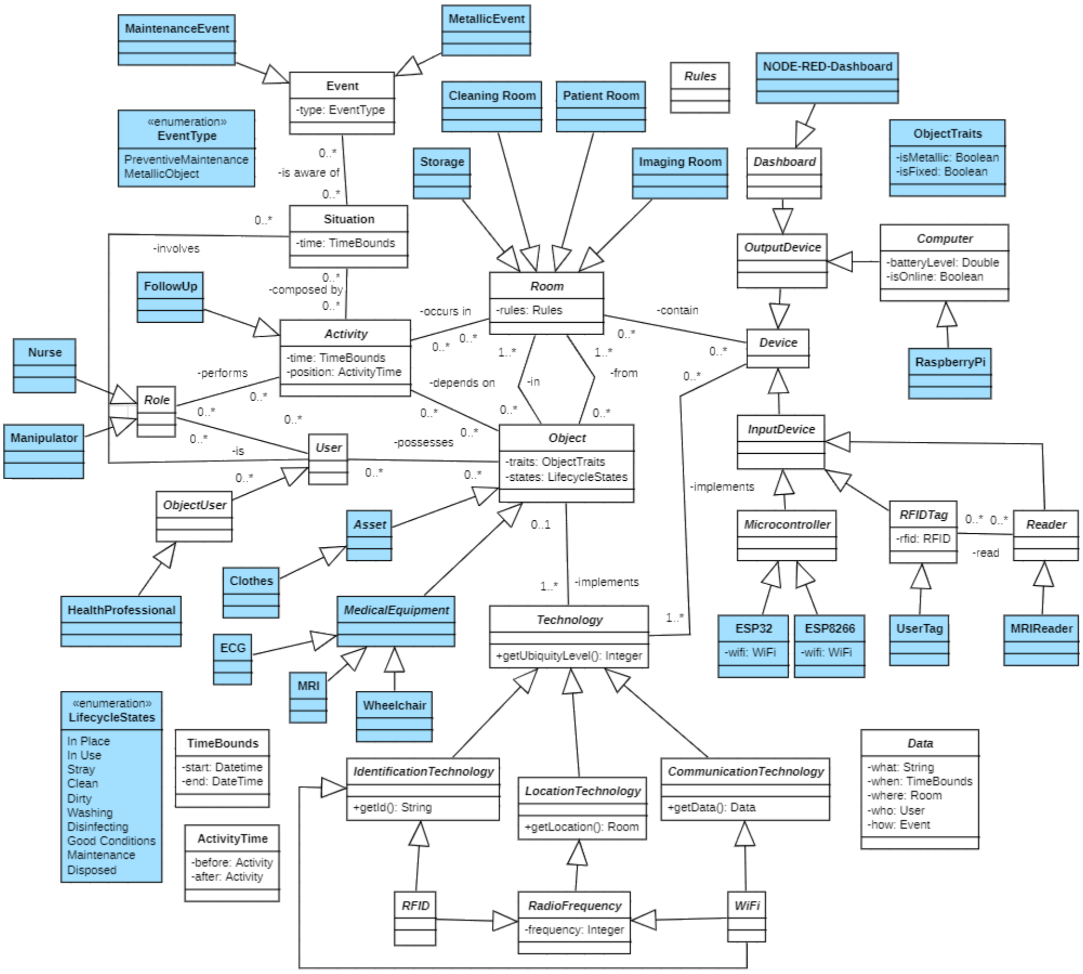

Figure 5.4 – Instantiation of the third representation for the experimental study

### 5.2.2 Instantiation for a Simple Part of a Hospital

The metamodel must be instantiated according to the requirements. The third representation was already instantiated for the proof of concept (Figure 4.9). The instantiation procedure is the same for a more complex list of requirements. The instantiated model is presented in Figure 5.4. Classes in blue are new or modified.

Technologies were removed, except for **RFID** and **Wi-Fi**. **RFID** will serve to identify the usage of **MRI**. **Wi-Fi** will be used for all three functionalities: identification, localization, and communication. Host names within the network will identify objects, users, and rooms. Localization will be based on proximity. **Wi-Fi** will also be the communication protocol, and collected data will be sent via **MQTT** for storage and analysis. **User Traits** and **User States** will not be used, so they were suppressed. The self-association of users was also removed, as there will be one user at a time in the simulation.

**ESP32** and **ESP8266** are subclasses of **Microcontroller**, as these Wi-Fi-enabled devices will be used. **User Tag** refers to the cards used to inform MRI usage, which occurs by bringing it close to the **MRI Reader**, a device with an RFID reader. **Raspberry Pi** is a subclass of **Computers**, as one will be responsible for displaying the **dashboard**. The other subclasses of Computers were suppressed. The dashboard will be developed using a low-code platform called **Node-RED**[9]. Low code allows the creation of applications with minimal coding.

The subclasses **Implicit User** and **System User** were suppressed, as they are still complex concepts that need to be implemented in the first version of an application. Only **Object User** was retained, referring to **health professionals** in the same room as objects. As **Roles**, users can be **Nurses** or **Radiology Manipulators**. Only the **Object Traits** “is Metallic” and “is Fixed” were kept, as they directly impact the system decisions. The enumeration **Lifecycle States** was populated with all the states provided in the diagram in Figure 5.3. An object hierarchy was included by adding **Asset** and **Medical Equipment** as subclasses, which in turn have **Clothes**, **ECG**, **MRI**, and **Wheelchair** as subclasses.

**Environment** and **Sector** were suppressed, as the hospital does not have specific rules and is not divided into sectors. The instance previews two events: an alert to be displayed on the dashboard if preventive maintenance is needed and another alert in case of **metallic objects** inside imaging rooms.

### 5.2.3 Creation of an Application

The requirements permitted to instantiate the metamodel. An IoT software system was created from this instantiation, following the tailoring methodology in Figure 5.2.

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[9] https://nodered.org/

This section describes the **translation process**, in which the instantiated model is used to develop the code for an actual IoT application to be applied in a hospital simulation.

The available hardware for the experiment is a **Raspberry Pi**, three **ESP8266**, eight **ESP32**, **one MFR522 RFID reader**, cables, LEDs, and power banks. **ESP32** is **Wi-Fi**-enabled and **BLE**-enabled. The area does not have available Wi-Fi networks; the only solution would be using the researcher's smartphone 4G network. Note that while this solution was suitable for the context of an experiment, in a real-world application, if any of the environment's facilities lack an internet connection, the software system must be designed to use alternative communication methods, such as BLE instead of Wi-Fi. Additionally, internet connectivity may be intermittent, and the software system should be prepared to handle scenarios where data is not received for an extended period.

BLE was initially adopted as the technology for both localization and communication to avoid it. Each room would have a fixed **ESP32** configured as a **station**, while each mobile object would carry an **ESP32** configured as an **access point (AP)**, using the **Proximity** localization strategy. The stations would communicate RSSI and AP identifiers via BLE to the Raspberry Pi, which would process the data using the low-code tool Node-RED. Data was set to be analyzed as soon as every station found the same AP, which happened on average every 5 seconds. This strategy ensured constant information updates and introduced the possibility of collecting incorrect RSSI data from the stations.

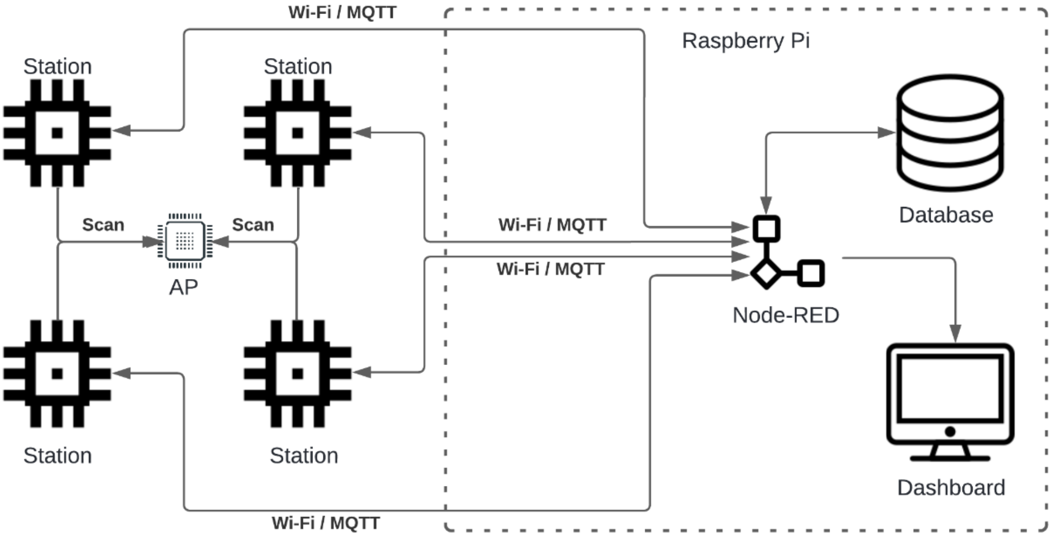

Figure 5.5 – System's architecture, using Wi-Fi

Pairing multiple BLE devices simultaneously with a single Raspberry Pi was challenging. The more paired devices, the greater the probability of one unpairing briefly. This architecture was replaced because the pairing between stations and Raspberry Pi was unstable, constantly unpairing and losing data. In addition, this architecture does not permit the software system to send information back to the station nor permits stations to subscribe to MQTT topics. These problems could be solved with Wi-Fi. Although a 4G network is not ideal for the experiment, it performed well as long as the smartphone remained near the center of the room. Figure 5.5 provides the system's architecture. Stations scan for APs and publish data through the messaging protocol MQTT. A Node-RED flow subscribes to the corresponding topics and analyzes the data to decide which rooms the objects are in. The data is stored in a MySQL database and provided in a dashboard.

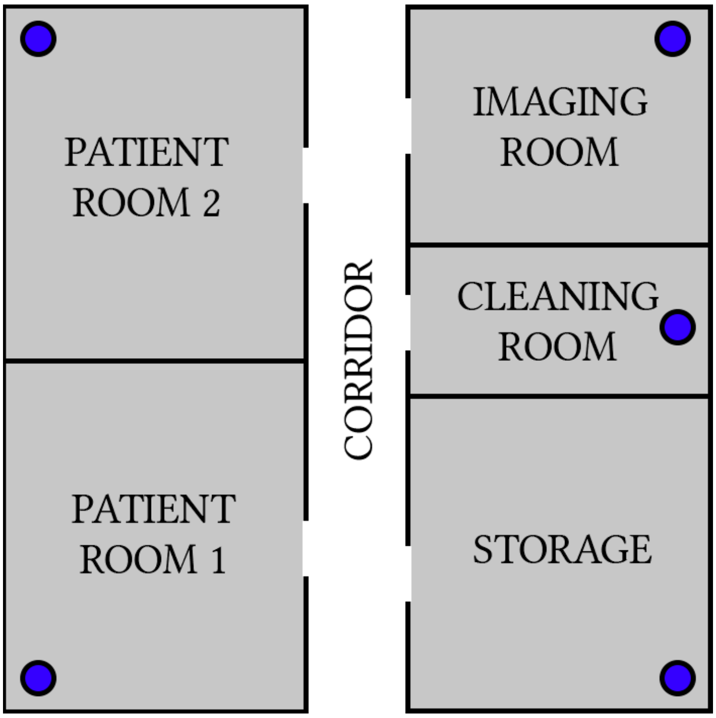

Figure 5.6 – Map of the simulated hospital

A 7m x 7m space was provided for the simulation. This area was divided into five rooms connected by a corridor, as shown in Figure 5.6. Two **patient rooms**, an **imaging room**, a **storage room**, and a **cleaning room** were implemented. Five ESP32 were allocated as stations, one for each room, represented in Figure 5.6 by blue circles. Three ESP32 were allocated as access points to an **ECG**, one piece of **clothing**, and another to a **Wheelchair**, the only mobile objects implemented. An **MRI** was implemented but not located, as its position is fixed in the **imaging room**. Two Wi-Fi-enabled **ESP8266** were allocated as access points to a **nurse** and a **radiology manipulator** to be worn as badges. In the experimental study, participants perform tasks alone, but the same participant assumes two distinct roles (Table 5.2). The third available **ESP8266** was assembled with an RFID reader to manage the use of the MRI.

Node-RED was chosen for data management due to its ease of implementation, requiring little code and organizing logic into visual flows. Additionally, it already contains pre-implemented logical nodes for publish and subscribe functions and pre-implemented components for creating dashboards[10]. MySQL was adopted for the database, including the tables and stored procedures the data manager accessed.

Node-RED has components for directly accessing databases. Therefore, stored procedures were implemented to intermediate the manager and the tables, similarly to API services. The *move_object* stored procedure is called every time the object moves to a new room. Internally, it checks if the object entered or left the cleaning room and calls the *update_object_state* stored procedure to manage the **Cleaning** states planned in Figure 5.3Whenever a user is tracked inside a room, a flow manages the Ownership states by calling the change_object_owner_state stored procedure, which changes the states of all the objects in the same room to In Use. As for the Maintenance states, users explicitly manage them in the dashboard. They must select the object's name and click a button, which calls the *update_object_state* to change the object’s state, removing it from every dashboard listing.

Figure 5.7 presents the dashboard, divided into three parts. The first part contains an **overview** of each object, indicating the **room** where they are and their three simultaneous **states**. Another part indicates which objects need maintenance. To implement the **preventive maintenance** logic, the database was populated with fake historical data of past objects, including state changes from acquisition to disposal. If the average usage of active objects approaches the threshold of discarded objects of the same type, a preventive maintenance event is triggered, which adds the objects to the listing. Finally, the third part contains a combo box for sending objects to maintenance. Initially, these three areas were intended to be on separate tabs, but all were kept on the same screen for usability purposes. The overview dashboard was populated by the *get_overview* stored

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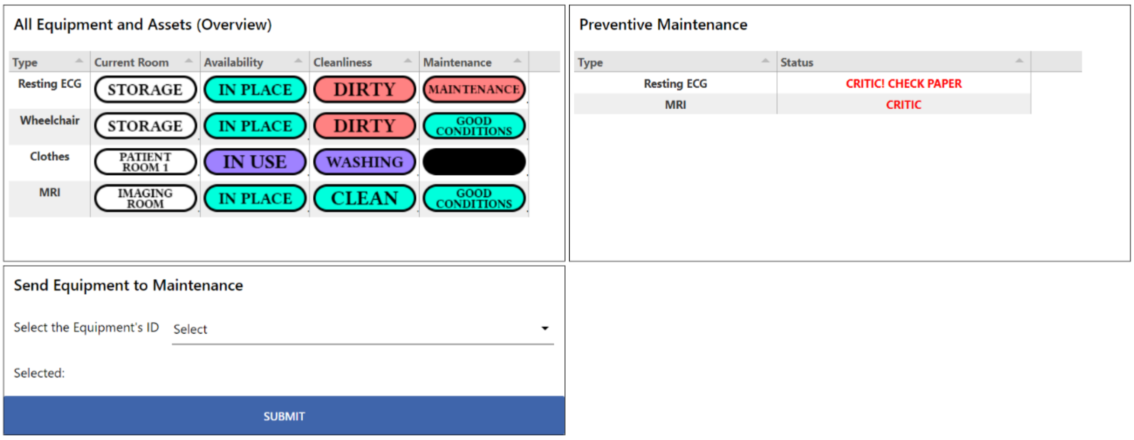
[10] https://flows.nodered.org/node/node-red-dashboard

procedure, while the preventive maintenance dashboard was inhabited by the *get_objects_nearly_breaking* stored procedure.



All Equipment and Assets (Overview)

| Type | Current Room | Availability | Cleanliness | Maintenance |
|---|---|---|---|---|
| Resting ECG | STORAGE | IN PLACE | DIRTY | MAINTENANCE |
| Wheelchair | STORAGE | IN PLACE | DIRTY | GOOD CONDITIONS |
| Clothes | PATIENT ROOM 1 | IN USE | WASHING | ● |
| MRI | IMAGING ROOM | IN PLACE | CLEAN | GOOD CONDITIONS |

Preventive Maintenance

| Type | Status |
|---|---|
| Resting ECG | CRITIC! CHECK PAPER |
| MRI | CRITIC |

Send Equipment to Maintenance

Select the Equipment's ID: Select

Selected:

Figure 5.7 – Application's Dashboard

Note that the overview dashboard also includes the MRI. It will always be in the imaging room. Its **Maintenance** state can be altered through the combo box. The other states are managed through explicit interaction with an RFID reader. Users approximate their personal RFID cards to indicate they are using the MRI, which changes the **Ownership** state from In Place to In Use and the **Cleaning** state from Clean to Dirty. Another card suggests the usage has ended, but the user cleaned the MRI before that. Using this card switches the states back to In Place and Clean and counts one use for preventive maintenance. A feedback **LED** was assembled with the ESP8266 containing the RFID Reader, which lights up if the **ECG** or **wheelchair** enters the imaging room, as they are metallic objects. When these objects are detected in the room, the system triggers a **Metallic Object** event, which, through a Node-RED flow, publishes an alert topic that the ESP8266 subscribes.

Figure 5.8 provides the entity-relationship model used for the solution. It maintains historical information about **users**, **objects,** and **rooms** while also containing elements to allow measurements for the experimental study. The main table is **Object**, which has Object Types that are initially from a **Room** and have a unique identifier represented by the **Tag** table. Note that **Tag** relates to **Objects**, **Users,** and **Rooms**, as these system entities depend on identification. **Rooms** have **Room Types,** while **Users** have **Roles**. Certain **Object Types** are not allowed in certain **Rooms**, registered in the **Not Allowed Object** table.

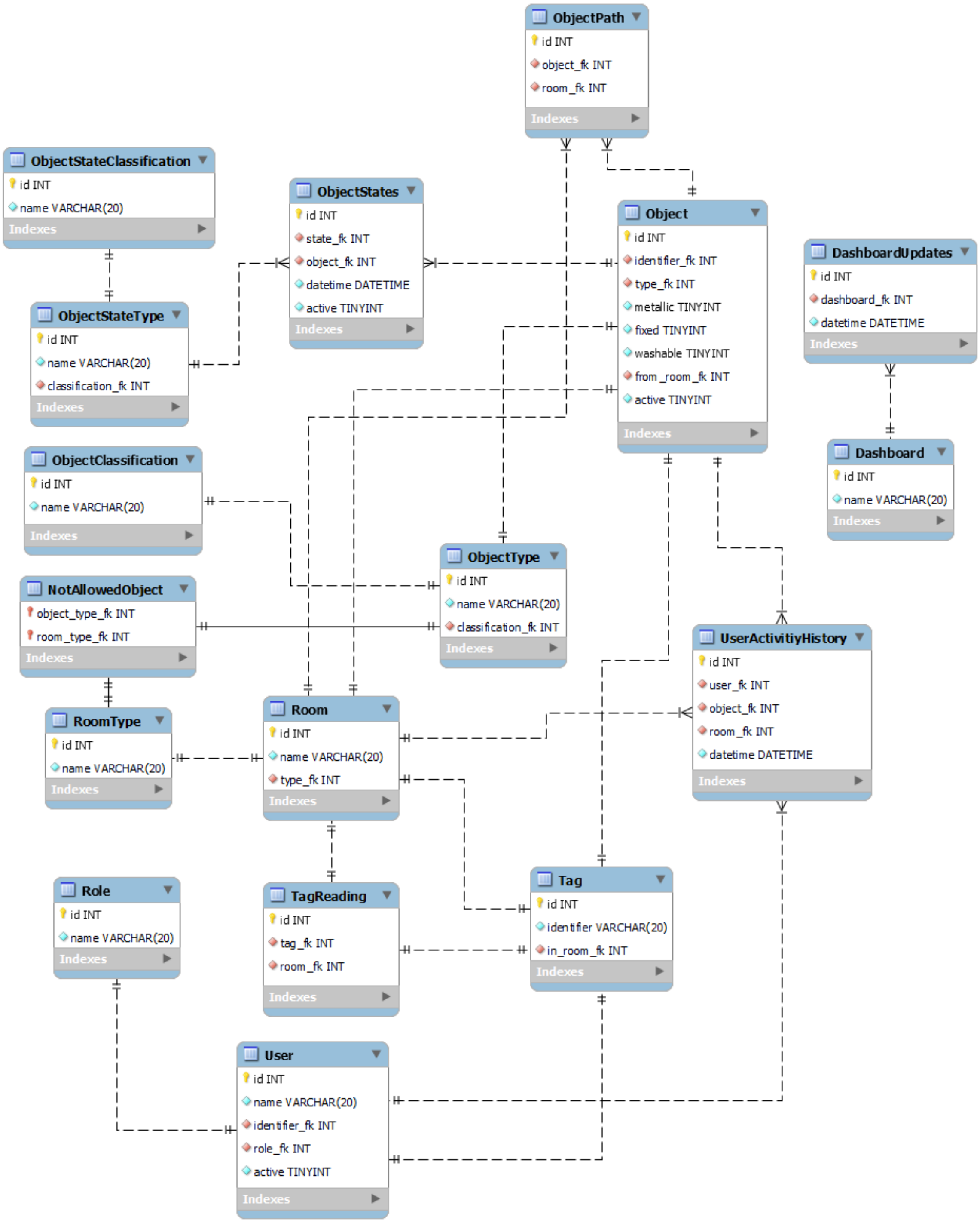


Figure 5.8 – Entity-relationship model

**Objects**’ state changes are stored in the **Object States** table. Each state has an **Object State Type** (e.g., Dirty), which in turn has an **Object State Classification** (e.g., Cleaning). The **Object Path** table stores each visit of an Object to a Room. The **User Activity History** table stores each instance of **Objects** in use by a **User** in a specific **Room**. Entries are only included in this table if the Object is in use. A separate table,

**Dashboard Updates**, has the sole purpose of recording when each dashboard tab is updated. This way, it is possible to identify bottlenecks in the corresponding queries.

