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Physical Access Control Systems in Healthcare

Healthcare Workers' Perceptions of Efficiency, Security, and User Experience

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Abstract

This master thesis investigates how physical access control systems (PACS) influence efficiency, security, and user experience in healthcare environments. As hospitals face increasing operational demands, PACS play a critical role in supporting workflows while maintaining necessary levels of security. However, existing systems may introduce friction in daily workflows and are often not designed with sufficient consideration of healthcare workers' needs. The purpose of this study is to investigate healthcare workers' perceptions and experiences of PACS, as well as to identify design implications for future physical access solutions in healthcare. The study adopts a mixed-methods approach, combining a systematic literature review, semi-structured interviews, and field observations conducted at three hospitals in the southern part of Sweden. The qualitative data provides insights into healthcare workers' experiences, behaviours, and challenges related to PACS, while quantitative observations illustrate operational impacts in the form of differences in passage times during different types of movement. The findings show that current PACS frequently disrupt workflows through repeated authentication, slow door behaviour, sensor interference, and inconsistent door logic. These interruptions were particularly problematic in time-critical environments such as emergency rooms, where rapid movement and coordination are essential. At the same time, healthcare workers generally viewed access control measures as important for maintaining security and safety, especially in environments associated with threats or violence. The study further shows that efficiency, security, and user experience are closely interconnected, where measures intended to improve one aspect may negatively affect another. Healthcare workers often adapted their behaviour through workarounds and informal practices in order to maintain workflow efficiency. The study contributes with a user-centred perspective on PACS in healthcare environments, an area that remains relatively underexplored in existing research. Furthermore, the study identifies several design implications for future physical access solutions, highlighting the importance of adaptive and context-aware systems that better align with the needs of healthcare workers.

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Sjukhus kan ses som komplexa miljöer där personal, patienter och utrustning är i ständig rörelse mellan och inom olika avdelningar. För att skydda patienter, vårdpersonal och känslig information används olika typer av passersystem och dörrlösningar, så kallade Physical Access Control Systems (PACS). Dessa innefattar allt från kodlås, kortläsare, automatiska dörröppnare och sensorer som styr vem som får tillgång till olika delar av sjukhuset. Samtidigt måste vårdpersonal kunna röra sig snabbt och smidigt, särskilt i akuta situationer där sekunder kan vara avgörande för en patients hälsa. På grund av detta uppstår ofta en balansgång mellan säkerhet och effektivitet. Det finns även en trend inom sjukhusmiljöer där avdelningar går mot ökad säkerhet, vilket leder till att fler dörrar med passersystem installeras, vilket sätter användarupplevelsen av dessa system i ett större fokus. Denna studie undersöker hur vårdpersonal upplever dagens passersystem i sjukhusmiljöer med fokus på effektivitet, säkerhet och användarupplevelse. Studien bygger på en litteraturstudie av tidigare forskning inom området, samt intervjuer och observationer genomförda på tre sjukhus i södra delen av Sverige. Intervjuerna och observationerna fokuserade främst på akutmottagningar, kirurgavdelningar och vårdcentraler, men inkluderade även annan vårdpersonal. Dessa verksamheter representerar olika typer av sjukhusflöden, där arbetstempo, storlek och passersystem varierar mellan miljöerna. Materialet från intervjuerna, och delvis även observationerna, analyserades genom tematisk analys där återkommande mönster, upplevelser och utmaningar identifierades och organiserades i teman och underteman. Syftet med studien var att skapa en bättre förståelse för hur dörrar och passersystem påverkar det dagliga arbetet för sjukvårdspersonal inom vården idag. Studien syftade även till att identifiera implikationer baserade på sjukvårdspersonalens upplevelser för bättre design av framtida passersystem.