## 5.3 First Experiment

The metamodel's third representation was **instantiated** based on requirements for a simple part of a hospital. The instantiated model was **translated into code** to create a simulation application as part of an **experimental study**. This section presents the planning, execution, analysis, and discussion of the experimental research. The first experiment was conducted in LAMIH/UPHF in France.

### 5.3.1 Planning and Execution

The goal of the experimental study is presented in Table 5.1, using the Goal-Question-Metric (GQM) structure (Basili et al., 1994). The study aims to (1) verify whether the metamodel can be used to create an application that meets the objectives of managing the location and use of supplies and (2) verify if the application collects accurate data, ensuring that the quality of the information displayed on the dashboard is not compromised.

Table 5.1 – Study goals, structured using GQM

| Main goal | Secondary goal |
|---|---|
| *analyze* the Health Centers metamodel for managing the location and use of medical equipment<br>*to characterize*<br>*concerning* its completeness and feasibility<br>*from the point of view of* software engineers<br>*in the context of* supporting the creation of an IoT software system for locating and managing equipment in Health Centers | *analyze* the IoT software system for locating and managing equipment in Health Centers<br>*to characterize*<br>*concerning* the accuracy in indicating the right location and use of medical equipment<br>*from the point of view of* software engineers<br>*in the context of* individuals moving and using simulated equipment in an *in vitro* hospital. |

The participants will follow two scenarios individually, being a **nurse** and a **radiology manipulator** in the second. Each scenario comprises a list of tasks involving moving objects, assisting fictitious patients, and performing tasks in the simulated hospital. Among participants, three health professionals could participate, but most were doctoral students and professors from LAMIH[11], where the experiment took place. In total, 17 people participated: eight PhD students, six professors, two nurses, and one geriatrician. Since each worked individually, the study relied on 17 executions. Table 6.1 provides a summary of the scenarios. The scenarios cover all state changes in Figure 5.3,

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[11] https://www.uphf.fr/lamih/departements/informatique

except for the **Disposed** state, which was not implemented, and the **Washing** state, as the procedure for cleaning clothes was not included.

Table 5.2 – Summary of the Scenarios

| Scenario | Role | Summary of the scenario |
|---|---|---|
| 1 | Nurse | An elderly patient arrives at the hospital and goes directly to the imaging room due to an emergency. The nurse takes the wheelchair and goes to the imaging room. The wheelchair is not allowed in the imaging room, so the LED turns on. The nurse quickly moves the patient in the wheelchair to one of the patient rooms. The nurse leaves momentarily and takes the ECG for further exams with the patient. While the ECG is in use, the nurse cleans the wheelchair and moves it to the storage. The ECG could not print the exam because it was lacking paper. This problem is listed in the preventive maintenance dashboard. The nurse sends the ECG to maintenance, cleans it, and moves it to the storage. |
| 2 | Radiology Manipulator | Another patient arrives and goes directly to the imaging room. The manipulator takes hospital clothes and goes to the imaging room to perform exams on the patient. The manipulator informs that they will use the MRI, and when the exam ends, the manipulator cleans the MRI and tells that the cleaning was done. The manipulator takes the wheelchair and moves the patient to one of the patient rooms. Then, the wheelchair is cleaned and moved to the storage. After the last usage, the MRI showed up on the preventive maintenance dashboard, so the manipulator sent it to maintenance. |

During the scenarios, the application constantly collects data on objects' and users' positions. Since the scenarios are the same for all participants. Ideally, all the collected data should be the same regardless of the participant. This does not occur in practice due to environmental interferences and how participants behave while performing each task. However, composing an oracle containing each object's expected sequence of rooms and state changes is possible. The data collected from each execution will be compared to the oracle to measure how well the application can understand the situations occurring in the context.

For each participant, the researcher presents the objectives, the division, and the meaning of rooms and objects, as well as demonstrates the application's functionalities. Once the participants have no doubts, they sign a confidentiality agreement (*Annex G – First Experiment Consent Letter*) requesting permission to collect data and take photos. The participant then leaves to place objects in their initial position. After the experiment, the participant answers a questionnaire with SUS (System Usability Scale) questions about the system's usability (Brooke, 1996), demographics, and open questions. In the end, the researcher exports the collected data for subsequent analysis.

Figure 5.9 provides four photos taken during the experimental study. Starting from the top left: (1) the **MRI**, represented by a scanner. Next to it, an RFID reader is used to inform that the MRI will be in use; (2) a participant takes the **clothes**, represented by a coat, while reading the scenarios; (3) a participant moves the **wheelchair** in the corridor; (4) a participant moves the **ECG** represented by a box. Since all the rooms in the simulation are fictional, their walls are made of wooden partitions, and their doors are poster stands.

Figure 5.9 – Simulated objects in use during the first experimental study

### 5.3.2 Data Analysis

Data was collected in two ways: (1) through the database, which stored movement between rooms and state changes during the execution of each scenario, and (2) through a questionnaire (*Annex D – First Experiment Questionnaire*), which gathered participants' opinions on the system's usability. Five analyses were conducted: (1) the data exported from the database, (2) the demographic questions, (3) the SUS questions, (4) the open questions, and (5) "speak aloud" questions, which will be further described.

The datasets were analyzed in terms of objects' **paths** and states. Data is stored in the Object Path table whenever an object enters a new room, and every time an object's state changes, data is stored in the **Object States** table. These tables were queries for obtaining lists of rooms and states for the ECG, Wheelchair, and Clothes for each execution. The MRI was disregarded because it is always in the imaging room, and its state is changed based on explicit user interactions.

Following the scenarios in Table 5.2, the **ECG** starts in the **Storage**, goes to Patient Room 2, is cleaned in the Cleaning Room, and returns to the **Storage**. Its **Ownership** states are sequentially **In Place**, **In Use**, **Stray**, and **Place**. Its **Cleaning** states are sequentially **Clean**, **Dirty**, **Disinfecting,** and **Clean**. Its **Maintenance** states are sequentially **Good Conditions** and **Maintenance**. The **clothes** start in the **Storage**, go to the Imaging Room, and end in **Patient Room 1**. Its **Ownership** states are sequentially **In Place** and **Use**, while its **Cleaning** states are sequentially **Clean** and **Dirty**. In the first scenario, the **wheelchair** is taken from the **Storage** to the **Imaging Room**. Then, it is brought to the Patient Room, cleaned in the Cleaning Room, and returned to the **Storage**. In the second scenario, it goes to the **Imaging Room**, followed by the **Patient Room 2**. It is cleaned in the **Cleaning Room** and returned to the **Storage**. Its Ownership states are sequentially **In Place**, **In Use,** and **In Place**. Its **Cleaning** states are sequentially **Clean**, **Dirty**, **Disinfecting**, **Clean**, **Dirty**, **Disinfecting** and **Clean**.

To achieve the study's secondary goal (analyzing the system's accuracy in indicating the right location and use of objects), the data obtained from each dataset should be compared to the expected data above. A perfect dataset would contain the same expected values in the same order. In case of wrong patterns, data may be classified as false positives or false negatives.

**False positives** are data that were stored in the database, yet they are wrong in the context of the following scenarios. In some cases, the objects are wrongly detected in neighbor rooms, e.g., the **ECG** may be detected in the **patient room** while in the **imaging room**. In other cases, the object may be detected in a room just because it passed in front of it, e.g., the **ECG** is wrongly detected in the **cleaning room** while being moved from the **storage** to the **imaging room** (see the map in Figure 5.6). **False negatives** are data expected to happen but not stored in the database. For instance, a participant may enter the **imaging room** with a **wheelchair**, but the object is detected in the cleaning room.

Table 5.3 summarizes the percentage of expected data, false positives, and false negatives for each execution. Consider a given dataset with 40 entries, from which 20 are rooms, and 20 are states. If ten rooms and ten states are classified as false positives, we would get 50% of the expected results. Despite this, all the expected data would be there, as the dataset in this example has no false negatives. This example simplifies the obtained results. On the median, 51.58% of the data was classified as expected, while just 1.04%

were classified as false negatives. This means that, in most cases, the software system could adequately capture every movement of the participants and every change of state. However, it also captured the same amount of extra wrong data, which makes it impossible for the system to characterize situations correctly. Therefore, it could not make predictions and provide more complex functionalities. For it to improve, false positives must be reduced, while false negatives must be eliminated.

Table 5.3 – Results for the data classification in each dataset

| Participant | Expected | False Positives | False Negatives |
|---|---|---|---|
| **01** | 51.26% | 48.74% | 0.00% |
| **02** | 42.50% | 57.50% | 0.00% |
| **03** | 47.14% | 52.14% | 0.71% |
| **04** | 56.76% | 39.19% | 4.05% |
| **05** | 32.58% | 52.81% | 14.61% |
| **06** | 58.23% | 37.97% | 3.80% |
| **07** | 48.18% | 51.82% | 0.00% |
| **08** | 51.58% | 48.42% | 0.00% |
| **09** | 40.00% | 54.74% | 5.26% |
| **10** | 53.75% | 42.50% | 3.75% |
| **11** | 50.00% | 48.84% | 1.16% |
| **12** | 60.00% | 38.75% | 1.25% |
| **13** | 60.29% | 38.24% | 1.47% |
| **14** | 58.33% | 40.63% | 1.04% |
| **15** | 39.42% | 60.58% | 0.00% |
| **16** | 56.07% | 43.93% | 0.00% |
| **17** | 55.26% | 44.74% | 0.00% |
| **Median:** | **51.58%** | **48.42%** | **1.04%** |

Participant errors only occurred twice. Once, a participant confused one room with another but immediately left. In another case, it was due to an unrealistic ordering of tasks in the second scenario. One of the nurse participants observed that the radiology manipulator must clean the MRI in the patient's presence. The nurse pointed out that medical equipment must not be cleaned before patients; therefore, these tasks were intentionally swapped based on medical experience.

As for the demographic questions, the invitation to participate was submitted to professors and PhD students from LAMIH and some available health professionals. Of those who consented to participate, eight were PhD students, six were professors, and three were health professionals. Most participants were between 24 and 31 years old, aligning with the typical age range for PhD students in LAMIH. Concerning the gender, 47.1% of the participants identified as women, while 52.9% identified as men. Finally, most of the participants were French, while others were Moroccans, Brazilians, Tunisians, Mexicans, and Indians, reflecting the cultural variety of the research laboratory. These results are summarized in Figure 5.10.

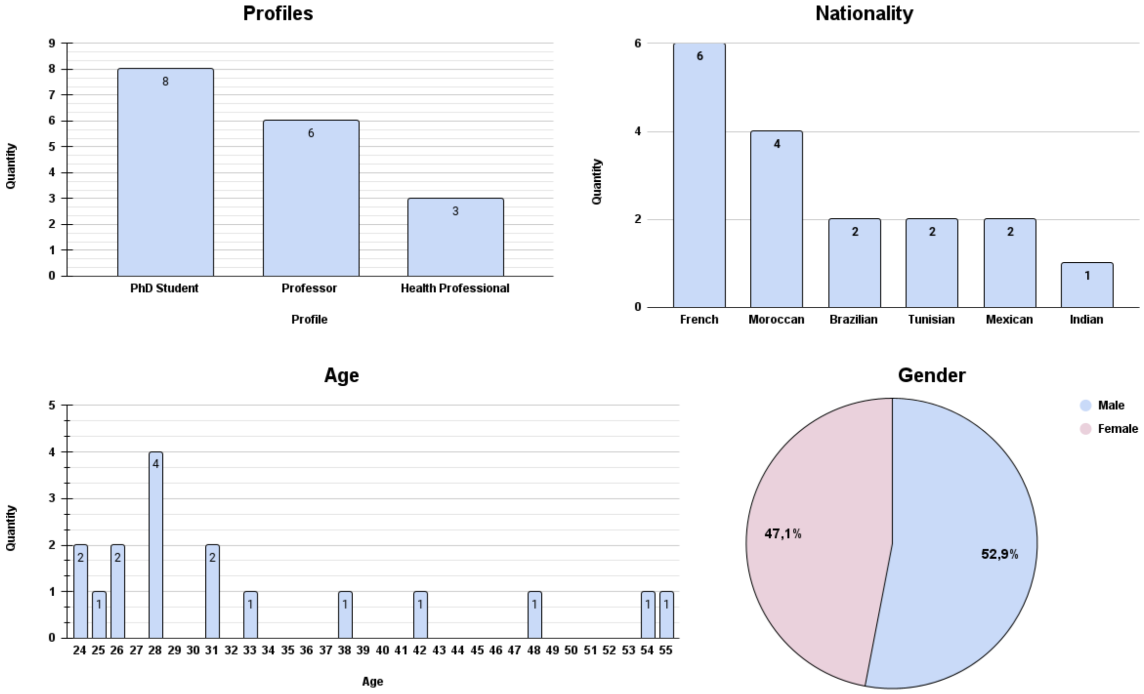

Figure 5.10 – Demographic results

The questionnaire’s SUS (System Usability Scale) questions allowed participants to provide feedback on the system’s usability. SUS is a Likert scale with ten questions that can be answered from strongly agree to disagree (Brooke, 1996). Although it is a Likert scale, a score can be calculated from the results. The responses are mapped to numbers 1 to 5 and applied to a formula[12], resulting in values between 0 and 100.

A score above 68 is considered good. The lowest score was 70, while the median was 90. This exceptionally positive result implies that participants feel the system is useful and valuable. The participants approved the software system’s concept and found it helpful and exciting. Figure 5.11 provides the questions and a summary of the number of answers.

The open questions in the questionnaire captured the participants’ perception of the system’s characteristics and its relevance in a hospital environment. The responses were in English, French, Portuguese, or Spanish, depending on the participant. They were carefully translated into English to ensure the context of the reactions was not lost in translation and then were analyzed in this language.

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[12] $S = 2.5 \times [(Q1-1) + (5-Q2) + (Q3-1) + (5-Q4) + (Q5-1) + (5-Q6) + (Q7-1) + (5-Q8) + (Q9-1) + (5-Q10)]$

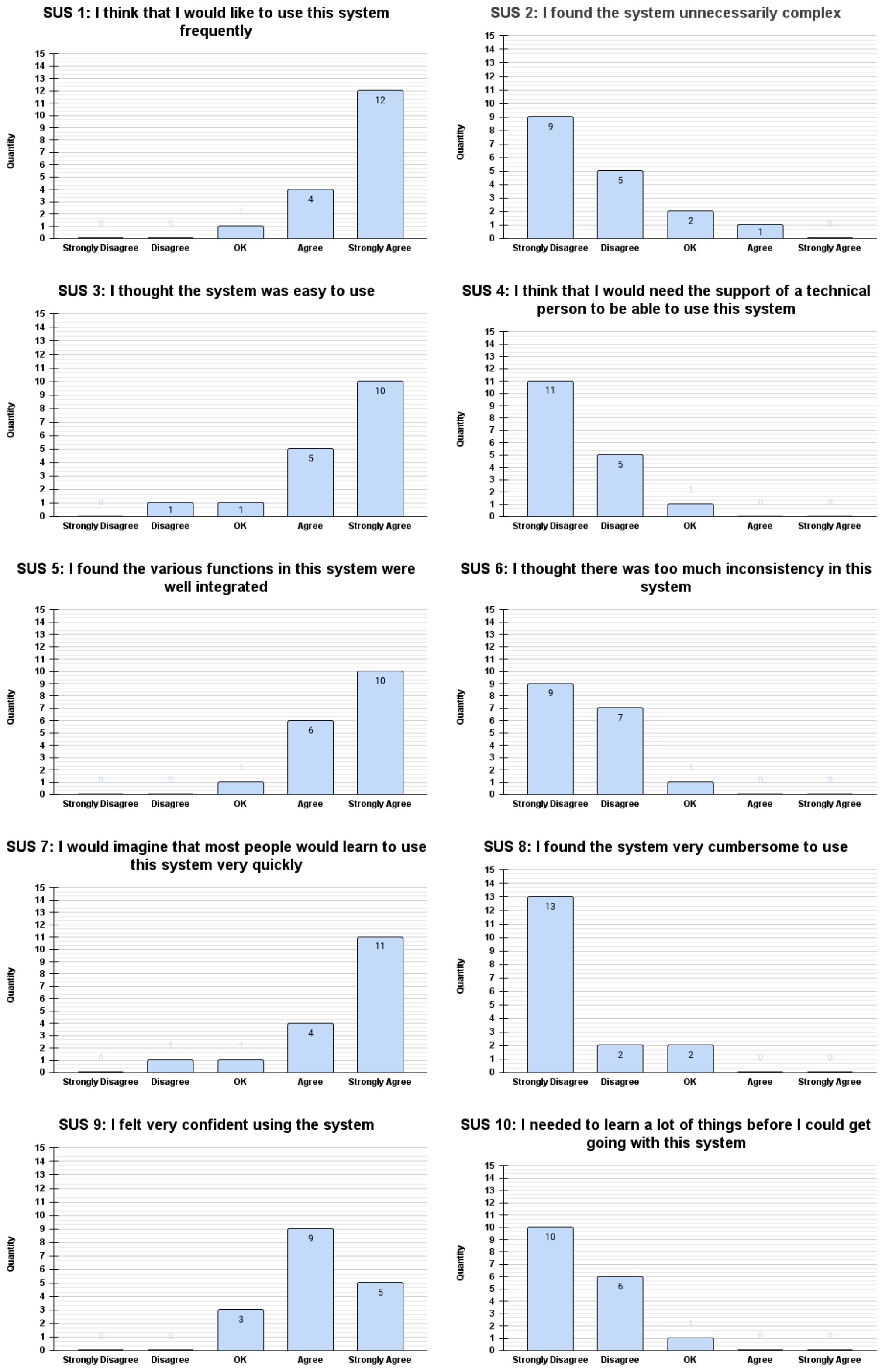


Figure 5.11 – Quantity of each answer for each SUS statement

The first question asked whether participants would accept being located by the software system in an actual situation, similar to what happened in the experiment. Tracking users within an environment can pose ethical concerns, potentially preventing the deployment of a software system in a hospital. Out of 17 answers, 11 were simply cheerful. These answers indicated no issue, considering the system would be part of their job.

Three answers were positive, but some conditions were imposed. Two participants pointed out that being located is only acceptable in a working environment and during service, not during breaks. Another participant stated: "*I wouldn't mind being located in a professional context, for certain periods (not continuously) and only if it makes the organization of work much easier*." Two participants were positive; however, they highlighted some confidentiality concerns that might hinder the software system from being implemented initially. Only one participant was decidedly negative.

The second question asked whether participants encountered any errors in the dashboard. Twelve answers indicated that no errors were found when querying the dashboard, from which one participant assumed that maybe it was just inattention due to being focused on the tasks of the scenario. Five answers stated that errors were found, of which four specified the issues. Three participants pointed out the same problem: the wheelchair was still considered dirty after being moved inside the cleaning room. One participant noted an inconsistency with the ECG: "*Yes, when there was a problem with the ECG, it was not written on the dashboard."* In this case, the participant looked for this information on the overview table, not the preventive maintenance table.

The third question asked about participants' feelings about using a system that feeds on implicit interactions. Participants provided more opinions rather than just being positive or negative. Three participants were simply positive without further explanations. One concerned participant stated: "*I feel no problem with that as long as I do not think that unsaid other objectives are behind this interaction.*" Three participants said this interaction is more natural, permitting them to focus on the activities. Four participants highlighted the quality characteristics of the software system: two pointed out it was **easy to use** due to these interactions, and two pointed out that it is **comfortable** to use the system because the sensors do most of the hard work. Four participants were positive about automating essential tasks by making work life more manageable. Two participants indicated concerns about proper functioning. One of them said: "*I had the urge to check if things were 'clean' after taking them*," possibly because the system did not instill confidence that it would update the dashboard correctly. Another participant was concerned about people who may forget to send equipment to maintenance, making the displayed data inaccurate.

The fourth question demanded comments or suggestions. Five participants did not provide any, but in contrast, some provided several remarks. One participant suggested wearing a smaller badge, likely due to a misunderstanding that the badge with the ESP8266 was just part of a simulation. One participant recommended testing with actual equipment for an authentic experience. One participant suggested making the dashboard editable: "*User can send a request to change the state of an object… The change in the state of an object must not be automatic/systematic because the user can make mistakes*". Five participants offered superficial improvements to the procedure, such as altering the wording in scenarios or providing less information at the beginning.

The following suggestions were considered as improvements in the subsequent experimental study. Two participants recommended conducting the experience with concurrent users and simultaneous patients. Two others advised enhancing the dashboard's user-friendliness, and one suggested making it accessible on a portable device. Three participants expressed concerns about the absence of feedback when using the RFID device attached to the MRI, as stated here: "*It would be interesting to add sound effects to the system*." Activating the RFID card provided neither visual nor audio feedback. These suggestions were considered in the experimental study conducted afterward.

In the scenarios, some steps were followed by a request for participants to verbally describe some behaviors occurring at that moment. The researcher took notes of the participants' answers at the exact moment. These questions were inspired by the SAGAT method (Endsley, 1988a) (see Section 2.1.3), a tool for evaluating situational awareness in high-risk contexts. This method develops questions to measure the participants' situational awareness of the system. In our case, it was to guarantee that the participants were attentive and understood the functionalities.

The first question asked if the red-light alert was turned on when the participant entered the imaging room with the wheelchair. Fourteen participants (82.4%) answered that the LED was on. Therefore, the wheelchair was correctly detected in the room. The second question asks if the ECG was marked as "Critic!" in the preventive maintenance table. Sixteen participants (94.1%) answered that the problem occurred as expected. The third question referred to a final condition: MRI and wheelchair should be clean. Thirteen participants (76.5%) stated that the wheelchair was clean, and fifteen (88.2%) noted that the MRI was clean. These results suggest that the system was accurate for these specific cases. The results are summarized in Figure 5.12.

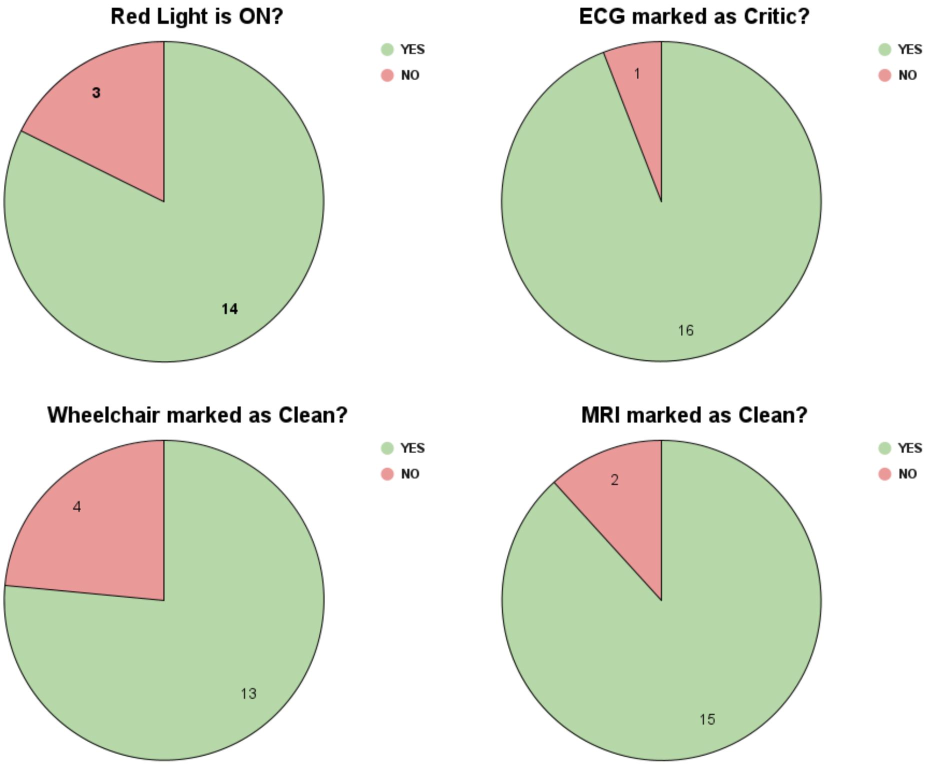


Figure 5.12 – Results for the “speak aloud” questions

### 5.3.3 Discussion

This section summarizes findings and conclusions based on the datasets and questionnaire analysis. The results of the experimental study highlighted flaws in the modeling. Applying the metamodel to create an actual application is a much more compelling experience than through proofs of concept, as the latter only allows one to verify if the concepts align with a narrative. At the same time, an actual implementation requires that the modeling strictly adhere to the requirements.

The application qualifies as **IoT** as it defines ***things*** and follows the **MQTT** architecture, considering the **Perception**, **Transport,** and **Processing** Layers. It is **context-aware** due to well-defined environmental boundaries, technologies used, and target users. However, ensuring that the application is **situation-aware** is more challenging. Data was collected based on a sequence of steps to be followed by participants. Within datasets, the expected data was mainly found in the correct sequence, as indicated by the deficient number of false negatives. However, we can only ascertain this because the experience occurs in a controlled context. The amount of collected false positives was nearly the same as expected, which means the system cannot accurately determine what is happening. The software system cannot be considered **situation-aware** if the functionalities depend on RSSI.

The metamodel requires improvements. The implementation was developed considering various enhancements not yet present in the metamodel. First, the software modeling is incorrect. Only identification, location, and communication technologies are considered, whereas the IoT software system may depend on middleware, databases, and data managers. In the third representation, it is impossible to include Node-RED and MySQL. The ubiquity level should be removed from Technology because the decision about which technology to use is made during requirements elicitation, not application execution. The associations of Devices are also inconsistent. Currently, only rooms can contain devices, but in practice, users and objects are also included in the application. Objects cannot implement technologies as this is an abstract concept; instead, they must contain Devices that implement technologies. Various other inconsistencies occur in the modeling of Devices. A microcontroller is currently only associated with sensors, whereas one is connected to an RFID reader. Moreover, a microcontroller is not inherently an input device; it depends on which other components are used. For example, an Arduino connected to an LCD would be an output device. Overall, the entire representation of the Device needs to be reconsidered.

There is a subtle inconsistency in the association between the User and the Object. Although users can possess objects, this information is already available. Activities know which user used which object and in which room. To avoid ambiguities, this association should be removed. Another point of attention is the association between Role and Activity. In practice, the user performs the activities; the role is merely a condition. A solution could be to transform Role into an association class. Users' traits and states will probably not be relevant in systems for locating objects. **Object User**, **System User**, and **Implicit User** subclasses should be removed because these are temporary characteristics. The comprehension of situations can indicate if the users currently interact with an object, a dashboard, or the environment without changing their inherited classes. Certain traits of Objects, such as being expensive or not, will never be used. If necessary, the object should reference the quantity of objects of the same type in the system.

The quantity of false positives was not an issue of the metamodeling. ESPs use Wi-Fi, which has a too extensive range for the space available (49m²). Furthermore, the transmission power was not reduced, remaining at the standard value of 20dBm. With this setting, the devices experienced interference from other devices on the 2.4 GHz frequency (Wi-Fi and BLE), extending way beyond the available area. For instance, anyone passing with a smartphone in a nearby hallway could alter our results. For the following experimental study, all devices should minimize their transmission power.

Even though promoting the reduction of explicit interactions is a primary motivation for the research, the questionnaire revealed that this functionality is not necessarily well-received. While it makes the system easier to use and reduces workload, there is a risk that users may feel unaware of what data is being collected, or they may end up paying extra attention to the dashboards to verify the accuracy of information. It might be better to balance implicit and explicit interactions so users feel they influence the results. Excessive automation was also responsible for the quantity of false positives. The transition between **In Use** and **Stray** was imprecise due to depending on the simultaneous location of the user badge and the object's access point. This caused a significant amount of alternation between these states. The following experimental study should consider shifting the responsibility to the users to report when they have an object like the approach already implemented with the MRI.

Despite the issues, participants liked the idea of what the software system proposes to do, as evidenced by the analyses of the SUS and open questions. The participants felt immersed in the experience and understood how such a system could significantly assist the daily activities of medical professionals.

### 5.3.4 Threats to Validity

Four categories of threats to validity should be considered in software engineering (Wohlin et al., 2012): internal validity, external validity, construct validity, and conclusion validity. This classification is general and applies to empirical research.

**Internal validity** refers to the conclusion about a possible causal relationship between treatment and outcome. The few health professionals among the participants might have made the results less rich. One nurse identified inconsistencies in the tasks of the second scenario, and similarly, other important insights could have been obtained with more health professionals. Also, setting up specific scenarios might have led to some unrealistic data, as participants were dictated to act instead of acting freely. To mitigate it, we monitored experimental conditions and participant actions to identify and correct any deviations from the planned procedures.

**External validity** refers to conditions that limit our ability to generalize the results. The study represented a hospital simulation, and the available area was tiny. The study did not describe interactions between users and included few objects. Moreover, PhD students and professors are generally less capable of providing insights than health professionals. To mitigate this, we devised scenarios derived from actual hospital workflows, consulting with a geriatrician for validation.

**Construct validity** refers to generalizing the experiment's result to the concept or theory behind it. The occurrence of false positives and negatives in object tracking hinders the system from being situation-aware. The software system was not constructed as expected, and the metamodel was not modeled as expected. To mitigate this, the developed application was not strictly based on the metamodel’s third representation.

**Conclusion Validity** refers to the issues that affect the ability to draw the correct conclusion. Based on the outcomes, we may not conclude that the software system can manage the location and use of medical equipment. The metamodel still presents issues, and the application showed problems that are not directly related to the metamodeling. The short quantity of executions and a large amount of false positives might have hindered conclusions. To mitigate it, pilot tests were executed, leading to several corrections.

## 5.4 Conclusion

The proposed metamodel was tested as a possible tool for creating IoT software systems for managing the location and use of medical equipment in health centers. A first experimental study was conducted to verify the feasibility of using the third representation to create applications and to check the accuracy of collected data in the resulting applications. It was a collaboration between LAMIH/UPHF and a French hospital.

The **tailoring methodology** (Section 5.1) was employed, considering three levels of abstraction: the **conception** of the metamodel, its **instantiation**, and its **translation into code** for specific applications. **Tailoring** involves using instantiated models as evidence for further evolving the foundations of the metamodeling. During the instantiation process, the metamodel adapts based on requirements, removing non-applicable classes and adding new ones. Instantiated models can be used to develop several applications through the translation process.

The **first experimental study** (Section 5.3) revealed issues in the third representation, such as not correctly representing software entities and presenting inconsistencies in the representation of devices. These and several other problems led to tailoring the metamodel, resulting in a fourth and consolidated representation. The study highlighted that users may not feel comfortable in the presence of software systems, which are essentially composed of implicit mechanisms. The accuracy of the application was still inadequate, as nearly half of the data were false positives. Based on the results, the metamodel must be evolved again, and its evolution must be applied in another experimental study, described in Chapter 6.

# 6 Second Experimental Study: Evaluating the Consolidated Metamodel

Two experimental studies were conducted to determine the **Feasibility** of applying the proposed metamodel to developing IoT software systems for managing the location and use of medical equipment in health centers. The first experimental study was presented in Chapter 5. The problems highlighted by the study led to **tailoring** the metamodel into a fourth representation, which we will refer to as the **consolidated metamodel**. Again, the metamodel will undergo an **instantiation**, **building** an IoT software system and its application in an **experimental study** with similar characteristics. Unlike the previous experimental study, the application built upon the consolidated model is expected to mirror precisely the consolidated metamodel entities without any necessary structural changes.

## 6.1 Fourth Representation: Consolidated Model, Instantiation, and Coding

This section presents the **consolidated metamodel**, its **instantiation** based on **requirements**, and its **translation into code** for composing an IoT software system, which will be applied to an experimental study in Brazil.

### 6.1.1 Consolidated Metamodel

The previous representation was too large, making it unintelligible. To facilitate understanding, the metamodel was divided into three thematic packages: **Real-World**, **Devices**, and **Software**. Figure 6.1 summarizes the three packages. All the classes are **abstract,** so they can be later instantiated to create a specific model for a health center. An annex provides the descriptions of each class and attributes in the packages (*Annex F – Consolidated Model Data Dictionary*).

The **Real-World package** is presented in Figure 6.2, displaying interfaces to external classes in gray. This package represents classes that define the world and exist independently of the software system. It contains two context awareness elements: the **user** and the **environment**. The metamodel is intended for designing indoor IoT software systems inside one or more buildings. In this sense, the previous **Environment** class was intentionally renamed to **Installation**, which, according to the Cambridge Dictionary, is *a place with people, buildings, and equipment with a particular purpose*. The **Sector** class was also renamed because this term is too tied to economics. At the same time, the **Department**, also in the Cambridge Dictionary, is *one part of a large organization, such* *as a company or university, that deals with a particular area of work, business, study, etc*.

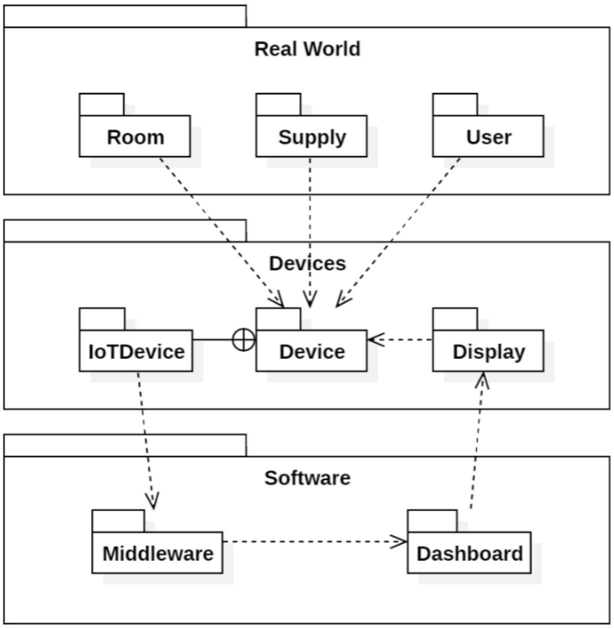


Figure 6.1 – Package diagram summarizing the three packages

The representation of situations was reorganized. The previous **Activity** class was renamed **Task**, just like in the first and second representations. The **Situation** class was renamed to **Activity**. Situation awareness is far more than just keeping a sequence of actions; it is the perception of elements, comprehension of their meanings, and projection of their status (Endsley, 1988b). The situation should not be a class but an understanding of what is happening. It is possible to achieve this by utilizing the Event, Activity, and **Task** classes. **Tasks** are unitary actions, such as moving a supply from one room to another. The **Activities** comprise a set of tasks happening in a time interval. The set of tasks with a complete meaning characterizes an **Activity**. For example, a nurse taking a wheelchair is a task. Moving it to a reception while another nurse arrives with an electrocardiogram could be interpreted as an attendance activity involving many professionals. Depending on the purpose of the activities, events may occur.

The previous **Object** class was renamed to **Supply** to avoid confusion with the term “object” in object-oriented programming. It has a self-association because certain supplies may depend on others. The **Object Traits** class was suppressed, and the relevant properties were added directly to the **Supply** class. The “is metallic” property was replaced by a **Material Type** enumeration. The **Cleaning Mode** enumeration indicates how the supply should be cleaned. For example, a wheelchair should be disinfected, while clothes should be washed. Until the third representation, the supplies could only keep their current state. It was impossible to store past states, which is essential for the system to understand the situation. Now, the history of states is represented by the **Supply State** class, which stores states over time. As a basic behavior, the supplies can **move** to a new room and **change** to a new state.

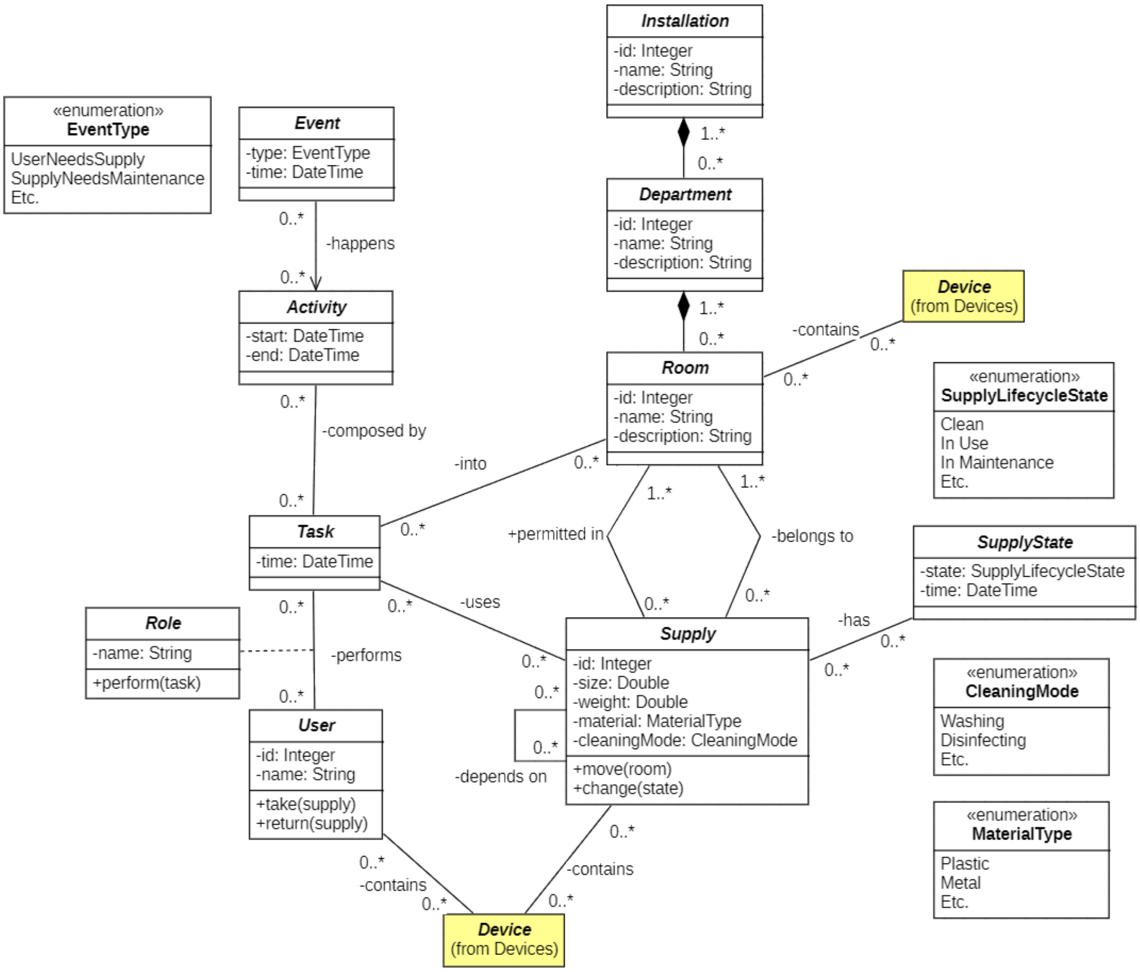


Figure 6.2 – Real-world package

Now, **Users** perform **Tasks**. A role is a condition for a user to perform a task; therefore, it became an association class. For example, being a radiologist is a rule for a user to analyze the results of a magnetic resonance exam. Also, the users are no longer associated with supplies to avoid redundancy. The **Tasks** already inform about the **Supplies** possessed by users. A user can take or return a supply as a basic behavior, while a role permits the user to **perform** a task.

The associations between rooms and supplies were changed. Previously, a supply would be **in** a room while being **from** another room. The association was suppressed because this information can be inferred from the **latest task**. The **form** was kept but renamed to **belongs to**. A new association, **permitted in**, indicates which rooms the supply can visit. This association may represent that metallic supplies are prohibited in the imaging room. In addition, this association clarifies whether a supply is shared and why the “is shared” property was suppressed.

The representation of **time** was simplified. Where applicable, the Time Bounds class was replaced by one or more Date Time properties. The **Activity Time** class was suppressed due to its complex concept. The software system only needs to check their occurrence intervals. In addition, the previous idea of transforming activities into a linked list hinders the possibility of two activities occurring in parallel (inclusion/interception) (Cimino et al., 2012).

The **Device package** is presented in Figure 6.3, displaying interfaces to external classes in gray. It represents the hardware in the **platform**, the context’s third element. In the third representation, **Rooms** could contain devices, but **Users** and **Supplies** could not. In the new modeling, the **Device** class is intricately linked to the **User**, **Supply**, and **Room** classes, representing the various devices that can be integrated into an IoT software system for location and use management. The system focuses on the supplies, but specific devices can also be allocated to users or placed in rooms to serve the same purpose, illustrating the metamodel’s versatility and adaptability.

**Devices** are a set of mechanisms that provide functionalities. One of these mechanisms concerns **processing**, such as a microcontroller. Other mechanisms are the **input** or **output** of data. Devices with **output** mechanisms can provide information to users, such as displays (LCDs, monitors), printers, or simple LEDs that light up in certain situations. Devices with **input** mechanisms are responsible for collecting data, which are then interpreted by the software system. Sensors such as gyroscopes can be attached to supplies, ultrasonic sensors can be connected to room entrances, and cameras can be placed inside rooms. However, the most common input strategy for object positioning is using ultra-high frequency radio technologies (UHF), such as Wi-Fi and BLE. In this strategy, **readers** scan the surroundings for the presence of other broadcasting **identifier** devices and, upon finding them, can estimate the distance through RSSI.