Resultaten visar att vårdpersonal generellt anser att passersystem är viktiga för trygghet och säkerhet, särskilt på avdelningar där det finns risk för hot, våld eller obehörig åtkomst. Flera respondenter beskrev att säkerheten förbättrats jämfört med äldre sjukhusmiljöer, där obehöriga personer lättare kunde ta sig in på avdelningar. Samtidigt upplevdes systemen ofta som ett hinder i det dagliga arbetet. Upprepade identifiering med kort och kod, långsamma dörrar och otydliga funktioner skapade frustration och avbrott i arbetsflödena. Problemen blev särskilt tydliga vid patienttransporter och akuta situationer där personalen behövde röra sig snabbt genom många dörrar, samtidigt som deras händer ofta var upptagna med utrustning. Studien visar också att vårdpersonal ofta utvecklar egna lösningar och arbetssätt för att hantera systemen. Exempelvis ställs dörrar ibland upp manuellt för att undvika upprepade passager, trots att detta kan innebära säkerhetsrisker. Riskerna blev särskilt tydliga när brandcellsdörrar, som måste kunna stänga automatiskt vid brand, hölls uppställda under längre perioder. Personalen beskrev även hur de vant sig vid ineffektiva delar av systemet eftersom dessa uppfattas som en naturlig del av arbetsmiljön. Detta visar att det ofta finns en skillnad mellan hur systemen är tänkta att användas och hur de faktiskt används i praktiken.

Ett annat resultat från studien är att PACS varierar mellan olika sjukhus och även mellan olika delar av samma sjukhus. Äldre byggnader använder ofta enklare lösningar, medan nyare delar av sjukhusen i större utsträckning använder automatiserade dörrar och sensorbaserade system. Denna variation skapade skillnader i hur systemen fungerar och upplevs av personalen. Nyare system kunde underlätta arbetet genom mer automatiserade funktioner, men de kunde också skapa nya problem när sensorer eller andra dörrfunktioner inte fungerade som personalen förväntade sig. Skillnaderna mellan avdelningar och byggnader innebar dessutom att personal som rörde sig mellan olika delar av sjukhuset behövde anpassa sig till olika typer av passersystem, vilket ökade den kognitiva belastningen. Studien visar därmed att PACS inte bara är en teknisk säkerhetslösning, utan en viktig del av vårdens arbetsmiljö och arbetsflöden. Passersystem påverkar hur snabbt personal kan förflytta sig, hur smidigt samarbeten fungerar och hur trygg arbetsmiljön upplevs. Åtgärder som förbättrar säkerheten kan samtidigt försämra arbetsflöden, medan lösningar som gör arbetet mer effektivt ibland kan skapa säkerhetsrisker.

Utifrån resultaten pekar studien på behovet av mer användarcentrerade och situationsanpassade lösningar för passersystem inom vården. Identifierade implikationer för design av framtida lösningar visar att passersystem exempelvis skulle kunna anpassa sig efter vem användaren är, vilken roll personen har och hur situationen ser ut. Lösningar som automatiskt känner igen behörig personal vid patienttransporter utan att personalen behöver använda sina händer för att identifiera sig. I akuta situationer skulle passersystemen kunna minska onödiga avbrott utan att kompromissa med säkerheten. Samtidigt visar studien vikten av att utveckla system som fungerar på ett konsekvent och tydligt sätt för att minska kognitiv belastning och osäkerhet hos användarna. Studien visar också att framtidens sjukhus behöver passersystem som inte enbart fokuserar på säkerhet, utan stödjer vårdpersonalens faktiskt arbetsflöden och är utvecklat med deras behov i åtanke. Genom att bättre förstå samspelet mellan teknik, människor och vårdmiljöer finns möjligheter att skapa säkrare, effektivare och mer användarvänliga sjukhus.

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1. Introduction

Virtually every modern industry, including critical infrastructure like healthcare organisations, is currently undergoing a major digital transformation (Muciaccia and Tedeschi, 2023). This process, often referred to as digitalisation, is driven by digital technologies such as Artificial Intelligence (AI), Machine Learning (ML), the Internet of Things (IoT), and Industry 4.0, which refers to the integration of digital and physical systems to enable intelligent autonomous manufacturing (Kumar, Verma and Mirza, 2024). The pace of this transformation was accelerated by the COVID-19 pandemic, which is illustrated across multiple sectors. Educational institutions have increasingly adopted collaborative online platforms, business models have become more hybrid, and the healthcare sector has rapidly increased its use of telemedicine (Heinrichs et al., 2022). Beyond telemedicine, the healthcare industry has also seen growing adoption of a wide range of digital health innovations, such as advanced data management systems, digital decision support tools, and patient-facing technologies (Tahmasbi et al., 2025). The increased use of digital technologies in healthcare has, however, given rise to concerns regarding digital privacy and security, including issues related to control over personal data and bodily autonomy (Małagocka, 2024), highlighting the need for careful consideration when developing and implementing such technologies.

The pandemic can be said to have intensified safety concerns in other ways as well, as hygienic-related challenges have also become increasingly prominent. In response, the adoption of touchless technologies has accelerated, as minimising physical contact came to be understood as an essential part of safety and infection control (Iqbal and Campbell, 2021). However, safety in healthcare environments extends beyond hygiene and infection prevention. Hospitals also face broader physical security risks, including unauthorised physical access to restricted areas (Ritchey, 2019). Controlled physical access is a central aspect of hospital safety, as the majority of departments require restricted entry to support safe and confidential practices. As a result, physical access control systems play a key role in shaping everyday movement and operational work flows within healthcare environments.

The digitalisation of building systems means that physical security is now inseparable from digital infrastructure. Over the past two decades, there has been a considerable increase in the integration of, and dependence on, technology within the daily environment, leading to buildings that can sense and communicate information, which are called smart buildings (Ahmed, O. G., 2025). This transformation is characterised by systems that prioritise seamless technological integration, robust cybersecurity, and human-centered design, to enhance both operational efficiency and the overall user experience (Haiyirete, Zhang and Gao, 2024). Healthcare facilities represent a particularly relevant example of this transformation, as they are among the most complex and demanding operational systems in our society today (Miranda et al., 2020). Hospitals must balance high patient flow, strict safety requirements, and time-critical workflows while ensuring that staff, patients, and equipment move through the environment efficiently and securely (Hall, 2013). As these demands grow, there is increasing pressure on healthcare providers to modernise processes and reduce friction in everyday operations. In the context of smart buildings and infrastructure, one area with significant improvement potential is the management of doors and access points, given their central role in hospital logistics.

In complex healthcare environments, the placement and operation of doors affect workflow efficiency and patient flow by shaping how staff, patients, and equipment move through the facility (Ransolin et al., 2024). Therefore, doors constitute a key component of physical access control in hospitals, as they regulate who can access specific locations and under what conditions (Masoumzadeh, van der Laan and Dercksen, 2022). As such, they also influence security boundaries and staff workload. Although modern hospitals are already highly digitalized environments, there is still considerable potential to further improve physical access control systems in ways that better support healthcare workflows and user needs. By integrating technologies such as AI, ML, and IoT, access systems such as smart doors can move toward more adaptive and automated systems, rather than basic access control. These technologies may improve security through better authentication and anomaly detection, while also supporting more seamless workflows and user experiences (Capogrosso et al., 2023; khan et al., 2026). However, research on the practical impacts of access systems in hospital environments remains limited, as existing studies often focus on technical performance or security aspects in isolation, rather than examining how these systems are integrated into and affect everyday clinical workflows. In the context of healthcare physical access control systems, efficiency, security, and user experience emerge as particularly important aspects. Physical access control systems should support efficient and uninterrupted workflows, while simultaneously maintaining necessary levels of security and safety. At the same time, healthcare workers interact with these systems continuously in their everyday work, making user experience and usability important factors, influencing how physical access control systems are perceived and used in practice.