Note that devices are not necessarily IoT. For a device to be IoT, it must communicate through Middleware. For example, a device composed of an Arduino (processing), a sensor (input), and an LCD (output) is not IoT, as its functionality is offline. However, a device with a connected microcontroller, such as an ESP32, that obtains data from a sensor and uses Wi-Fi to publish to an MQTT broker is an IoT device. As a basic behavior, **IoT devices** can publish or subscribe to topics.

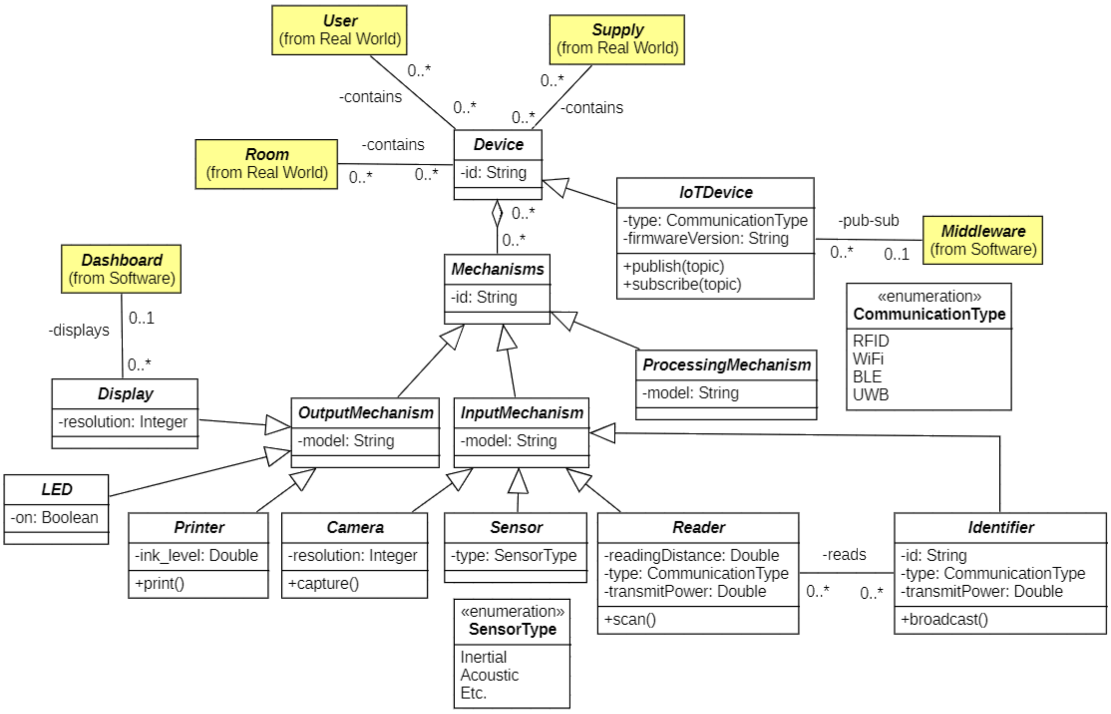


Figure 6.3 – Devices package

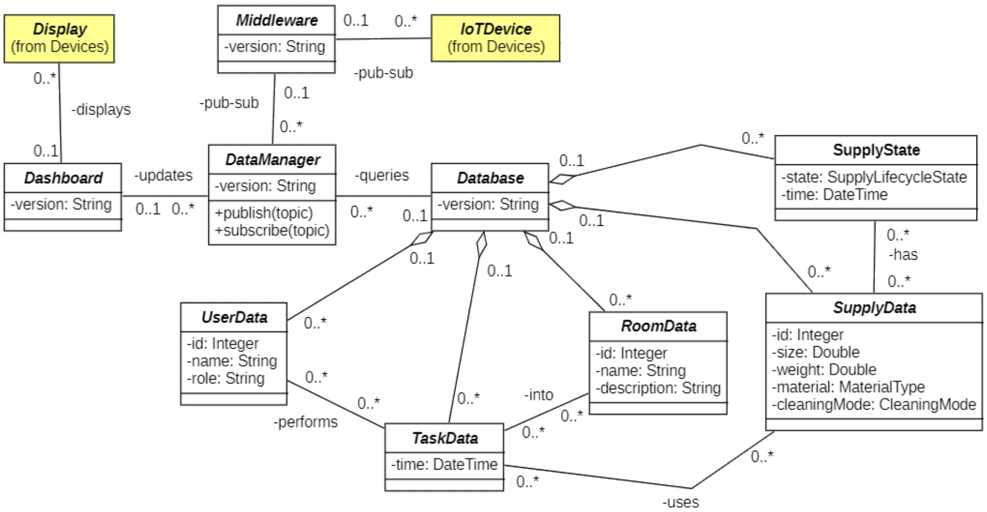


Figure 6.4 – Software Package

Figure 6.4 presents the software package, displaying interfaces to external classes in gray. It represents the software in the **platform**, context's third element. Note that up to the metamodel's third representation, the software was only considered regarding **identification**, **location**, and **communication**, which refer to the **Perception** and **Transport Layers** of IoT. However, the structure of the **Processing Layer**, which is responsible for storing, analyzing, and processing the received information, was not considered.

The **middleware** is the interface between **IoT devices** and the **data manager**. The **data manager** is responsible for receiving, submitting, and interpreting data. The received data is processed and interpreted, and relevant information is displayed on a dashboard, stored in a database, or sent back through the middleware. Note that in previous versions, the dashboard was modeled as hardware when specific output devices displayed software. Like IoT devices, the **data manager** can publish or subscribe to topics as basic behaviors.

The application's **database** is essential for the target system to analyze historical data on the use and location of supplies. Thus, usage patterns and paths can be understood. The database should contain at least tables on **users**, **rooms**, **tasks** performed over time, **supplies**, and their **states** over time.

### 6.1.2 Requirements for a Simple Part of a Hospital

To create an IoT software system capable of managing the location and use of medical supplies in a specific health center, it is necessary to **instantiate** the metamodel to include the essential classes based on requirements. Although a hospital is being simulated, realistic elements are included to ensure the system functions similarly to a real-world environment. A partner nurse assisted in planning the supplies, user roles, room arrangements, and user behaviors. The software system to be developed this time should resemble the previous, however considering the improvements in the metamodel and implementing the various points discussed in the results of the earlier study, such as increasing the number of explicit interactions, reducing transmit power, adding visual feedback when applicable, among others.

The hospital will only contain four supplies: **oximeters**, **wheelchairs**, **resonance machines** (MRI), and **electrocardiograms** (ECG). It will not be divided into departments and will include only six types of rooms: **triage rooms**, **cleaning rooms**, **maintenance rooms**, **imaging rooms**, **warehouses** (previously called storage), and **patient rooms**. Locating a supply means it has been found within one of these rooms, just like before. Existing MRIs will permanently be fixed in imaging rooms.

There will be only three possible user roles: **nurses**, **cleaners**, and **maintenance technicians**. Users, referred to as health professionals, can perform specific actions with supplies depending on their role: **notifying problems**, **cleaning**, **fixing**, or **disposing**. In addition to taking and returning supplies, which are basic behaviors, these actions should trigger events for changing the state of supplies.

The tasks performed by health professionals may be implicit or explicit. Moving around the hospital with a supply is an implicit task, which generates a path for the software system. However, all the actions that trigger events result from explicit interactions. For example, the health professional may only take, return, notify problem, clean, fix, or dispose of supplies by explicitly interacting with some device or user interface. Implicit or explicit tasks may cause a **state change**, depending on the diagram in Figure 6.5.

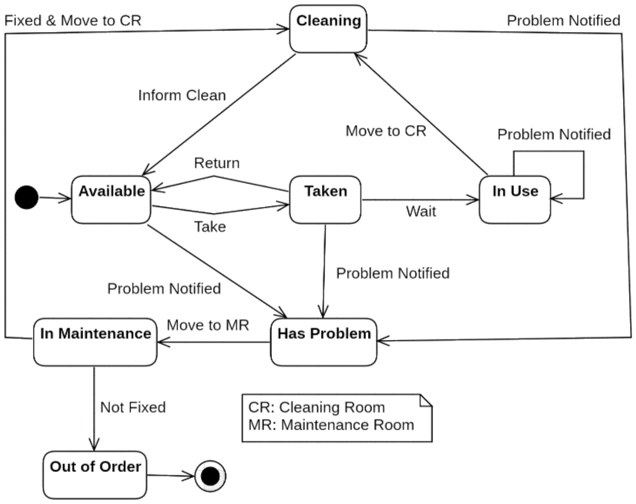


Figure 6.5 – State diagram for supplies

Objects will have only one state at a time, simplifying system maintenance, development, and data visualization on the dashboard. The new **Available** state, for instance, means that the supply is clean, not in use, and not under maintenance, as if the previous classification still existed. All supplies start in the **Available** state, indicating they are ready to use. When a user takes a supply, the state changes to **Taken**. This state was created to give the user time to change their mind and return the supply, if necessary. If the user immediately returns the supply, it will return to the **Available** state. If the user continues using the supply for a specific time, it changes to the **In Use** state. The supply will continue **In Use** until it is moved inside a cleaning room. This movement changes the supply’s state to **Cleaning**. When a cleaner informs that they have cleaned the supply, it changes to **Available** again.

At any time, users can report problems. If the supply is in the **Available**, **Taken**, or **Cleaning** states, it can be changed to the **Has Problem** state. However, if the supply is **In Use**, the system still forces it to go through the cleaning procedure before switching to **Has Problem**. Once a supply is defective, it must be taken to a maintenance room. This movement changes the state to **In Maintenance**. A technician must indicate whether the supply could be repaired. If it fails, the supply changes to the **Out of Order** state. If it is repaired, it changes to the **Cleaning** state, forcing cleaning procedures. These transitions refer to mobile supplies, which can be moved between rooms. Fixed supplies such as the MRI must change states without leaving their place.

Wi-Fi devices will manage supply location. These low-cost devices constantly and automatically detect each supply's current location. They do not interfere with existing supplies. Devices implemented as **stations** will continuously scan for devices implemented as **access points**. **Stations** will be placed inside each existing room, while **access points** will be attached to each oximeter, wheelchair, and ECG.

There will be a **dashboard** accessible within the hospital’s local network, which may be displayed on monitors or even on smartphones. Any health professional may use the dashboard to check the location and state of supplies and notify problems. In addition, technicians would use the dashboard to inform if they fixed or disposed of a supply that was in maintenance. The health professionals will use RFID devices to inform when cleaning is finished when taking and returning supplies, specifically to cleaners. Each user will have a personal RFID card to perform these explicit tasks.

Previously, in the literature investigation, a systematic mapping of the use of RFID in interactive systems was conducted. One of the research questions was about quality characteristics that can be used to evaluate the use of RFID. Among the quality characteristics outlined by ISO/IEC 25010, the most common in these applications were **Performance Efficiency** and **Reliability**. The study also accounted for ubiquitous system quality characteristics (Carvalho et al., 2017). Attention was the most prevalent quality characteristic, defined as the system’s ability to keep the user’s focus on real-world interactions rather than technology. These three characteristics will result in quality requirements.

Based on the results of the open questions from the first experimental study, it was decided that only the location would be calculated implicitly this time. In contrast, all other tasks would result from explicit interactions. Actions are performed through **dashboards** or **RFID devices**. Therefore, both must be available in as many rooms as possible to prevent health professionals from visiting neighbor rooms. Indirectly, it refers to **Mobility**, which *refers to the continuous or uninterrupted use of the systems while the user moves across several devices*.

Wi-Fi devices use RSSI readings as distance measurements, which are inherently imprecise, so the calculation must be performed with a large set of collected RSSI values. However, the longer the system takes to collect them, the more it delays the dashboard updates, impacting users' data visualization. As a **Performance Efficiency** requirement, the application will be optimized to collect as many RSSI readings as possible within 10-15 seconds, which we evaluate as the maximum acceptable wait time for a user to receive new information.

Although RSSI readings are imprecise, the collected data on location must be consistent with what is happening in the context. To facilitate accurate data collection, as a **Reliability** requirement, the transmit power of the stations and access points must be adjusted to a value that ensures communication occurs only between nearby devices, minimizing interference with distant devices and others like smartphones. If an access point is scanned only by the stations in the nearest rooms, it is more likely that the software system will correctly identify where a supply is. The transmit power for these devices must be calibrated during the development.

The location of supplies is handled automatically, leaving users with only a few responsibilities, such as informing them when they take or return supplies or notifying them of problems via the dashboard. Most of the time, users focus on their work and forget about the software system. This relates to the quality characteristic of **Attention**, and the software system must operate this way because, in a medical environment, health professionals already have many severe responsibilities and should spend as little time as possible on the application.

### 6.1.3 Instantiation for a Simple Part of a Hospital

The instantiation of the metamodel must align with the requirements. Figure 6.6 presents the **instantiated Real-World model**, indicating interfaces to external classes in light gray and new subclasses in dark gray. The hospital is not split into departments; thus, **Installation** and **Department** were suppressed. The hospital contains subclasses for four types of supplies, six rooms, and three roles. Depending on the role, the health professional may perform additional actions.

The tasks were extended as **implicit** or **explicit**. Subclasses were also created for each event, corresponding to each **explicit task**. Supplies moving with users between rooms will be monitored as **implicit tasks**. User activities are functions that occur within a time interval and have a meaning in the context. The **Supply Lifecycle State** enumeration contains all the states defined in Figure 6.5. The **cleaning mode** enumeration only contains Disinfecting as an option since all the supplies are cleaned this way. The **material type** contains plastic or metal as options for the materials used in the supplies.

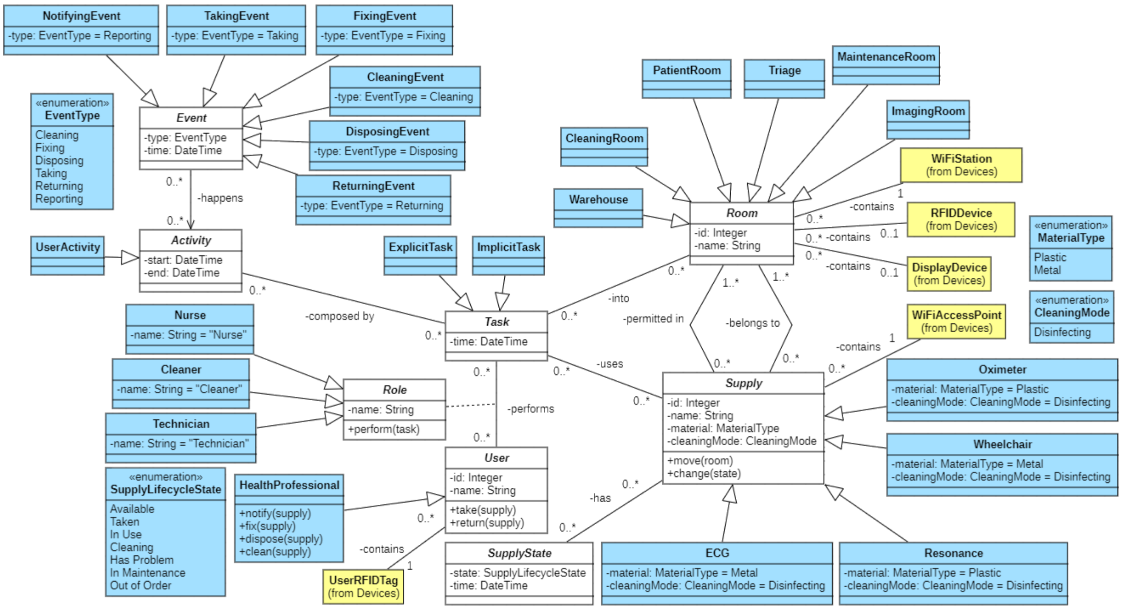


Figure 6.6 – Instantiation of the Real-World Package

Figure 6.7 presents the **instantiated Device model**, indicating interfaces to external classes in light gray and new subclasses in dark gray. Five types of devices were created according to requirements. Each supply carries a **Wi-Fi Access Point**. Meanwhile, **Wi-Fi Stations** are fixed in each room. An **RFID device** with a reader is placed in rooms for users to inform when taking, returning, or cleaning supplies. Each user also has a personal RFID card that must be approximated to the reader, followed by another card that identifies the supply. **Wi-Fi stations** and **RFID devices** are the only IoT devices since they publish data in middleware. APs are not IoT Devices because they just broadcast signals to be scanned by nearby stations.

**Display Devices** are intended to display the **dashboard**, which, in addition to providing information, will also permit users to notify problems and inform whether supplies have been fixed or disposed of. Monitors will be included in several rooms so that health professionals can view supplies' status from anywhere. For the processing, devices will use **ESP** microcontrollers powered with Wi-Fi capabilities. A **computer** subclass was generically included to represent the machines displaying the dashboard using a monitor as an output mechanism. The stations, access points, RFID readers, and tags are set as input mechanisms. The **Camera**, **Sensor**, and **Printer** classes were suppressed because requirements do not preview them.

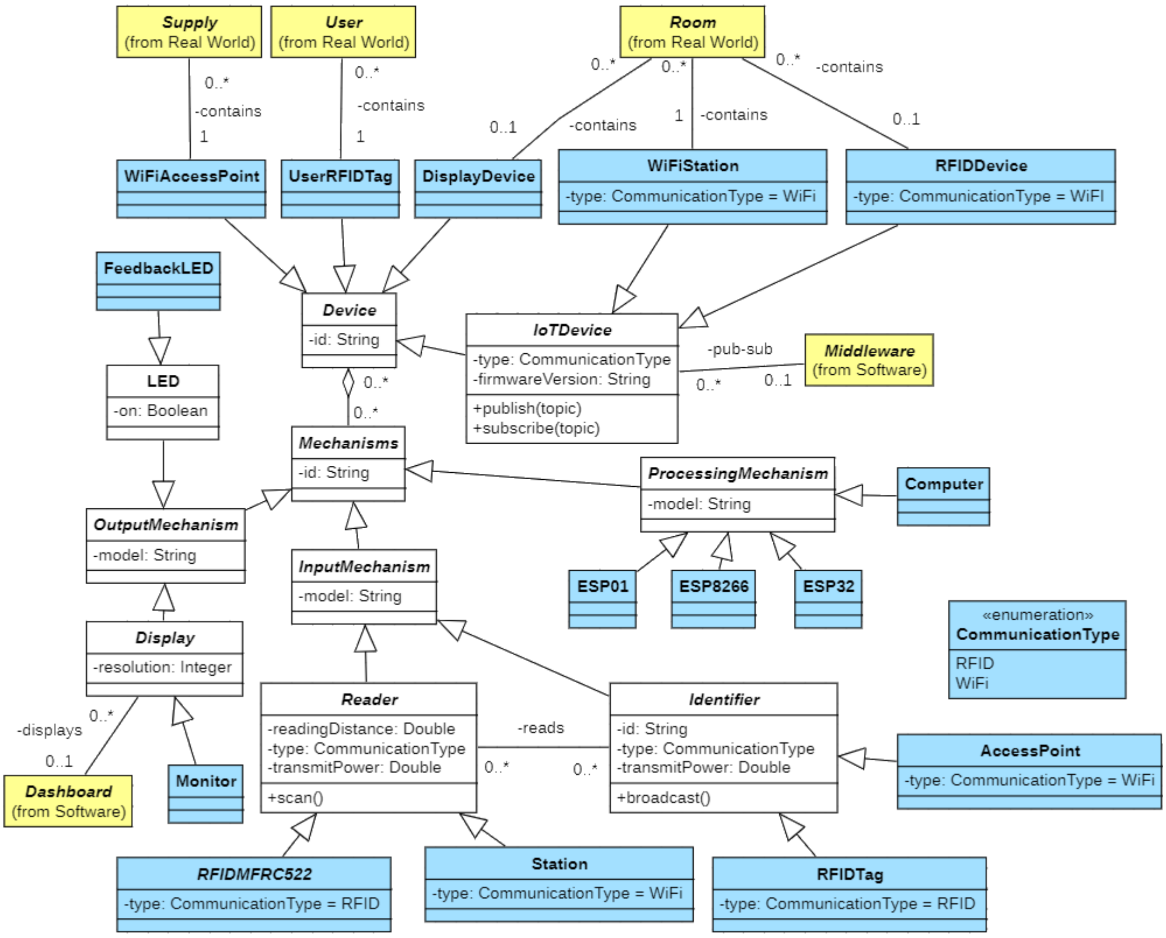


Figure 6.7 – Instantiation of a Devices Package

Figure 6.8 presents the **instantiated Software model**, indicating interfaces to external classes in light gray and new subclasses in dark gray. In it, the subclasses indicate which technologies should be used and how they communicate with each other. The RFID devices and Wi-Fi stations publish data via **MQTT**, which will be read by a data manager subscribing to the same topics. The manager will be responsible for updating data on the dashboard and storing relevant data in a **MySQL database**. The dashboard displays the current room and state for each supply. The data manager and the dashboard will be made using **Node-RED**, just like in the previous experiment.

### 6.1.4 Creation of an Application

In this section, we describe the **translation process**, in which implementation decisions and available resources led to creating a single application with three main functionalities: locating supplies, managing supply usage through states, and providing information on location and use via a dashboard. Although the coding adheres to all the defined attributes and associations, the instantiated models served as a requirements specification rather than a basis for direct coding. Due to the IoT architecture's nature, the metamodel entities' implementation is distributed across different parts, such as microcontrollers, databases, and data managers.