The study applies a mixed-methods approach to examine physical access control systems and healthcare workers' interactions with them. A structured literature review is conducted to examine past research, while data regarding current systems is collected from three hospitals in southern Sweden through interviews and field observations. This variation enables the inclusion of perspectives with different access needs and workflow characteristics, drawn from selected departments and workflows relevant to physical access control systems. The thesis contributes to existing literature by providing an empirically supported understanding of healthcare workers' perspectives on how access systems influence their daily workflows. It contributes by identifying how physical access control systems affect efficiency, security, and user experience in real-world healthcare environments from the perspective of healthcare workers. While previous research on efficiency in hospitals has primarily focused on patient flows, this thesis highlights the perspectives and needs of healthcare workers, addressing the lack of user-centered and empirically grounded approaches to examine physical access control systems. Building on these insights, the thesis identifies design implications for future access solutions aimed at improving efficiency, security, and user experience based on empirical evidence.

1.1. Research Questions

The purpose of this thesis is to investigate how physical access control systems influence healthcare workflows and healthcare workers' experiences in relation to efficiency, security, and user experience, as well as to identify design implications for future physical access solutions in healthcare environments. To address this purpose, the thesis combines a systematic literature review with interviews and observational field studies. The literature review examines existing research on healthcare workers' perceptions and experiences of access systems, while the interviews and observational field study explores how healthcare staff experience and interact with current physical access control systems in practice. Based on these insights, the study aims to identify design implications for future smart access solutions to better support healthcare workflows. Hence, the following research questions are addressed in this study:

RQ1:

> What do existing studies report on healthcare workers' perceptions of physical access control systems in healthcare environments?

RQ2:

> How do healthcare workers perceive the role of current physical access control systems in relation to efficiency, security, and user experience in healthcare environments?

RQ3:

> What design implications for future physical access solutions can be identified based on the findings of this study, in order to better support healthcare workers' needs?

RQ1 examines how healthcare workers' perceptions of physical access control systems have been described in existing research. Building on this, RQ2 investigates how healthcare workers experience and interact with current physical access control systems in practice, within the empirical context of this study. Finally, RQ3 utilises the findings from both the literature review (RQ1) and empirical studies (RQ2) to identify design implications for future access solutions intended to better support healthcare workflows and healthcare workers' needs.

1.2. Delimitations

This thesis is delimited to the study of physical access control systems within selected healthcare environments, with a particular focus on how these systems are experienced and used by healthcare workers in their daily workflows. Consequently, the study does not include logical access control systems such as access to electronic health records or other digital information and data. This delimitation was made to maintain a clear focus on the interaction between users and the physical components, which aligns with the aim to provide design implications for physical access control systems.

The study is further delimited to selected groups of healthcare workers who are directly involved in daily workflows requiring frequent interaction with physical access control systems, or involved in planning and implementation of these systems. In this thesis, the term healthcare workers refers to physicians, nurses, assistant nurses, and medical secretaries who work in healthcare environments. Other professions within healthcare environments were excluded to prioritise roles where physical access control systems have a direct impact on their daily workflows, or have an impact on the planning and implementation of these systems. Another delimitation is the study's focus on staff perspectives, meaning that patients, visitors, and external contractors are not included as primary subjects of analysis. While these groups interact with access systems, the focus on healthcare workers allows the study to examine physical access control systems involving access cards, personal codes, and restricted access areas. This focus was further motivated by the identified research gap, as previous research has rarely explored healthcare workers' perceptions and experiences of physical access control systems in healthcare environments.

The empirical study is delimited to three hospitals within a region in the southern part of Sweden. These hospitals were selected to provide variation in size, age, number of patients, and level of technology in the physical access control systems used. As such, the study does not consider private healthcare providers, international settings, or other regional contexts. Within these three hospitals, the study focuses on three departments; emergency rooms (ERs), surgical departments and healthcare centers. These were chosen to capture different operational contexts within healthcare environments. The ER represents one of the most time-sensitive departments in a hospital, with unpredictable patient flows, rapid decision-making, and high variety in cases. In such environments, even small delays of movement, access or coordination can result in significant consequences for both efficiency and patient care. The ER can therefore represent a healthcare context where the physical access control systems matter the most. In contrast, the surgical department was chosen to represent a more common and structured workflow in a hospital setting. The department typically has planned procedures, and clearly defined patient flows and staff movements. This makes for an environment that is transferable to other departments. Lastly, healthcare centers were included to represent healthcare environments with more open and accessible workflows, where physical access control systems are generally less restrictive.

Compared to the hospital departments, healthcare centers often involve more interaction between staff, patients, and visitors, while also having fewer locked doors. Including this context enables comparison between highly controlled hospital environments and more accessible ones, allowing the study to capture a broad range of access-related contexts. Consequently, other departments such as psychiatric care, administrative units, and outpatient clinics were excluded from the empirical study. These delimitations enabled a broad foundation for an in-depth analysis while maintaining a manageable scope.

The scope of the thesis is restricted to workflows and processes directly related to physical access control, with a primary focus on staff movement through doors and interaction with physical access control systems. The study does not aim to evaluate full hospital performance or patient outcomes, but rather to understand and assess how physical access control systems influence efficiency, security, and user experience from a staff perspective. This delimitation ensures that the study remains focused on the perceptions and experiences of healthcare workers related to physical access control systems.

2. Background and Related Work

This chapter provides the background relevant to physical access control systems within healthcare environments by reviewing relevant research from areas that frame the study. It begins by placing healthcare environments as complex sociotechnical systems with dynamic workflows and various actors. It then reviews research on access control systems, with particular focus on physical access control systems and its role in healthcare environments, followed by a discussion of the digitalisation of healthcare environments, including smart hospitals, smart access solutions, and future access control technologies. The chapter further discusses how healthcare workflows relate to efficiency. It then reviews existing research on evaluating efficiency, security, and user experience in healthcare systems, and finally identifies the research gap addressed in this study. Taken together, these topics establish the conceptual basis for understanding how physical access control systems influence healthcare workflows, and provide a foundation for discussing future design implications for physical access solutions in healthcare environments.

2.1. Healthcare Environments as Complex Systems

Healthcare environments, such as hospitals, are often described as complex adaptive systems, characterised by a collection of individual independent agents, non-linear interactions, and emergent system behaviour (Plsek and Greenhalgh, 2001). The word “emergence” refers to phenomena where the whole system behaves in ways that are not just greater than, but also fundamentally different from, the sum of its parts (Norwitz, Rubin and Reed-Tsochas, 2025). Thus, the complexity stems from the mutual influence of system components (Kannampallil et al., 2011). Healthcare environments consist of many interdependent actors with distinct professional roles, norms, guidelines, and responsibilities, whose activities must be coordinated across organisational and spatial boundaries. These agents, such as physicians, nurses, specialists, and support staff, operate under varying conditions and adapt their practices based on patient characteristics and situational demands (Mahajan et al., 2017). The people within the hospital system also interact with the organisation itself and the organisational culture can impact the interactions between agents (Mahajan et al., 2017). Due to the complexity and time-critical nature of hospitals and other healthcare environments, efficient coordination between multiple actors is critical to successful care delivery, which from an operational perspective can be described in terms of workflow efficiency (Mahajan et al., 2017).

The complexity of healthcare systems is not only a result of the agents inside them, but is also shaped by the surrounding environment, and the requirements placed upon that environment. Complex environments such as hospitals require well-supported decision-making, steady coordination, and constant alertness, as patient situations can develop quickly and place demands on the staff (Bayramzadeh and Aghaei, 2021). Access to reliable and timely technology can support healthcare workers in managing this complexity, as digital systems and technical equipment are essential components of everyday work in healthcare environments (Bayramzadeh and Aghaei, 2021). Several approaches in healthcare research emphasise the interdependence between people, processes, technologies, and the physical environment. One such example is the Systems Engineering Initiative for Patient Safety (SEIPS), which conceptualises healthcare as a work system made up of interacting components that shape outcomes together (Carayon et al., 2006). From this perspective, technology is understood as a component in a broader system, and safe and effective care depends on how well technologies are aligned with both work processes and the physical environment (Bayramzadeh and Aghaei, 2021).