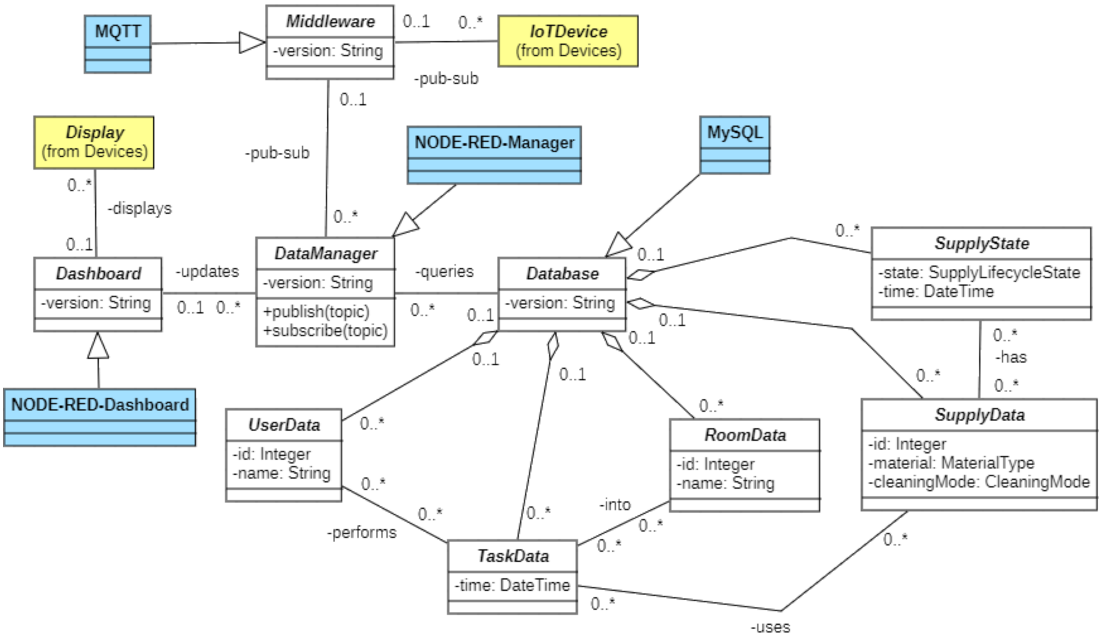


Figure 6.8 – Instantiation of a Software Package

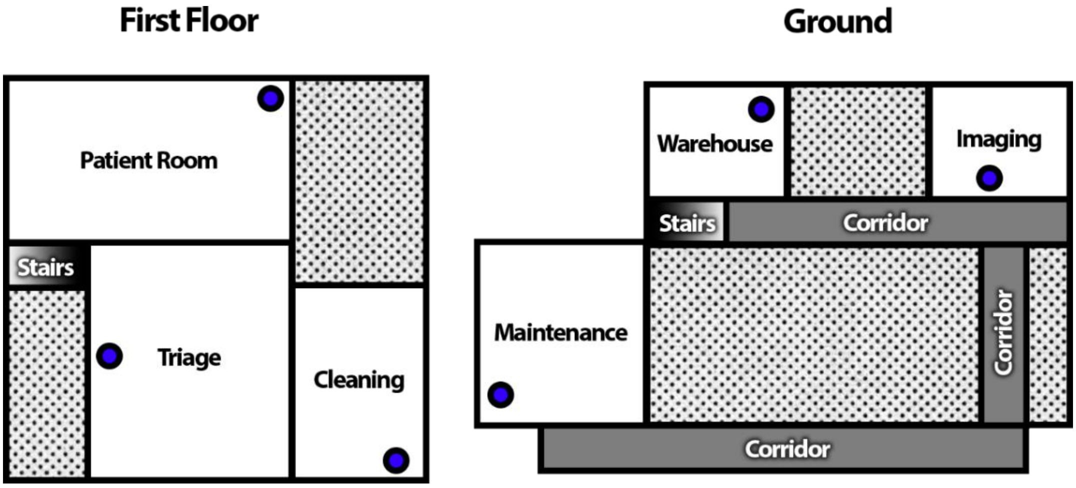


Figure 6.9 – Map of the simulated hospital

Only one of each supply was implemented: an oximeter, a wheelchair, an MRI (Magnetic Resonance Imaging), and an ECG (electrocardiogram), all simulated by boxes. Six rooms were available for implementing the simulated hospital, as shown in the map in Figure 6.9. In the map, unused spaces have patterns, and blue circles represent the positions of Wi-Fi stations. Only one of each room type was set based on this spatial limitation. Stairs and corridors were considered ways in our system, not rooms. Note that the area has two floors, with three rooms on the ground floor and three on the first floor. The ECG, Wheelchair, and Oximeter are kept in the warehouse, while the MRI is always in the imaging room. As for the users, the application expects four health professionals to interact with supplies in parallel.

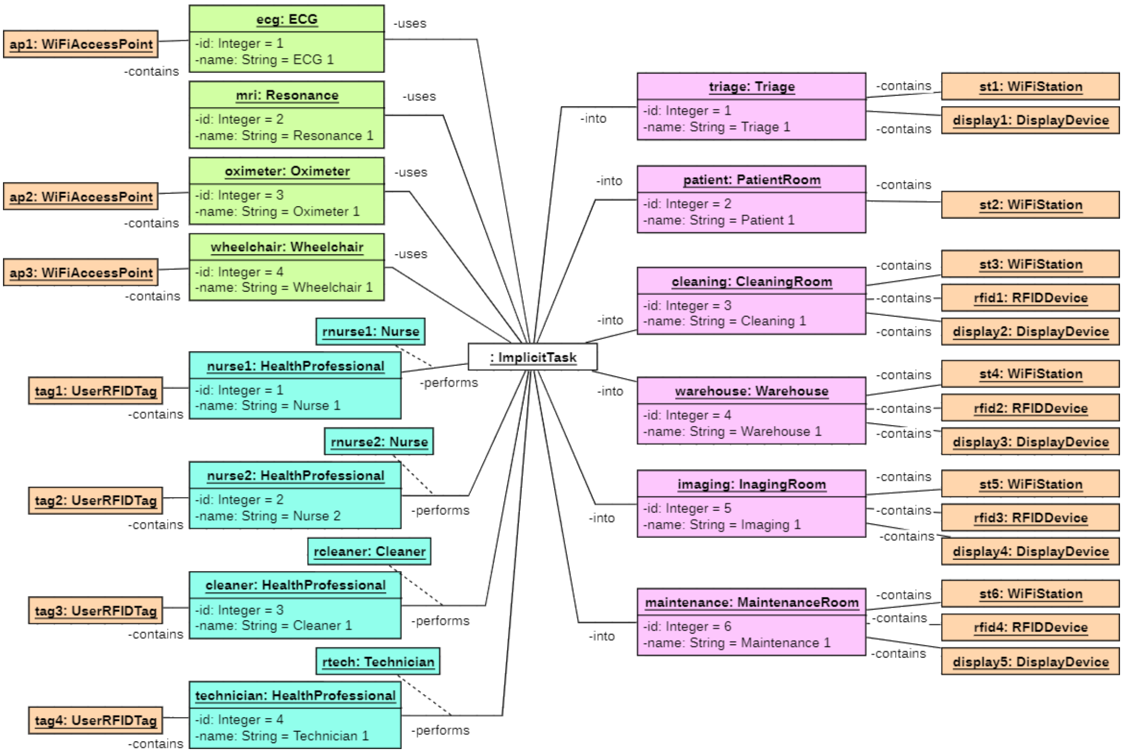


Figure 6.10 – Object diagram summarizing the main real-world and device instances

The transition between the supply states **Taken** and **In Use** (Figure 6.5) was set as 20 seconds for the context of this application, an interval that seemed plausible for users changing their minds. **ESP01** was used to compose access points, while ESP32 composed **stations**. The transmit power of the ESP01 and the ESP32 were calibrated so that the best values were 10dBm for ESP01 and 11dBm for ESP32 in the context of the simulation's map. As for the time the system waits to collect RSSI readings, a fixed time of 12 seconds was kept. In this interval, an average of 70 readings are collected for analysis. Given that readings from three simultaneous APs are expected, the average is 23 readings per AP (70/3) and about two readings per second per AP (23/12). This strategy provides more accurate data compared to the first experiment, in which data was collected from Stations and immediately used. In the current approach, a large set of data is collected over several seconds, and the value to be considered is the average.

The object diagram in Figure 6.10 summarizes how users, supplies, and rooms relate to implicit tasks. In the figure, devices are orange, users are cyan, events are gray, and the dashboard is red. The object diagram in Figure 6.11 exemplifies each type of event. For three types (Taking, Returning, Cleaning) through explicit interaction between the user tags and the RFID devices. For three other types (Reporting, Fixing, Disposing), through explicit interaction via the dashboard. The object diagrams in Figure 6.12 illustrate how each of the five device types is assembled.

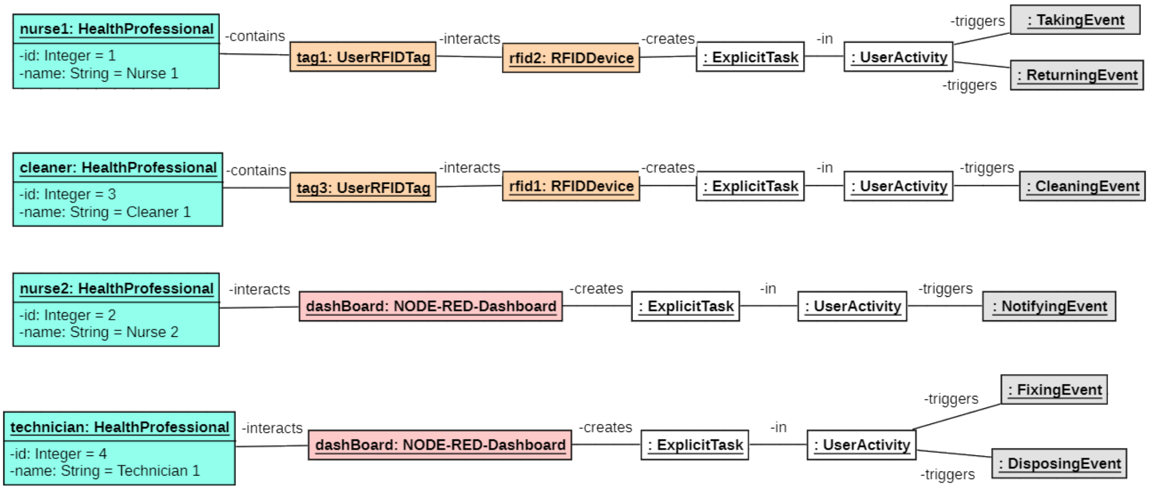


Figure 6.11 – Object diagram with examples of each event.

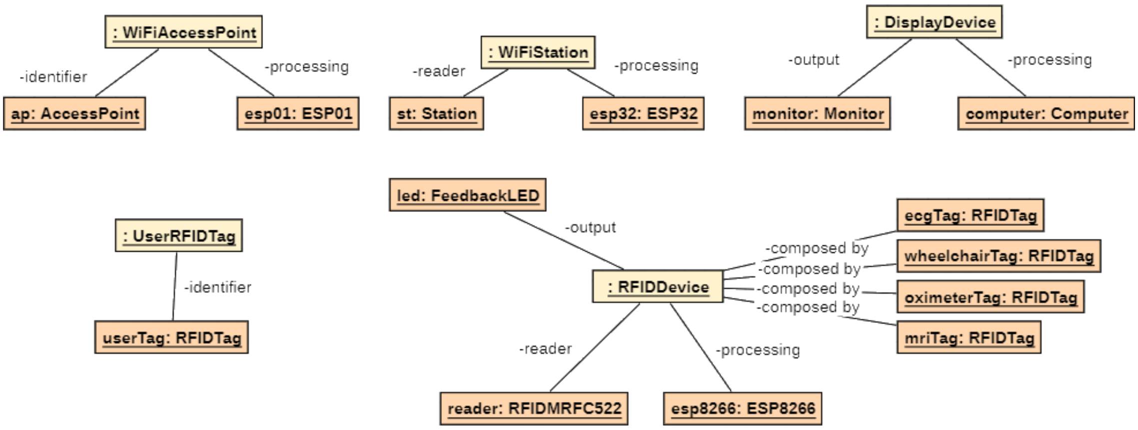


Figure 6.12 – Object diagram with device types and their mechanisms

RFID devices have an LED that lights up when users interact with the RFID tags, an improvement based on a suggestion obtained in the first experimental study. The coding related to the devices runs only within the ESPs. Since all devices are attached to some supply, room, or user, they are treated as proxies for these entities. For example, although the system calculates the distance between the AP (Access Point) and Station devices, it immediately interprets the result as the distance between a supply and a room. Similarly, RFID devices and user tags immediately provide data about users' interactions with supplies. The display devices have no coding; they are merely computers displaying the endpoints of the dashboard, although they follow the modeling.

The **Access Point devices** connect to Wi-Fi and set the transmit power to 10dBm. The **station devices** connect to Wi-Fi and the MQTT server, and the transmit power **is** 11dBm. In the loop, they scan the area for any access points. If found, stations send the RSSI value through an MQTT topic containing the station and the access point identifications. The **RFID devices** connect to Wi-Fi and the MQTT server, and the RFID reader is configured. They wait for the users' and supply’s tags to be in the loop.

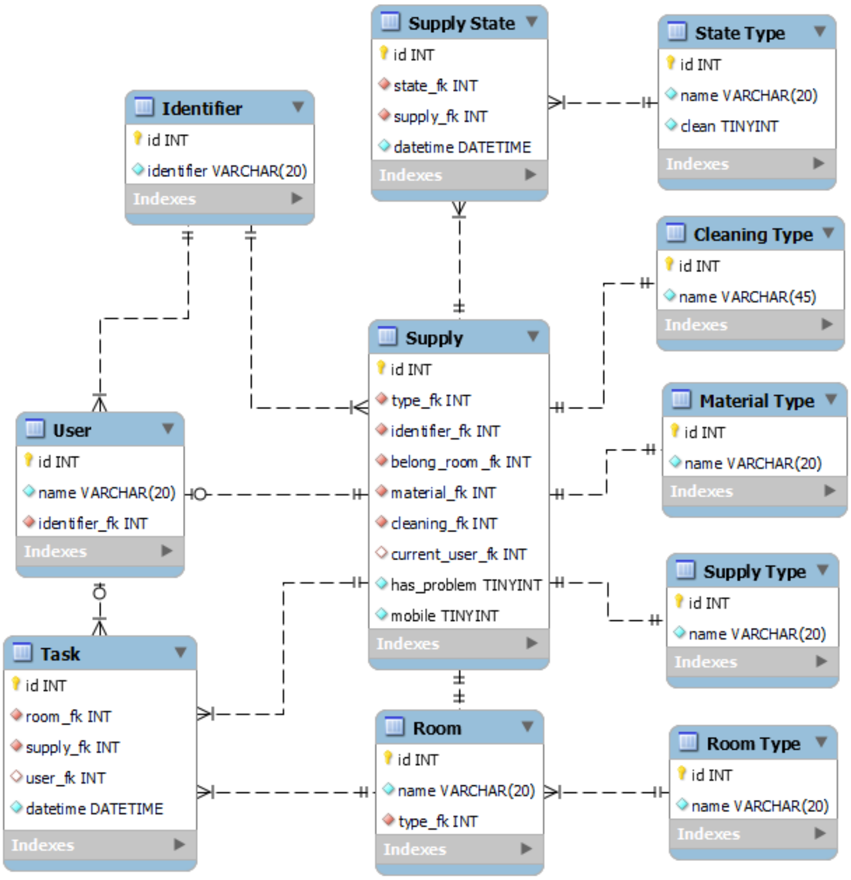


Figure 6.13 – Entity-relationship model

The database (entity-relationship model in Figure 6.13) stores the history of supply states and implicit tasks. Historical data will be used in the software system’s evaluation, and the data manager will use the most recent data to update the dashboard. The tables **User**, **Room**, and **Supply** are necessary to store the history of tasks. The tables

**Supply Type** and **Room Type** indicate names, which are the subclasses of the instantiated Real-World model (Figure 6.6). e.g., the Supply Type table includes ECG and a Wheelchair, while the Room Type table consists of the Cleaning Room and Warehouse. The history of states over time is stored in **Supply State**, which requires the **Supply** and **State Type** tables.

All tables and relationships follow the modeling of the instantiated models. The instantiated software model represents aggregations between the database and task data, user data, room data, supply data, and supply state. These are implemented as the tables task, user, room, supply, and supply state. These entities are also present in the instantiated Real-World model. Material Type and Cleaning Type tables relate to enumerations in the instantiated Real-World model.

Like in the previous experimental study, the database was used for more than data storage. **Stored Procedures** were used as an interface between the data manager and the tables to manage some behaviors. The *update_state* procedure manages all the state change rules in Figure 36 and is invoked in the manager's flows. The *set_usage* procedure modifies the supply ownership and is called by the data manager immediately after users interact with an RFID device. Since various explicit tasks can change the state, *set_usage* internally calls *update_state*. Two procedures encapsulate queries for populating the dashboard, which is called every five seconds. The *get_supply_info* procedure returns the current room name, origin room name, supply name, current user, current state, and Booleans for the cleaning and maintenance situations for all supplies in the system. The *get_supply_has_problem* procedure returns the names of supplies currently in the **In Maintenance** state to be displayed on the maintenance tab.

The data manager subscribes to MQTT topics, bringing data published by IoT devices. It interprets and processes these data to generate new tasks and state changes. Node-RED, a low-code platform, was used for this purpose. The logic is developed inflows, which, in our case, always start with data arriving via MQTT topics. The manager has two flows. Figure 6.14 presents an object diagram simplifying the relationship between IoT devices and software classes.

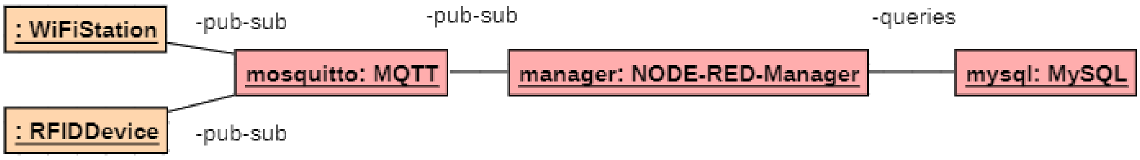
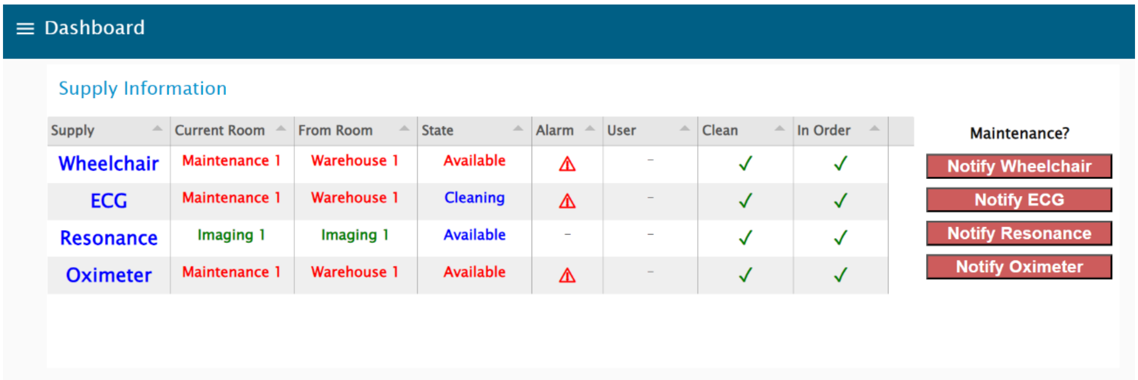


Figure 6.14 – Object diagram with IoT Devices in orange and Software in red

The **first flow** starts with topics published by the Wi-Fi Stations. The flow begins with identifying the room and the supply, along with an RSSI value, at a given moment. Data from these topics are accumulated for 12 seconds (see Section 6.1.2). After this period, the flow processes the RSSI data together to determine which room is closest to each supply in the dataset. The average RSSI per room is calculated for each supply, and the room with the highest average is considered the location where the supply is. The flow ends with creating a new task entry and a call to the stored procedure *update_state*. The **second flow** starts with topics published by the RFID Devices. Topics are received with user and supply identifications. With this data, the *set_usage* procedure is called.

The dashboard is also developed with Node-RED, which has components that simplify website data display. The goal of the dashboard is to provide helpful information to the system's users: the current location and state of supplies. The dashboard is a single software system component accessible within the hospital's network. Thus, any device connected to the network, including users' smartphones, can access it.