Previous research has shown that physical artefacts such as doors play an active role in shaping clinical practice. For example, changes in door and room design have been shown to influence how healthcare workers approach and enter patient rooms, affecting both behaviour and perceived roles (Andersen et al., 2026). This suggests that access points are not only technical tools or neutral elements, but rather actively influence interactions and workflows within healthcare environments.

Taken together, this section highlights how operational efficiency in healthcare is dependent on, and shaped by, how effectively the different components of the work system interact and support one another in practice. Understanding healthcare environments as complex systems therefore provides an important foundation for examining how different technical systems embedded in the physical environment, such as physical access control systems, should be designed. This perspective motivates the need for evaluation approaches that considers interactions between people, processes, technologies, and the organisation and environment in which they operate.

2.2. Physical Access Control Systems in Healthcare Environments

Healthcare environments are complex settings that manage highly sensitive information and data, and operate on critical infrastructure where high security is necessary (Appari and Johnson, 2010). Because of this, they rely on robust access control systems to ensure patient and staff safety, privacy and confidentiality, and operational efficiency. Sandhu and Samarati (1994, p. 40) defines access control as “[it] constrains what a user can do directly, as well as what programs executing on behalf of the users are allowed to do”. Access control is an important aspect of security and assists in satisfying security properties of confidentiality, integrity, and availability (Fotiou et al., 2016). Confidentiality refers to information being kept private and only accessed by authorised users, integrity protects information from being tampered with by unauthorised users, and availability contains the ability of an authorised user to access a resource (Tchernykh et al., 2019).

Beyond information security, physical access control is important for safeguarding restricted areas in healthcare environments. Unauthorised access may compromise patient and staff safety, disrupt workflows, or lead to breaches of confidentiality (Bos and Blobel, 2007). Moreover, hospitals operate continuously and have to cater to diverse groups of users’ needs, including staff, patients, visitors, and external contractors (Ardagna et al., 2010). This creates a complex access environment where security must be weighed against operational efficiency and usability.

Physical access control is a fundamental part of an organisation’s security system, intended to control who can access a physical resource or location, and when they are allowed to do so (Masoumzadeh, van der Laan and Dercksen, 2022). Given security requirements, administrators create a physical access control policy, which is dependent on the capabilities and placements of the enforcement points. The access decisions are made according to the policy and includes information about the user’s attributes (role, clearance etc.), and the environment (location, time etc.). Physical Access Control Systems (PACS) need to be designed with an acceptable trade-off between convenience and security. PACS that are too inconvenient will lead to workarounds by the user, and too low security may lead to unintended users abusing the system. An example of unintended users abusing a system is called “tailgating”, which occurs when unauthorised subjects enter a space by following an authorised user through an enforcement point (Siegmund et al., 2018).

From a security perspective, access points within healthcare can be divided into three categories; employee entries, life safety egress doors, and patient doors (Colling and York, 2009). Employee entries should be access-controlled and are used to separate staff from patients and visitors. Life safety egress doors are used to facilitate evacuation of the building for employees, patients and visitors, and should be able to adapt for a safe exit of the building. Patient doors on the other hand, are doors used by patients and visitors that require clear directions and access control for that specific purpose.

Radio Frequency Identification (RFID) is a technology that uses radio waves for collecting and transferring data wirelessly (Yao, Chu and Li, 2012). RFID-based access systems are commonly used in healthcare environments and consists of a RFID device, a reader, and the host system (Camacho-Cogollo, Bonet and Iadanza, 2020). The device is usually embedded in a tag or an access card, and for access systems, the maximum reading range is about 10-15 centimeters from the reader, in accordance with the ISO standards for contactless proximity objects (ISO, 2018). The tag is worn by the user and can be paired with a personal identification code for added security. The devices used for access control are passive tags, meaning they have no internal power supply, but are activated when in the proximity of a reader (Camacho-Cogollo, Bonet and Iadanza, 2020). When a user presents the tag, the host system identifies the user and grants or denies access based on the predefined permissions in the access control protocol (Kriplean et al., 2007). Long-range RFID technologies can be used for other purposes than access control, such as real-time tracking of patients, equipment and personnel (Sundaresan, Doss and Zhou, 2015; Yao, Chu and Li, 2012).

RFID-based access control systems offer fast and contactless authentication, but they also have limitations, some of which can pose potential security threats. Since access is granted based on possession of a tag or an access card, such systems are vulnerable if the device is lost or stolen (Kriplean et al., 2007). RFID systems are also susceptible to security threats such as cloning or eavesdropping, particularly systems with limited protection mechanisms such as encryption (Juels, 2006; Karygiannis et al., 2007).

Existing studies on access control systems in healthcare have mainly focused on managing access to data (Saeed et al., 2022, Khater et al., 2024), and electronic health records (Cobrado et al., 2024). Research on physical access control in healthcare environments is very limited, especially from a user perspective.

2.3. Digitalisation of Healthcare Environments and Smart Access Solutions

Digitalisation in healthcare can be described as a broad digital transformation of how healthcare is organised and delivered, where hospital digitalisation in particular is expected to increase the efficiency and quality of health service delivery, as well as reduce the costs of those very processes (Vogel et al., 2024). Digitalisation in hospitals can therefore affect everyday work practices and coordination within hospitals (Agarwal et al., 2010).

One manifestation of healthcare digitalisation is the development of smart systems within hospitals. Levina et al. (2024, p. 2) refer to this concept as smart hospitals, defined as “[...] institutions that optimise, redesign, or build new clinical processes, management systems, and infrastructure to improve medical and economic performance through the use of the latest technologies (in healthcare, management, and IT)". Within the digitalisation of hospitals, smart building technologies refers to the use of digital systems to manage and monitor the hospital's physical environment and infrastructure (Levina et al., 2024).

The latest technologies applied in smart buildings include Internet of Things (IoT) and artificial intelligence (AI) with the purpose to enhance the functionality, safety, and energy efficiency of the buildings (khan et al., 2026). IoT uses connected devices and sensors in buildings to collect real-time data on occupancy, temperature, and lightning (khan et al., 2026). AI provides intelligent decision-making, using methods such as machine learning (ML) and predictive analytics to optimise building systems based on historical and real-time patterns (khan et al., 2026). These technologies offer several opportunities for physical access control systems. AI can enhance surveillance and biometrics by using data from sensors and biometric systems to manage and verify access (Capogrosso et al., 2023; Almheiri et al., 2024). It also supports anomaly and unauthorised access detection through vision-based analysis, and ML models continuously adapt to emerging security threats by regularly updating their anomaly detection performance (khan et al., 2026). Smart technologies facilitate smart contracts that can automate authorisation. The smart contracts only grant entry to restricted areas once a set of predefined conditions are met, which reduces the need for central authority and minimises the risk of human error and administrative burden (khan et al., 2026).

2.3.1. Smart Doors and Future Technologies

As hospitals adopt smart access control systems, smart doors become an essential part of them. Smart doors leverage advanced technologies such as IoT to allow for remote or automated control of entry and exit (Almheiri et al., 2024), but can also be discussed as being able to predict the intention of people near the door based on contextual information such as their movement, direction, and proximity to the door (Capogrosso et al., 2023). Some smart doors use keyless technology, where users can unlock doors without a physical key, which increases the overall system reliability (Paranagama and Hettige, 2022). Current smart door systems have evolved from simple metallic locks to advanced structures that utilize several steps of authentication to ensure safety (Motwani et al., 2021). Almheiri et al. (2024) discuss smart door systems as frequently combining something you know, like a PIN or password, something you have, like a smartphone app or an access card, and something you are, which can be biometric data like fingerprints or facial recognition. Modern smart doors utilize several kinds of technology, such as biometric systems, knowledge-based systems, credential-based systems, and wireless and remote connectivity systems (Paranagama and Hettige, 2022).