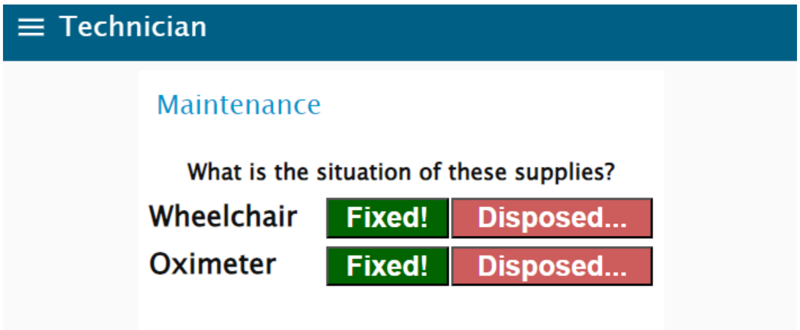


| Supply | Current Room | From Room | State | Alarm | User | Clean | In Order |
|---|---|---|---|---|---|---|---|
| Wheelchair | Maintenance 1 | Warehouse 1 | Available | ⚠ | - | ✓ | ✓ |
| ECG | Maintenance 1 | Warehouse 1 | Cleaning | ⚠ | - | ✓ | ✓ |
| Resonance | Imaging 1 | Imaging 1 | Available | - | - | ✓ | ✓ |
| Oximeter | Maintenance 1 | Warehouse 1 | Available | ⚠ | - | ✓ | ✓ |

Figure 6.15 – Supply Overview Dashboard

The dashboard has two tabs: one with an overview of the supplies and another to list objects in the Maintenance state. **Two flows** in Node-RED create these tabs. The overview tab is updated every five seconds and displays the formatted output of the stored procedure *get_supply_info*. Figure 6.15 provides a screenshot of the overview dashboard. At the end of each line, a button triggers a Notifying Event for the corresponding supply. The maintenance tab, intended for technicians, updates every five seconds and lists the output of the stored procedure *get_supply_has_problem*. The list includes two buttons at the end of each line, allowing the technician to indicate whether the supply has been fixed or will be discarded, triggering the Fixing Event or the Disposing Event. Figure 6.16

presents a screenshot of the maintenance tab when the technician repairs the wheelchair and the oximeter.



What is the situation of these supplies?

Figure 6.16 – Maintenance Dashboard

## 6.2 Second Experiment

The consolidated metamodel was divided into three packages. Based on requirements, this representation was instantiated and translated into code for an IoT application simulating a simple part of a hospital. This section presents the planning, execution, analysis, and discussion of the second experimental study conducted in PESC/COPPE in Brazil.

### 6.2.1 Planning and Execution

The second experimental study has the same goals as the first, previously presented in Table 5.1. The IoT software system was created to be implemented in a simulated hospital containing rooms, supplies, and users. It was set up in a complex of rooms, of which six were used. The supplies were simulated with boxes, and participants assumed the roles of health professionals using these supplies according to predefined scenarios. The selection of participants was based on convenience. Actual health professionals were unable to participate in our study due to scheduling conflicts between our medical contacts and the available time for the study. Instead, the invitation was to undergraduates, MSc students, and PhD students from COPPE[13], Brazil, where the study occurred. In total, 18 participants accepted the invitation.

Four scenarios were developed to simulate the simultaneous work of three health professionals, a suggestion obtained in the first experimental study. Each scenario contained a sequence of steps to be followed, such that one person's work eventually affects the others' work. A partner nurse reviewed and approved these scenarios,

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[13] https://coppe.ufrj.br/

summarized in Table 6.1. Since the scenarios depended on the simultaneous participation of three health professionals, the 18 participants were divided into six trios. For each trio, the researcher presented the objectives, the rooms, the supplies, and the software functionalities. Given the complexity of the explanation, one of the scenarios was selected for training, allowing participants to learn practically what was expected of them without fear of making mistakes.

Table 6.1 – Summary of the Scenarios

| Scenario | Roles | Summary of the scenario |
|---|---|---|
| 1 | Two nurses<br>one cleaner | A patient arrives at the hospital with pain. Nurse 1 is assigned to treat this patient. The wheelchair and the oximeter are taken. After use, the oximeter is handed over to nurse 2, who uses it briefly on another patient. The wheelchair remains in use until the end. The patient's condition seems severe, so an imaging exam is conducted in the imaging room. After the exam, the patient rests in the patient's room. Throughout this time, the cleaner checks the dashboard for any supply needing cleaning cleans it and returns it to the warehouse. This scenario was used for training with three trios. |
| 2 | One nurse<br>one cleaner<br>one technician | The nurse notices that the warehouse's ECG is malfunctioning. The issue is reported through the dashboard. The technician sees the notification in the dashboard, goes to the warehouse, and takes the ECG to the maintenance room for repair. After repairing it, the technician leaves the ECG in the cleaning room, where the cleaner performs the cleaning and then places it back in the warehouse. |
| 3 | One nurse<br>one cleaner<br>one technician | An older woman visits the hospital for a routine check-up. The nurse takes the ECG and the oximeter to the triage room. During the check-up, the oximeter malfunctions. The nurse reports the problem through the dashboard. Then, the oximeter and the ECG are left in the cleaning room. The cleaner cleans them, and then the technician arrives in the cleaning room to collect the oximeter. It is taken to the maintenance room, and after repair, it is brought back to the cleaning room, where the cleaner cleans it again. Finally, the oximeter is taken to the warehouse. |
| 4 | One nurse<br>one cleaner<br>one technician | The nurse takes a patient for exams in the imaging room, but the resonance machine malfunctions. The nurse immediately calls for the cleaner and the technician to come to the imaging room. The technician fixes the resonance machine, and the cleaner cleans it afterward so the nurse can proceed with the patient's exam. This scenario was used for training with three trios. |

The participants signed a confidentiality agreement (*Annex H – Second Experiment Consent Letter*) at the beginning of the experiment to allow data collection. After the experiment, they completed (1) a questionnaire with SUS (System Usability Scale) questions (Brooke, 1996) regarding the system's usability, (2) demographic, and (3) open questions.

The participants' actions constantly generated new data on the location and status of the supplies. Since the scenarios are predefined, ideally, the software system should consistently collect the same data regardless of who participates. Therefore, we created

**oracles** from the scenarios with lists of expected paths and state changes for each supply over time. To achieve our secondary goal, the collected data from each execution should be as close as possible to the data predicted by the oracles. The database was exported to analyze the collected data, organized by trio and scenario, and manually compared with the respective oracles. Figure 6.17 provides three photos taken during the experimental study: (1) a participant with a box representing the ECG, reading a scenario while checking the dashboard, (2) a box representing the oximeter, (3) the triage room with the dashboard and a Wi-Fi device on the table.

Figure 6.17 – Photos of the second experimental study

### 6.2.2 Data Analysis

Data was collected in two ways: (1) through the database, which stored movement between rooms and state changes during the execution of each scenario, and (2) through a questionnaire (*Annex E – Second Experiment Questionnaire*), which gathered participants' opinions on the system's usability. As the participants follow scenarios, supplies are moved among rooms. Even though the scenarios are predefined, and we have oracles, the results vary due to several factors.

According to the map (Figure 6.9), a supply moving from the cleaning room to the patient room must pass through the triage room. It might not be detected in this room if moved quickly, which will vary with each execution. Another case is the movement of a supply from the cleaning room to the maintenance room, which, in addition to passing through the triage room, goes through a long corridor in front of the warehouse and the imaging room. Thus, although it is possible to create an oracle with rooms that will necessarily be visited during the scenarios, several additional collected data need to be analyzed individually.

A new entry is added to the Supply State table with each new state of a supply. Each supply detection in a different room adds a new entry to the **Task** table. All the data from these two tables were collected for comparison with the oracles. For each single state or room, the researcher assigned a classification: **Expected**, **Walking**, **False Positive**, **False Negative**, or **Participant Error**. Table 6.2 exemplifies how the classification worked.

If specific data matches the oracle, it is classified as **Expected**. If specific data is not in the oracle but is part of a plausible path between two rooms, it is classified as **Walking**. If particular data represents a distant room or indicates an alternation between two neighboring rooms (one being **Expected**), it is classified as a **False Positive**. If specific data is incorrect but occurred due to a deviation from what the participant was supposed to do, it is classified as **Participant Error**. The researcher monitored the participants during the execution and took notes to keep track of their errors. If specific data is missing, however, it exists in the Oracle, it is manually added and classified as a **False Negative**.

Table 6.2 – Example of data classification for one of the datasets

| **Oracle for ECG in Scenario 2** | | **Example of Collected Data** | | | |
|---|---|---|---|---|---|
| **States** | **Path** | **States** | **Classification** | **Path** | **Classification** |
| ***Available*** | ***Warehouse*** | Available | Expected | Warehouse | Expected |
| ***Has Problem*** | ***Maintenance*** | Has Problem | Expected | Maintenance | Expected |
| ***In Maintenance*** | ***Cleaning*** | In Maintenance | Expected | Triage | False Positive |
| ***Cleaning*** | ***Warehouse*** | Cleaning | Expected | Maintenance | Expected |
| ***Available*** | | Available | Expected | Triage | Walking |
| | | | | Cleaning | Expected |
| | | | | Maintenance | False Positive |
| | | | | Patient | Walking |
| | | | | Warehouse | Expected |

In the first experimental study, cases equivalent to **Walking** were considered **False Positives**. The previously available area was much smaller, so the simulated rooms could be traversed in one or two steps. Now that the simulated rooms are actual rooms, it is easier to distinguish the patterns because the available area for the simulation is more extensive, more realistic, and has greater distances between rooms.

**False Positives**, **Walking**, and **Participant Error** occurred with some frequency. However, we did not obtain any data classified as **False Negative**. These data would arise if a Wi-Fi Station could not detect the Wi-Fi Access Points while the user was in the room with the supply. However, whenever these situations occurred, the system could correctly detect it, even if amidst some **False Positives**. During the coding, the transmit power parameter of the ESPs was calibrated to the minimum possible value that did not cause false negatives and generated the minimum number of false positives. The existence of false negatives is severe, as it would mean the software system could not capture what is happening in the context.

Table 6.3 – Summary of the results for the paths. Colors refer to each trio.

| Exec. ID | Expected % | Walking % | False Positives % |
|---|---|---|---|
| **01 (Sc1)** | 55.88% | 20.59% | 23.53% |
| **02 (Sc2)** | 60.00% | 10.00% | 30.00% |
| **03 (Sc3)** | 64.00% | 12.00% | 24.00% |
| **04 (Sc4)** | 85.71% | 0.00% | 14.29% |
| **05 (Sc1)** | 66.67% | 23.81% | 9.52% |
| **06 (Sc2)** | 66.67% | 25.00% | 8.33% |
| **07 (Sc3)** | 75.00% | 18.75% | 6.25% |
| **08 (Sc4)** | 69.23% | 0.00% | 30.77% |
| **09 (Sc1)** | 53.33% | 33.33% | 13.33% |
| **10 (Sc2)** | 64.29% | 21.43% | 14.29% |
| **11 (Sc3)** | 60.71% | 14.29% | 25.00% |
| **12 (Sc4)** | 61.54% | 15.38% | 23.08% |
| **13 (Sc1)** | 56.67% | 20.00% | 23.33% |
| **14 (Sc2)** | 66.67% | 25.00% | 8.33% |
| **15 (Sc3)** | 66.67% | 19.05% | 14.29% |
| **16 (Sc4)** | 100.00% | 0.00% | 0.00% |
| **17 (Sc1)** | 65.22% | 21.74% | 13.04% |
| **18 (Sc2)** | 66.67% | 16.67% | 16.67% |
| **19 (Sc3)** | 66.67% | 19.05% | 14.29% |
| **20 (Sc4)** | 83.33% | 16.67% | 0.00% |
| **21 (Sc1)** | 66.67% | 23.81% | 9.52% |
| **22 (Sc2)** | 56.25% | 18.75% | 25.00% |
| **23 (Sc3)** | 53.13% | 15.63% | 31.25% |
| **24 (Sc4)** | 71.43% | 28.57% | 0.00% |
| **Average:** | **66.77%** | **17.48%** | **15.75%** |

All collected states were classified as **Expected**, meaning the system did not fail to identify state changes in supply across all executions. State changes occur through interaction with the RFID Devices or moving through the cleaning and maintenance rooms. None of these implicit or explicit tasks generating state changes failed during the study. Table 6.3 summarizes the percentage of **Expected**, **Walking**, and **False Positive** data concerning paths (rooms) for all supplies. It also indicates which execution refers to each scenario and trio.

On average, 66.77% of the collected data were classified as Expected, 17.48% as Walking, and 15.75% as False Positives for paths. Note that all data in the oracle appeared among the collected data, which is why no false negatives were found. Finding 66.77%

of Expected data does not mean the rest were not found. It means that our “cost” for achieving 100% precision, according to the oracle, was obtaining 33.23% of unexpected data. Although from the oracle’s perspective, walking data are false positives, we consider that these are not incorrect, given that it would be impossible not to obtain them with the simulated hospital setup we devised. Therefore, the system’s accuracy rate was 84.25% (66.77% + 17.48%).

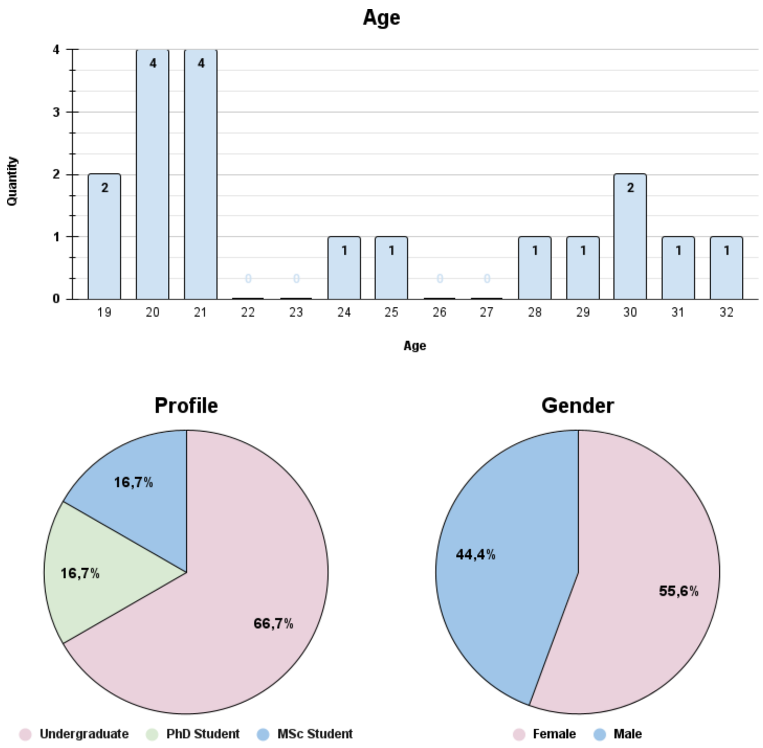

Figure 6.18 – Demographic Results

The questionnaire included three questions to characterize the participants regarding their age, gender, and profile. The invited profiles included undergraduates, MSc students, and PhD students from various engineering courses at COPPE. Unfortunately, it was impossible to ask health professionals. All participants were Brazilians. Regarding gender, 55.6% of the participants identified as women, while 44.4% identified as men. The number of MSc and PhD students participating was the same, three of each (16.7%). Due to the large number of undergraduates, the average age was between 19 and 21. Figure 6.18 summarizes and presents these results.

The questionnaire’s SUS (System Usability Scale) questions allowed participants to provide feedback on the system’s usability. Although it is a Likert scale, a score can be calculated from the results, which must be above 68 to be considered reasonable. Among the results, three scores were below it: two from PhD students (40 and 65) and one from an undergraduate student (60). The median score of the 18 responses (one per participant) was 87.5, indicating that participants were overall satisfied with the system's usability. Figure 6.19 summarizes the number of responses for each question.

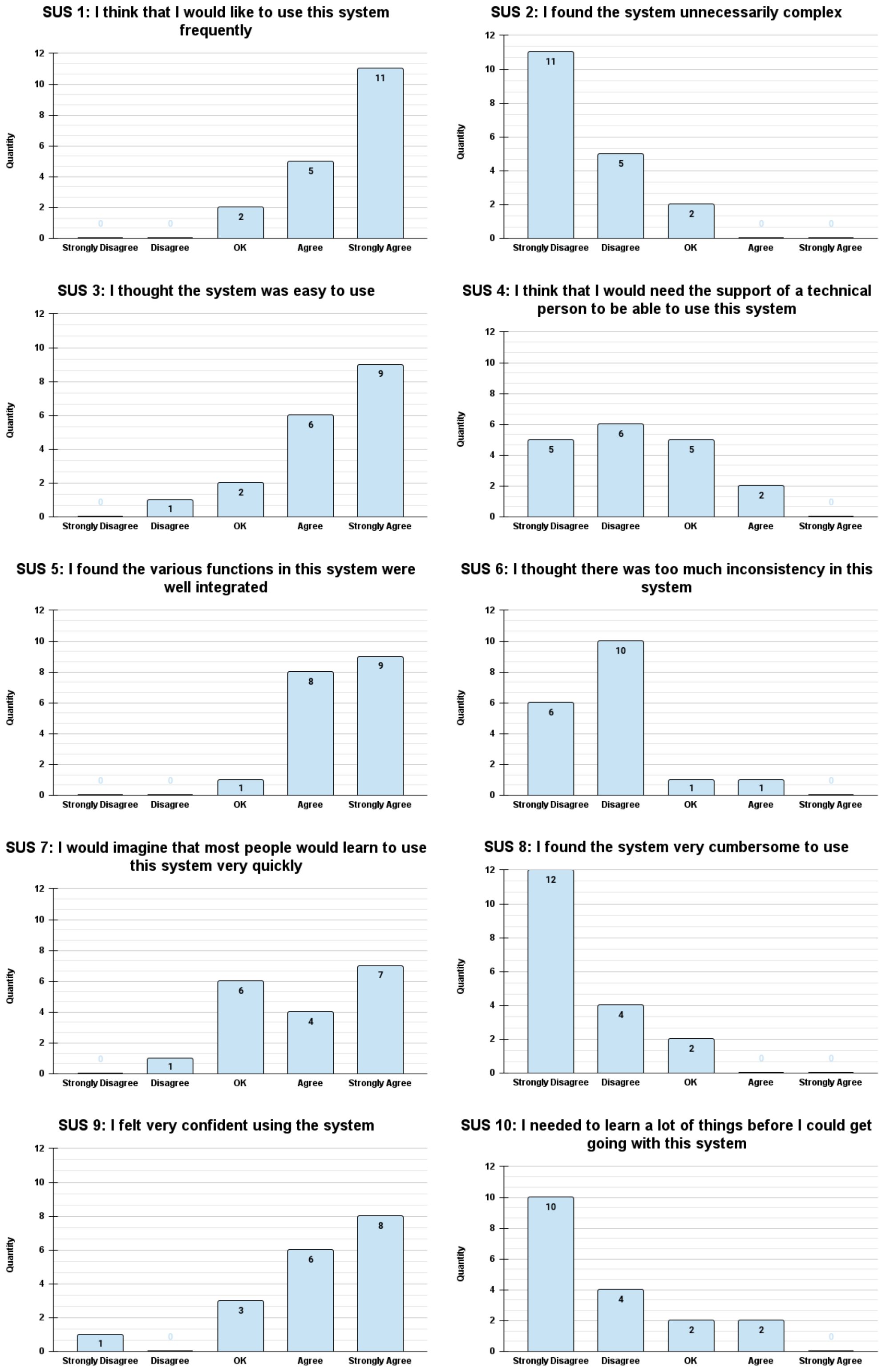

Figure 6.19 – Quantity of each answer for each SUS question

Open questions in the questionnaire permitted participants to identify their perceptions regarding specific characteristics of the software system and their overall experience. All participants are Brazilian, and therefore, their responses were in Portuguese. They were carefully translated into English to ensure the context of the reactions was not lost in translation and then analyzed in this language.

The first question asked whether participants would accept being located by the software system in an actual situation. Five responses affirmed yes without any conditions. Two responses said no. Eight responses indicated yes, but with a condition: being located only within the work location and hours and always respecting users' privacy. For instance, one participant stated, "*Yes, as long as it is not too invasive, respecting the employee's integrity and privacy.*" Three responses indicated they would not allow it, highlighting their discomfort with this type of surveillance. One participant mentioned, "*I think there would be complex ethical implications, and I'm not sure I would feel very comfortable with someone always knowing my location.*"

The second question asked whether participants encountered any errors in the dashboard or the RFID devices. Seven responses stated that they did not see any errors. Six responses indicated discrepancies between the Cleaning state and the Boolean displayed in the Clean column (Figure 6.15). One participant noted, "*The dashboard is not synchronizing the columns indicating whether the device needs cleaning and whether it is clean.*" Two responses noted issues with the Wi-Fi connection, which was especially weak in the imaging room due to being the farthest room from the router. Three responses reported encountering errors when checking the location in the dashboard. For instance, one answer was, "*The only problem found was that sometimes the equipment's location didn't update correctly.*"

The third question asked about participants' feelings about using a system that feeds on implicit interactions. Twelve responses approved this type of interaction. They mentioned that it is excellent for optimizing the environment; it is comfortable, convenient, and great for the dynamic scenario of a hospital. One of the answers was, "*I liked it a lot. It's one less thing to remember. I just need to check the dashboard if I need to locate equipment, and it speeds up my search process. I don't go in circles unnecessarily*". Three responses were indifferent to the interactions. One response suggested informing about what is being collected so that users can decide whether to participate.

Two responses commented on their perceptions of the system’s transparency: one participant said that if it were not for the RFID devices, the perception of the system’s existence would be null. Another participant said differently: “*I did not feel that way, maybe because I feel that the sensor system is part of the software system*,” i.e., stating that the system is not so invisible because participants can see the devices in the rooms. They relate to the Transparency quality characteristic (Carvalho et al., 2017), which is the system’s ability to hide its computing infrastructure in the environment so the user does not realize it interacts with a set of computational devices. We did not establish transparency in our quality requirements because the RFID devices must be adequately visible so as not to confuse users.

The fourth open question asked for suggestions. We received various ideas for improving the software system and the protocol itself. Seven responses stated they had no comments. Two responses noted that the system is generic enough to be integrated into various contexts beyond health centers, such as in the answer, “*This system can be integrated into any area where there is the movement of people and objects.*” One response expressed concern that elderly health professionals might have difficulty using the system and would require training. Another response suggested that due to the information provided at the beginning, creating documentation or a manual for the participants would be good.

Six responses suggested improvements to the dashboard, two referring to the Cleaning state’s ambiguous display. Having two columns for the same information is confusing, so it would be better to remove the Boolean column. Three responses indicated that an undo option is missing, which would be helpful in cases where a user performs an incorrect action that impacts the dashboard data. For instance, one participant said, “*In case of an error in indicating the device (e.g., an oximeter instead of an ECG), there is currently no way to undo the selection.*” One response suggested enhancing the dashboard's textual support.

Three responses pertained to the system’s usability. One suggested, “*Use different colored cards for different equipment.*” Another suggested placing the RFID devices near the room exits to remind users to inform them when taking a supply. However, another suggested further reducing explicit interactions by removing the reference to who is using the equipment and simply identifying that someone is using it based on movements.

One response suggested implementing features for prioritizing actions occurring in the environment so the system could propose an optimized order. Another response suggested applying artificial intelligence algorithms to the collected data, which could help with this prioritization. Two responses suggested including more types of sensors in the rooms besides the Wi-Fi devices, such as ultrasonic sensors at the doors.

Some trios had difficulties performing the tasks in Scenario 4 (see Table 6.1). Due to the distance between the imaging room and the router in the triage room, the Wi-Fi signal was weaker than in the other rooms. Therefore, one response suggested including Wi-Fi repeaters in the way. Table 6.4 briefly summarizes all the difficulties presented by each trio.

Table 6.4 – Difficulties presented by each trio

| Trio | Difficulties |
|---|---|
| **1** | 1) Several times, already returned equipment in the *Available* state was *Taken* and returned within a few seconds, reverting to the *Available* state again. This indicates that participants were unsure if they had been returned, possibly due to delays in the dashboard.<br>2) In scenario 4, a participant took a long time to return the ECG, causing the equipment to enter the in-use state. The waiting time between Taken and In-Use was probably too short.<br>3) In scenario 3, a participant took and immediately returned the Oximeter instead of moving it to the triage room. This suggests that the support material was not explicit enough. |
| **2** | In scenario 4, a participant indicated *Taking* the *Resonance* without being defined, suggesting that the support material was unclear. |
| **3** | In scenario 4, a participant returned the MRI very quickly, not triggering the subsequent need for cleaning procedures. In the same execution, the Wi-Fi connection did not perform well in the *imaging room*. |
| **4** | No difficulties. Also, the execution of scenario four was completed without false positives. |
| **5** | No difficulties. |
| **6** | 1) The Wi-Fi connection was unstable during the execution of scenario 4, although it did not affect the collected data.<br>2) A participant returned, took, and then returned the *Oximeter* twice. This indicates that the participant was unsure if the equipment had been returned, possibly due to delays in the dashboard. |

The participants' feedback reflects both appreciation and ideas for improvement. Many participants were open to being tracked in a future version under specific conditions that ensured their privacy within work settings. They approved implicit interactions, noting their potential to optimize health centers, though some demand transparency on the collected data. Suggestions for enhancing the system included refining the dashboard, integrating additional sensors, and guaranteeing reliable Wi-Fi connectivity.

### 6.2.3 Discussion

The feasibility study allowed testing of the metamodel to verify whether it is comprehensive enough to be instantiated and translated into the IoT software system code for managing the location and use of medical equipment in health centers.

The metamodel was instantiated based on requirements, and an application was created. The application qualifies as **IoT** as it defines ***things*** and follows the **MQTT** architecture specified in the metamodel, in which perceived data is communicated through a middleware for processing. **Context awareness** is represented by the interaction between users in a physical environment with rules, while technologies characterize what happens with the equipment within the context. For the application to be **situation-aware**, the perception of the context must be accurate so that the system can comprehend these data and provide services based on future predictions. The secondary goal of the feasibility study was to analyze how accurate this perception is.

Data on the location and status of supplies were collected from lists of tasks followed by six trios across four scenarios, totaling 24 executions. These scenarios together cover all possible state changes defined in Figure 6.5. Above all, false negatives must not occur in the datasets, as this means the system could perceive everything that happened in the context concerning state changes and room transitions. The occurrence of false positives was expected, and our goal was to minimize them. In our previous experimental study (Section 5.3), 48.42% of data were false positives, using a smaller area to simulate the hospital without adjusting the transmit power. Now, it was calibrated, and the available area for the experiment was much larger, critical decisions that led to improvements, with 15.75% of false positives.

The number of false positives could have been further reduced if the stations' clocks had been synchronized. The devices have a short delay between scanning periods. If an AP is near a particular station, but the station is in its delay period, the AP may end up located in a neighbor's room. This problem would not occur if all scanning and delay periods were synchronized across stations. This improvement was learned from analyzing the data, which will be implemented in future applications. Overall, in response to the study's secondary goal, we consider the accuracy of this application satisfactory for progressing to the development of prediction functionalities in new applications.

The study's primary goal is to evaluate whether the metamodel can be used as a basis for creating an application for managing the location and use of medical equipment. To make this evaluation, it must be possible to instantiate it based on a set of requirements without changing the metamodel's structure. Additionally, the instance must be usable for translating the concepts into code, which must perform the management functionalities appropriately. The instantiation was done without altering the metamodel's structure. The original classes were either kept intact or suppressed because they were not crucial for the requirements, as was the case with the Camera class since we did not use any in our hospital. The instance was able to represent all requirements appropriately. However, the possibility of conducting the second experiment on a two-floor map highlighted a potential improvement in the metamodel representation to be considered in future representations. The Real-World package accounts for departments divided into rooms but does not assume these rooms may be on different floors. In a real scenario, transporting equipment, such as wheelchairs, between floors can pose a challenge. Therefore, the metamodel must incorporate this information in future evolutions.

The development was not object-oriented, so the instantiated model was not used directly for class definition. Instead, the model was used as a requirements specification, ensuring that the rules strictly followed the associations and attributes wherever there was code. This use of the metamodel was a strategy to accelerate development time. Additionally, directly applying the metamodel to constructing an object-oriented IoT system must be further studied. The **Device Package** conceptualizes how the various devices in the system can be structured in terms of their mechanisms. However, the system does not need to include classes such as **Mechanism** or **Device** when, in practice, each microcontroller will have quite simple C++ code to collect sensor data. A similar issue arises with the **Software Package**, as its entities represent the software components the system requires and their relationships with devices. The only justified object-oriented implementation in such an IoT software system is using the **Real-World Package** for modeling the data manager, which integrates physical devices and the database. This object-oriented applicability will be examined in future studies. Even with coding distributed among microcontrollers, databases, and low-code development, we could still complete the development according to the modeling.

Finally, the application was tested through the experimental study, and the participants positively received its functionalities and usability. The metamodel could be used without modifications in response to the study’s primary goal. The research is also motivated by creating software systems with as many implicit interactions as possible to avoid unnecessary effort by health professionals. The metamodel implies this possibility through the potential to implement devices with UHF RF capabilities that use RSSI, sensors, and cameras. The ubiquity of our application was very well received, with one participant suggesting further reducing explicit interactions with the RFID device. In contrast, two others noted the need to implement the quality characteristic of Transparency.

### 6.2.4 Threats to Validity

Four categories of threats to validity should be considered in software engineering (Wohlin et al., 2012): internal validity, external validity, construct validity, and conclusion validity. This classification is general and applies to empirical research.

**Internal validity** refers to the conclusion about a possible causal relationship between treatment and outcome. Inconsistencies in the simulated hospital setup, state diagram inaccuracies, and participant comprehension biases may cause it. The number of participants and the fact that they are not health professionals might have led to a less conclusive result for the study. To mitigate it, we performed pilot testing and monitored experimental conditions and participant actions to identify and correct any deviations from the planned procedures.

**External validity** refers to conditions that limit our ability to generalize the results. The most evident case in this study is the use of a simulated hospital, which does not replicate the dynamic and complexity of an actual hospital. Moreover, the participants do not accurately reflect medical professionals' behaviors. To mitigate it, we devised scenarios derived from actual hospital workflows, consulting with a partner nurse to validate their realism.

**Construct validity** refers to generalizing the experiment's result to the concept or theory behind it. False positives represent a misalignment between the simulated scenarios and the data collected. These differences indicate that the software system needs further improvements to be considered situation-aware. To mitigate this, we calibrated the transmit power in devices to reduce errors, which also led to no false negatives.

**Conclusion Validity** refers to the issues that affect the ability to draw the correct conclusion. Again, the number of participants and the fact that they were not health professionals may have yielded less conclusive results. Also, the created application only adopted RF communication, so we may not conclude that other applications would properly work if strategies such as sensors and cameras were adopted. To mitigate it, classes and functionalities defined in the requirements have been appropriately implemented and put to the test.

## 6.3 Conclusion

The metamodel evolved based on the results of the first experimental study, addressing several corrections. For clarity, it was divided into three packages: Real-World, Devices, and Software. It was instantiated following requirements for a simple part of a hospital, leading to the building of another IoT software system (Section 6.1). The **second experiment** (section 6.2) applied the consolidated metamodel through a more complex simulation, although still very similar to the first. It involved multiple users working simultaneously, a larger area for representing the hospital, and a more refined implementation of the proximity algorithm. This study confirmed the robustness of the consolidated metamodel, given that no fundamental changes proved necessary. The data accuracy was satisfactory this time, yet there were areas for improvement in the proximity algorithm, such as the need to synchronize the Wi-Fi devices' clocks. The feasibility of using the metamodel as a foundation for creating IoT software systems for managing the location and use of medical equipment in health centers was validated.

The information about the medical context was superficial, considering only one hospital, which may not apply to other facilities. It is essential to research further health centers. Additionally, only RFID and Wi-Fi were explored in the experiments, which did not allow for the validation of other locating methods, such as using sensors, cameras, or even hybrid systems. Considering that data accuracy was considerably better in the second experiment, and there is the perspective of improvements through the synchronization of the device’s clocks, it is possible to create applications with more complex situation awareness functionalities, such as the conflict cases where multiple health professionals need the same equipment, as proposed in the second proof of concept. These points indicate a large number of possible future works.

# 7 General Conclusion

This chapter provides final considerations, offers contributions, outlines the research's limitations, and describes future works based on the outcomes of the experimental studies.

## 7.1 Final Considerations

This thesis is motivated by assisting health professionals by proposing a software solution that supports creating IoT software systems for managing the location and use of medical equipment in health centers. The adopted solution was a metamodel that can be used to develop countless applications based on the requirements of different health centers.

The research methodology was organized into three parts, starting from a **literature investigation** about fundamental subjects: literature reviews about context awareness and situation awareness, a systematic literature mapping on RFID applied in interactive systems, and a review of secondary studies on localization technologies. Subsequently, the **metamodel conception** encompassed the gradual evolution of the metamodel in three representations. The **first representation** focused on IoT concepts, context awareness, and radio-frequency technologies, validated by theoretical proof of concept. The **second representation** extended the metamodel by including additional localization strategies like cameras and sensors. Interviews with health professionals were conducted to gather information about the medical context. A **third representation** incorporated the medical context and situation awareness. This resulted in a modeling comprising all fundamental concepts validated by another theoretical proof of concept.

To evaluate the **feasibility** of the metamodel more formally, it was applied to creating IoT software systems for managing the location and use of medical equipment in hospital simulations. With the abstraction levels of metamodel conception, instantiation, and translation into code, the **tailoring methodology** proved effective in evolving the metamodel. By developing an actual application, severe problems are easily detected, allowing for rapid and efficient evolution. The **first experimental study** revealed inconsistencies in the software and device metamodeling, leading to improvements and a consolidated fourth representation. This **consolidated metamodel**, a testament to the robustness of our research, was used to create a second IoT application, which is still technically similar to the first but presents several relevant improvements. The **second experimental study** confirmed the robustness of the consolidated representation, as it did not require changes to its basic structure. The number of false positives was drastically reduced between the first and second simulations, but it is still possible to increase data accuracy further.

The research question (Section 1.2) was: *How can we support the engineering of interactive software systems for managing the location and use of medical equipment in health centers, considering environmental constraints and with little explicit human-computer interactions?* The proposed metamodel addresses the management of **location** with **reduced HCI** by enabling IoT applications to use radio frequency technologies, sensors, and cameras. It also addresses the management of **use** by enabling IoT applications with context and situation awareness functionalities. While the experimental studies validated the feasibility of the metamodel in simulated environments, additional validation in diverse settings is required to fully assess its applicability and scalability. Moreover, some objectives outlined in the introduction still need to be fulfilled. For instance, the measurement of explicit interaction reduction and the implementation of advanced situation-aware functionalities. These aspects are critical to further evolving the metamodel and are highlighted as priorities for future works.

## 7.2 Contributions

The main contribution of the thesis is the proposition of the consolidated metamodel presented in Section 6.1.1 to support the creation of IoT software systems for managing the location and use of medical equipment. It is versatile enough to represent the unique characteristics of different hospitals, embody IoT, context awareness, situation awareness, and the technologies that facilitate identification, localization, data communication, and implement implicit interactions. The significance of this research lies in its potential to revolutionize medical equipment management in healthcare settings while providing a way to build applications quickly and cheaply.

The first step in achieving the research goal was to research fundamental concepts. One of the main contributions of the research was conducting a systematic mapping of RFID applied in interactive systems. Initially, this review was intended to research a specific technology. Still, it showed evidence of how interactive systems use radio-frequency technologies to promote implicit interactions. The review was published in the Journal ACM Human-Computer Interaction (V. C. Maia, de Oliveira, Kolski, et al., 2023).

Another contribution of the research was the reports on the evolution of metamodels, leading to two publications. The metamodel's first representation and proof of concept were presented at the ACM Engineering Interactive Computing Systems 2023 (V. C. Maia, de Oliveira, da Silva, et al., 2023). The third representation of the metamodel and the second proof of concept were presented at the IEEE Conference on Business Informatics 2023 (V. C. Maia, Godaert, et al., 2023).

## 7.3 Limitations

Despite the valuable contributions, some limitations hindered better outcomes.

- Interviews with health professionals took place in a single hospital. Similarly, the two experimental studies modeled simple parts of hospitals similar to where the interviews were conducted. Therefore, the research did not consider the **diversity of medical centers**, such as emergencies, rural hospitals, field hospitals, and clinics.
- One of the central objectives of this research, as highlighted in the research question (Section 1.2), was to minimize explicit human-computer interactions (HCI) in the proposed IoT software systems, ensuring they integrate into the daily routines of health professionals without disrupting their workflows. This aspect **was not quantitatively measured during the experimental studies, and no specific method was established** to evaluate the reduction in explicit interactions based on requirements.
- Except for three health professionals who participated in our first experimental study, **most participants were students or professors**. This might have influenced the results, as health professionals would likely behave differently when performing the tasks in the scenarios and would provide better technical feedback.
- The research did not address the **system's scalability** for many devices, users, and simultaneous interactions, which is essential for implementing the IoT software system in large hospitals.
- The experimental studies were conducted in a simulated environment, which **might not capture a hospital's objective complexity and dynamics**. Due to this limitation, it is challenging to generalize the results.
- **Only RFID and Wi-Fi, besides BLE, were explored** briefly. Solutions with other methods, such as cameras, ultrasonic sensors, and gyroscopes, were not

implemented. Consequently, these respective entities were not validated in the metamodel.

- The software quality characteristics emphasized in this research were **Performance Efficiency**, Reliability, and **Usability** from the perspective of ubiquitous systems. However, other important quality characteristics remain to be considered. **Interoperability** should be addressed in future work, particularly when integrating the IoT software system with other systems present in the health centers. Additionally, **Security** must be a major focus in the future, given the sensitive data captured within the medical context.
- The research **resource limitations** required the network infrastructure to be implemented with Wi-Fi or BLE, as we only had ESP32, ESP01, and ESP8266. Additionally, the location available for the first experiment did not have Wi-Fi networks, forcing the use of 4G. In contrast, the area for the second experiment had a good Wi-Fi network, but it was weak in the most distant room.
- All user feedback was **translated into English** to ensure that all analyses were conducted uniformly. This was the case with the interviews and the experiments' open questions. Although the translations were done carefully, the research might not have captured all nuances.

## 7.4 Future Work

As the experimental studies were limited to one type of hospital, there is a significant amount of future work to be done to validate certain metamodel entities and improve them, considering other health centers.

- **Expansion to other health centers**: It is important to interview more health professionals with experience in various types of health centers so that characteristics not yet mapped can be incorporated into the metamodel. Consequently, new representations should be created and validated.
- **Scheduling**: The systems developed have focused on the immediate use of medical equipment. A solution enabling the scheduling of certain equipment usage should be implemented, which may lead to modifications in the metamodel.
- **Equipment Availability**: Implement functionalities that allow the IoT software system to provide real-time information on the availability of medical equipment within the health center. For example, even if a facility has three wheelchairs, the system should be able to identify and report when none are available for use due

to being in use, dirty or under maintenance. This functionality would ensure better resource management.

- **Scalability**: Future research should address the scalability of the IoT software systems to ensure its operation in environments with a high number of equipment, users, and simultaneous interactions. This includes evaluating performance under increased load and identifying potential bottlenecks, exploring techniques such as distributed computing.
- **More complex settings**: Plan a simulation similar to the second experiment but with more participants working in parallel on a much bigger map. This experiment would stress the limits of the metamodel when the settings are more complex than a simple part of a hospital.
- **Hybrid systems**: New implementations of IoT software systems must move beyond radio-frequency technologies and explore hybrid systems.
- **Auto Generation of Code**: Although we use the term **Translation** in the **Tailoring Methodology**, it refers to the manual development of source code. However, it may be possible to automatically generate code from requirements. Examples are tools such as **Xtext**[14], which enables the creation of Domain-Specific Languages, or **Acceleo**[15], which supports model-to-text transformations based on the Model-Driven Architecture approach. **Codebots**[16] or **JetBrains MPS**[17] may also be employed. Such tools would make the application of the metamodel even more efficient, cost-effective, and faster to develop.
- **Implementation in natural environments**: Although it involves complex protocols, an IoT software system created from the metamodel must be implemented and maintained continuously within a partner health center so that its usage can be evaluated in a natural environment.
- **Optimize the technical infrastructure**: In future implementations, the infrastructure should be improved to make the collected results more accurate. This involves improvements in the microprocessor code and possible enhancements in the data manager and database codes.

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[14] https://eclipse.dev/Xtext/

[15] https://eclipse.dev/acceleo/

[16] https://codebots.com/

[17] https://www.jetbrains.com/pt-br/mps/

- **Object-oriented programming**: The metamodel is represented as a class diagram; however, none of the translations into code for IoT software systems benefited from this structure. The data manager in both IoT software systems was built using the low-code platform Node-RED, while the microprocessors used C language. In future work, applications must use object-oriented programming to test if the current UML structure is adequate, such as C++ in the microprocessors and a data manager using Python, Java, or Node.js.
- **Interoperability**: The Software Package must consider the possibility of communicating with external systems. For example, integrating with a patient registration system could enable functionality that suggests the use of specific equipment for a newly arrived patient.
- **Data Security**: The security and privacy of the data obtained and transmitted are critical issues that have not yet been addressed in the metamodel. It is important to include entities that facilitate the implementation of more secure IoT systems. One possibility is the use of blockchain technology (R. Zhang et al., 2022), which prevents manipulation and ensures the integrity of transmitted data.
- **Situation awareness functionalities**: The metamodel incorporates fundamental elements for implementing situation awareness, enabling systems to predict future scenarios based on historical data and context. However, the experiments conducted so far have not yet implemented advanced functionalities to fully demonstrate its potential in creating situation-aware applications. Future research should focus on developing and testing functionalities that enable prediction and conflict resolution, such as scenarios where multiple users require the same equipment. These functionalities, potentially supported by artificial intelligence algorithms using data collected without false positives, are essential for assessing and evolving the metamodel's capacity to represent situation awareness, a concept that remains unexplored.

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# Annex A – Bibliographic Production

| Complete Reference | Type |
|---|---|
| Maia, V. C. (2022). Design and evaluation of RFID-based interactive devices distributed in socio-technical environments. CEUR-WS. (V. C. Maia, 2022) | Conference |
| Maia, V., Kolski, C., Marçal de Oliveira, K., & Travassos, G. H. (2023, June). Design and Evaluation of Interactive Software Systems to Support the Location and Management of Medical Equipment in Health Centers. https://hal.science/hal-04186413 (V. Maia et al., 2023) | Conference |
| Maia, V. C., de Oliveira, K. M., da Silva, P. F., Kolski, C., & Travassos, G. H. (2023). Towards the Management of the Location and Use of Medical Equipment with Reduced User Interaction in Health Centers 4.0. Companion Proceedings of the 2023 ACM SIGCHI Symposium on Engineering Interactive Computing Systems, 45–52. https://doi.org/10.1145/3596454.3597182 (V. C. Maia, de Oliveira, da Silva, et al., 2023) | Conference |
| Maia, V. C., de Oliveira, K. M., Kolski, C., & Travassos, G. H. (2023). Using RFID in the Engineering of Interactive Software Systems: A Systematic Mapping. Proc. ACM Hum.-Comput. Interact., 7(EICS). https://doi.org/10.1145/3593235 (V. C. Maia, de Oliveira, Kolski, et al., 2023) | Journal |
| Maia, V. C., Godaert, L., de Oliveira, K. M., Kolski, C., & Travassos, G. H. (2023). Supporting IoT system design for the location, use, and management of objects in health centers. 2023 IEEE 25th Conference on Business Informatics (CBI), 1–10. https://doi.org/10.1109/CBI58679.2023.10187422 (V. C. Maia, Godaert, et al., 2023) | Conference |

# Annex B – Systematic Mapping Extraction Form

| Date | Version | Description | Author |
|---|---|---|---|
|  |  |  |  |

| General Information | |
|---|---|
| **Title** |  |
| **DOI** |  |
| **Authors** |  |
| **Year** |  |
| **Snowballing?** |  |

| | |
|---|---|
| **Problem Domain** |  |
| **Context** |  |
| **Why RFID?** |  |
| **Who interacts?** |  |
| **How** |  |
| **Tag type** |  |
| **Requirements** |  |
| **Restrictions** |  |
| **Summary** |  |

| Quality Characteristics | Measures |
|---|---|
|  |  |
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# Annex C – Systematic Mapping Selected Papers

| Nº | Title | Reference |
|---|---|---|
| 1 | Textronic UHF RFID Transponder | (Jankowski-Mihułowicz et al., 2021) |
| 2 | Smart RFID sensors embedded in building structures for early damage detection and long-term monitoring | (Strangfeld et al., 2019) |
| 3 | Permutation matrix encryption based ultralightweight secure RFID scheme in Internet of vehicles | (Fan et al., 2019) |
| 4 | A review of passive RFID tag antenna-based sensors and systems for structural health monitoring applications | (J. Zhang et al., 2017) |
| 5 | SmartEscape: A mobile smart individual fire evacuation system based on 3D spatial model | (Atila et al., 2018) |
| 6 | FEKO™ modeling study of passive UHF RFID tags embedded in pavement | (Walvekar & Burkholder, 2018) |
| 7 | Autonomous wearable RFID-based sensing platform for the Internet-of-Things | (Lemey et al., 2017) |
| 8 | Smart traffic management system using Internet of Things | (Javaid et al., 2018) |
| 9 | Smart healthcare service model for efficient management of patient at a hospital outpatient visits | (Y. Kim et al., 2016) |
| 10 | VSMURF: A Novel Sliding Window Cleaning Algorithm for RFID Networks | (Xu et al., 2017) |
| 11 | Understanding the attention demand of touch and tangible interaction on a composite task | (Rekik et al., 2019) |
| 12 | Sleepstellar: A safety kit and digital storyteller for sleepwalkers | (Kaur et al., 2015) |
| 13 | Experimental evaluation of read performance for RFID-based mobile sensor data gathering applications | (Currie & Marina, 2008) |
| 14 | TagMark: Reliable estimations of RFID tags for business processes | (Chaves et al., 2008) |
| 15 | Data-Driven Analysis for RFID-Enabled Smart Factory: A Case Study | (Feng et al., 2020) |
| 16 | Performance evaluation of UHF RFID technologies for real-time passenger recognition in intelligent public transportation systems | (Oberli et al., 2010) |
| 17 | Urban road traffic congestion detection using RFID data of vehicles | (L. Zheng et al., 2018) |
| 18 | Environmentally adaptive real-time detection of RFID false readings in a new practical scenario | (S. Zhu et al., 2018) |
| 19 | Enhancing WSN-based indoor positioning and tracking through RFID technology | (Xiong et al., 2012) |
| 20 | A near-field RFID sensor network for the realtime monitoring of tire vulcanization | (Nappi et al., 2017) |
| 21 | Research on the influence of metal surroundings and reading method on the accuracy of UHF RFID tags tracking | (Zdziechowski et al., 2020) |
| 22 | Passive RFID-Based Diaper Moisture Sensor | (Tajin et al., 2021) |
| 23 | Developing advanced traffic violation detection system with RFID technology for smart city | (Wong et al., 2017) |
| 24 | Monitoring intelligent system for the Intensive Care Unit using RFID and multi-agent systems | (Rodrigues et al., 2012) |
| 25 | Integrated Smart House Security System Using Sensors and RFID | (Kamelia et al., 2018) |
| 26 | Vehicular pollution monitoring using IoT | (Manna et al., 2014) |
| 27 | A distributed approach to complex event processing in RFID-enabled hospitals | (Zappia et al., 2014) |
| 28 | RFID based Paid Parking System | (Bazzi et al., 2017) |
| 29 | Applications of wireless sensor networks and RFID in a smart home environment | (Hussain et al., 2009) |
| 30 | Integration of Active RFID and WSN for real time low-cost data monitoring of patients in hospitals | (Rajesh, 2013) |
| 31 | System architecture for tracking passengers inside an airport terminal using RFID | (Luis et al., 2018) |

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| 32 | Cost-Effective Wireless Sensors for Detection of Package Opening and Tampering | (W. Wang et al., 2020) |
| 33 | Research on Intelligent Monitoring and Analysis of Physical Fitness Based on the Internet of Things | (Huang et al., 2019) |
| 34 | An added value alternative to RAIN RFID items characterization in retail | (Farhat et al., 2018) |
| 35 | Data collection in a live mass casualty incident simulation: Automated RFID technology versus manually recorded system | (Ingrassia et al., 2012) |
| 36 | An improved RFID-based locating algorithm by eliminating diversity of active tags for indoor environment | (T. Zhang et al., 2009) |
| 37 | IoT-Based Car's Parking Monitoring System | (Dwiputra et al., 2018) |
| 38 | RFID Reader Planning for the Surveillance of Predictable Mobile Objects | (W. Zhu & Li, 2018) |
| 39 | RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain | (Abad et al., 2009) |
| 40 | Predicting RFID adoption in healthcare supply chain from the perspectives of users | (Yee-Loong Chong et al., 2015) |
| 41 | RFID temperature sensors for monitoring soil solarization with biodegradable films | (Luvisi et al., 2016) |
| 42 | SHMO: A seniors health monitoring system based on energy-free sensing | (F. Xiao et al., 2018) |
| 43 | A model for intelligent transportation of perishable products | (Hsueh & Chang, 2010) |
| 44 | IoT Enabled RFID Authentication and Secure Object Tracking System for Smart Logistics | (Anandhi et al., 2019) |
| 45 | CCTV-RFID enabled multifactor authentication model for secure differential level video access control | (J. Kim et al., 2020) |
| 46 | An infrastructure for smart hospitals | (Vecchia et al., 2012) |
| 47 | IoT security perspective of a flexible healthcare supply chain | (W. Zhou & Piramuthu, 2018) |
| 48 | RFID-based indoor location tracking to ensure the safety of the elderly in smart home environments | (S.-C. Kim et al., 2013) |
| 49 | Impact of passive UHF RFID Reader antenna locations for immobile object localization | (J. Choi, 2018) |
| 50 | Wireless sensor network based patient health monitoring and tracking system | (Yadav et al., 2017) |
| 51 | Multi–occupant movement tracking in smart home environments | (Azghandi et al., 2015) |
| 52 | Surface fusion: Unobtrusive tracking of everyday objects in tangible user interfaces | (Olwal & Wilson, 2008) |
| 53 | Simulation on RFID Interactive Tabletop of Working Conditions in Industry 4.0 | (Vispi et al., 2021) |
| 54 | RFID interactive tabletop application with tangible objects: exploratory study to observe young children’ behaviors | (Kubicki et al., 2015) |
| 55 | An RFID-based luggage and passenger tracking system for airport security control applications | (Vastianos et al., 2014) |
| 56 | Mobile robot for retail inventory using RFID | (J. Zhang et al., 2016) |
| 57 | Tracking customer behaviour in fashion retail using RFID | (Landmark & Sjøbakk, 2017) |
| 58 | A prison RFID network system using position computing | (H.-C. Xiao & Xiong, 2013) |
| 59 | Management of Distributed RFID Surfaces: A Cooking Assistant for Ambient Computing in Kitchen | (Lebrun et al., 2014) |
| 60 | Internet of Things Based Heart Failure Monitoring System using Radio Frequency Identification | (Alias et al., 2021) |
| 61 | IoT-Based Indoor and Outdoor Self-Quarantine System for COVID-19 Patients | (Chin et al., 2022) |
| 62 | Batteryless wireless temperature/humidity sensor for item-level smart pharma packaging | (D’Uva et al., 2021) |
| 63 | A novel inertial positioning update method, using passive RFID tags, for indoor asset localisation | (Hayward et al., 2021) |

|  |  |  |
|---|---|---|
| 64 | RF-Gait: Gait-Based Person Identification with COTS RFID | (Jiang et al., 2022) |
| 65 | A Batteryless RFID Sensor Architecture with Distance Ambiguity Resolution for Smart Home IoT Applications | (Khalid et al., 2022) |
| 66 | Towards Measurement Range Extension of UHF RFID Temperature Sensors for Industrial Applications | (Melia-Segui et al., 2022) |
| 67 | UHF RFID Wireless Communication System for Real Time ECG Monitoring | (Rahman et al., 2021) |
| 68 | A Remote Baby Surveillance System with RFID and GPS Tracking | (Sundarajoo et al., 2022) |
| 69 | Application of RFID and IoT technology into specimen logistic system in the healthcare sector | (Chit et al., 2021) |
| 70 | Plant Keeper: Towards Wireless Sensing to Ion Transmission of Plants | (J. Zhang et al., 2022) |
| 71 | Machine Learning-Based Structural Health Monitoring Using RFID for Harsh Environmental Conditions | (Zhao et al., 2022) |

# Annex D – First Experiment Questionnaire

1. Demographic:
   - Age: ______
   - Gender: ____________
   - Profile: ( ) Health Professional ( ) PhD Student ( ) PhD ( ) Post-Doc ( ) Professor

2. During the execution of tasks, you were asked if some situations were correct:
   - When you entered the Imaging Room with the Wheelchair as a Nurse, did the red light turn on? ( ) YES ( ) NO
   - When you checked the dashboard as a nurse, was the ECG marked as "Critic! Check paper!"? ( ) YES ( ) NO
   - When you checked the dashboard as a manipulator, were both the Wheelchair and the MRI marked as Clean? ( ) YES ( ) NO

3. The following questions are intended to characterize the use of the dashboard.

| **Questions** | **Strongly disagree** | | | **Strongly agree** | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| I think that I would like to use this system frequently. | | | | | |
| I found the system unnecessarily complex. | | | | | |
| I thought the system was easy to use. | | | | | |
| I think that I would need the support of a technical person to be able to use this system. | | | | | |
| I found the various functions in this system were well-integrated. | | | | | |
| I thought there was too much inconsistency in this system. | | | | | |
| I would imagine that most people would learn to use this system very quickly. | | | | | |
| I found the system very cumbersome to use. | | | | | |
| I felt very confident using the system. | | | | | |
| I needed to learn many things before I could get going with this system. | | | | | |

4. The following open questions are intended to characterize the interactions with the objects.
   - How do you feel about being located with the badge? Would you accept being situated in an actual situation?
   - Did you see any error about the objects in the dashboard?
   - Most of the input collected by this software system was implicit (collected by sensors), based on the movements of users and equipment. Except for eventually querying the dashboard, in most cases, the users may not feel they are using a system. How do you feel about this kind of interaction?
   - Do you have any comments or suggestions?

# Annex E – Second Experiment Questionnaire

1. Demográfico:
    - Idade: ______
    - Gênero: ____________
    - Perfil: (    ) Graduação (    ) Mestrado (    ) Doutorado (    ) Profissional de Saúde
2. As seguintes questões têm objetivo de caracterizar a usabilidade do sistema.

| **Questões** | **Discordo fortemente** | | | **Concordo fortemente** | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| Acho que iria gostar de usar este sistema com frequência. | | | | | |
| Achei o sistema desnecessariamente complexo. | | | | | |
| Achei o sistema fácil de usar. | | | | | |
| Acho que precisaria de apoio técnico para poder usar este sistema. | | | | | |
| Achei que as funções deste sistema estavam bem integradas. | | | | | |
| Achei que havia muita inconsistência neste sistema. | | | | | |
| Imagino que maioria das pessoas aprenderia a usar muito rapidamente. | | | | | |
| Achei o sistema muito complicado de usar. | | | | | |
| Eu me senti muito confiante usando o sistema. | | | | | |
| Eu precisei aprender muitas coisas antes de começar a usar o sistema. | | | | | |

5. As seguintes questões abertas têm objetivo de caracterizar a interação com os objetos.
    - Nesta experiência, apenas objetos foram localizados. Você aceitaria se, em uma situação real, você também fosse localizado pelo sistema?
    - Você encontrou erros no dashboard e nos dispositivos RFID?
    - A maior parte da informação coletada pelo sistema de software é implícita (por sensores), baseada nos movimentos dos equipamentos. Exceto pela eventual consulta ao dashboard, na maioria dos casos os usuários podem não sentir que estão usando um sistema de software. Como você se sente em relação a esse tipo de interação?
    - Deseja fazer comentários e sugestões?

# Annex F – Consolidated Model Data Dictionary

| Package | Classes and Attributes | Description |
|---|---|---|
| **Real-World** | **Installation** | Represents an entire medical facility. |
| | id | Unique identifier for the installation. |
| | name | Name of the installation. |
| | description | Description of the installation. |
| | **Department** | Represents a specific department within an installation. |
| | id | Unique identifier for the department. |
| | name | Name of the department. |
| | description | Description of the department. |
| | **Room** | Represents a room within a department. |
| | id | Unique identifier for the room. |
| | name | Name of the room. |
| | description | Description of the room. |
| | **Supply** | Represents supplies such as medical equipment and assets. |
| | id | Unique identifier for the supply. |
| | size | Size of the supply. |
| | weight | Weight of the supply. |
| | material | Material type of the supply (e.g., Plastic, Metal). |
| | cleaning mode | The way a supply is cleaned (e.g., Washing, Disinfecting). |
| | **Supply State** | Tracks the state of a supply at a specific time. |
| | state | Lifecycle state of the supply (e.g., Clean, In Use, In Maintenance). |
| | time | Time at which the state was recorded. |
| | **User** | Represents a user of the system, such as a health professional. |
| | id | Unique identifier for the user. |
| | name | Name of the user. |
| | **Role** | Defines the function of a user, determining their permitted tasks. |
| | name | Name of the role. |
| | **Task** | Represents a task performed by a user, such as using a supply. |
| | time | The time when the task was performed. |
| | **Activity** | Represents a series of tasks that make up an activity. |
| | start | Start time of the activity. |
| | end | End time of the activity. |
| | **Event** | Represents relevant events, such as a supply needing maintenance. |
| | type | Type of event (e.g., Supply Needs Maintenance). |
| | time | The time when the event was triggered. |
| | **Event Type** | Enumeration listing possible types of events. |
| | **Supply Lifecycle State** | Enumeration listing the possible states of a supply's lifecycle. |
| | **Material Type** | An enumeration defining the material types for supplies. |
| | **Cleaning Mode** | An enumeration defining the possible cleaning modes for supplies. |
| **Device** | **Device** | Represents a generic device used within the IoT system. |
| | id | Unique identifier for the device. |
| | **Mechanisms** | Represents different mechanisms that devices can implement. |
| | id | Unique identifier for the mechanism. |
| | **Input Mechanism** | Mechanisms used for data input, such as sensors or RFID readers. |
| | model | Model type of the input mechanism. |
| | **Output Mechanism** | Mechanisms used for data output, such as displays or LEDs. |
| | model | Model type of the output mechanism. |
| | **Sensor** | An input mechanism that captures data from the environment. |
| | type | Type of sensor (e.g., Inertial, Acoustic). |
| | **Sensor Type** | Enumeration listing different types of sensors. |
| | **Reader** | Input mechanism capable of scanning radio frequencies |
| | reading distance | The maximum distance at which it can scan radio waves. |
| | transmit power | The power at which the reader transmits data in dBm. |
| | **Identifier** | An input mechanism that broadcasts radio waves, to be identified. |
| | id | Unique identifier for the identifier mechanism. |

| | | |
|---|---|---|
| | type | Communication type used by the identifier (e.g., RFID, Wi-Fi). |
| | transmit power | The power at which the identifier transmits data in dBm. |
| | **IoT Device** | A device capable of communicating with middleware. |
| | type | Communication type used by the IoT device (e.g., Wi-Fi, BLE). |
| | firmware version | The firmware version running on the IoT device. |
| | **LED** | An output mechanism that visually signals certain conditions. |
| | on | Boolean state indicating whether the LED is on or off. |
| | **Display** | An Output mechanism that visually presents information to users. |
| | resolution | Resolution of the display screen. |
| | **Printer** | An Output Mechanism that prints information. |
| | ink level | The current ink level in the printer. |
| | **Camera** | Input device to capture pictures and videos of the environment. |
| | resolution | Resolution of the camera captures. |
| | **Processing Mechanism** | Responsible for processing data within the device. |
| | model | Model type of the processing mechanism. |
| **Software** | **Middleware** | Software that permits data to be communicated through a network. |
| | version | The version of the middleware being used. |
| | **Data Manager** | The software component responsible for managing received data. |
| | version | The version of the data manager software. |
| | **Database** | Software for storing relevant historical data |
| | version | The version of the database schema. |
| | **Display** | Output device that shows relevant information to users. |
| | resolution | The resolution of the display screen. |
| | **Dashboard** | Software that displays system information. |
| | version | The version of the dashboard software. |
| | **User Data** | Stores user information within the database. |
| | id | Unique identifier for the user in the database. |
| | name | Name of the user. |
| | role | Role of the user within the system. |
| | **Room Data** | Stores room information within the database. |
| | id | Unique identifier for the room in the database. |
| | name | Name of the room. |
| | description | Description of the room. |
| | **Supply Data** | Stores supply information within the database. |
| | id | Unique identifier for the supply in the database. |
| | size | Size of the supply. |
| | weight | Weight of the supply. |
| | material | Material type of the supply (e.g., Plastic, Metal). |
| | cleaning mode | Cleaning mode for the supply (e.g., Washing, Disinfecting). |
| | **Task Data** | Stores task-related data within the database. |
| | time | Timestamp when the task was performed. |
| | **Supply State** | Stores states of supplies over time within the database. |
| | state | The current supply state (e.g., Clean, In Use, In Maintenance). |
| | time | Timestamp when the state was recorded. |

# Annex G – First Experiment Consent Letter

## CONFIDENTIALITY AGREEMENT

**Full name:** ________________________________________________________

- Your name will not identify you in the research.
- A software system collects the location of both objects and participants inside the limits of room 118 in the Malvache Building.
- Your answers to the questionnaire will only be read by the researcher.
- All the media taken during the experiment will have anonymized faces.
- It is possible that certain people, particularly those linked to research ethics committees, will verify the smooth running of this project by accessing the research files. These people must follow the same rules as researchers to ensure the information remains confidential.

As a participant in an experiment aimed at researching the positioning and management of objects in a simulated hospital, I agree to:

1) Allow the use of data collected by sensors during my participation in the experiment.

**Signature:** ________________________________________________________

2) Allow the capture of photos and videos of the experience during my participation.

**Signature:** ________________________________________________________

# Annex H – Second Experiment Consent Letter

## ACORDO DE CONFIDENCIALIDADE

**Nome Completo:** ________________________________________________

- Você não será identificado pelo seu nome nesta pesquisa.
- Um sistema de software coleta a localização apenas de objetos, nos limites das salas H318, dentro do PESC, COPPE.
- Suas respostas ao questionário serão lidas apenas pelo pesquisador e orientadores.
- Toda mídia gerada durante o experimento terá faces anonimizadas.
- É possível que determinadas pessoas, em especial as vinculadas aos comitês de ética em pesquisa, verifiquem o bom andamento deste projeto tendo acesso aos arquivos da pesquisa. Essas pessoas são obrigadas a seguir as mesmas regras dos pesquisadores para garantir que as informações permaneçam confidenciais.

Como um participante em um experimento, focado em pesquisar o gerenciamento de uso e localização de objetos em um hospital simulado, eu estou de acordo com:

1) Permito uso de dados coletados por sensores durante a minha participação.

**Assinatura:** _______________________________________________________

2) Permito a captura de fotos e vídeos da experiência durante minha participação.

**Assinatura:** _______________________________________________________