According to Capogrosso et al. (2023), smart technology automation has developed across generations: from basic sensor- and camera-based detection systems, to technologies capable of interpreting user intent through speech and gestures, to finally proxemic and scene reasoning systems. Future technologies will allow smart doors to use deep learning for trajectory forecasting, which predicts a person's path to determine if they actually intend to enter or are just passing by the door, as well as using scene reasoning to understand environmental constraints such as walls to recognize how people behave differently in groups versus alone (Capogrosso et al., 2023). Additional emerging technologies include color image edge detection, which is used to make the facial recognition process faster by reducing the amount of data that needs to be stored and transferred (Motwani et al., 2021). Future smart door systems may also automatically count people, monitor body temperature, and detect the presence of face masks (Capogrosso et al., 2023). In the context of biometrics, beyond fingerprints and facial recognition, future systems might utilize iris and retina patterns, voice waves, DNA, and speech patterns for individual identification (Paranagama and Hettige, 2022).

Smart doors offer several advantages for operational efficiency, security, and user experience. The systems can maintain logs of visitors, recording exactly who entered and the duration of their stay (Motwani et al., 2021). Smart doors also provide an active approach that allows for immediate action during a threat, whereas traditional CCTV is a passive approach only used for investigating incidents after they happen (Paranagama and Hettige, 2022). However, the integration of technology also introduces new vulnerabilities, which include technical breaches, device malfunctioning, and device incompatibility (Almheiri et al., 2024).

This section has examined the technological foundations that enable smart hospitals and smart doors, in order to understand what future technologies are feasible and what future PACS can look like. This helps explain how future access solutions could change workflows, security, efficiency, and user experience.

2.4. Hospital Workflows

It is critical for hospitals to develop systems that provide the best possible patient care given limited resources to reduce costs (Hall, 2013). One of these limited resources is time, and PACS play a role in streamlining workflows in order to save time. To achieve this, hospitals seek to optimise different kinds of workflows. There are three levels of workflows within hospitals; the first includes processes occurring across organisations, the second within an organisation such as the flow of workers, patients and information within a department, and the third is the flow of an individual's thoughts related to a task (Karsh, 2009). In relation to PACS within healthcare environments, the first level can be understood as cross-departmental workflows involving movement of staff and transportation of patients. The second level relates to the workflows of healthcare workers within a department, while the third concerns the cognitive process of a worker passing through an access point. Staff movement and patient transport are central parts of everyday hospital work, particularly in time-sensitive environments where delays and interruptions to workflows may affect both efficiency and patient care.

Within systems development and healthcare research, studying workflows is important for understanding how technologies interact with users and existing work practices. Several theoretical perspectives emphasise the relationship between people, systems, and context in healthcare environments. Contextual design, for example, highlights the importance of understanding work practices, movement patterns, and user needs in the actual environment where systems are used (Sheehan and Bakken, 2012). From this perspective, healthcare workflows are not only shaped by formal procedures, but also by how staff adapt technologies and environments to support their everyday work.

Previous studies on healthcare workflows have examined a variety of specific clinical contexts and operational challenges, including ambulatory clinics for chronic disease care (Unertl et al., 2009), physicians workflow in OB/GYNs' (Kloß et al., 2010), in-hospital time delays in a stroke center (Wang et al., 2017), and reduction of readmissions in neurosurgery (Wu et al., 2024). However, existing workflow research rarely focuses specifically on how PACS influence the movement of healthcare workers and patients throughout healthcare environments. This suggests a need for research examining how PACS influence everyday hospital workflows and how they are experienced by healthcare workers in practice.

2.5. Efficiency, Security, and User Experience in Healthcare Environments

Evaluating efficiency, security, and user experience within healthcare systems requires the use of several different methodological approaches and analytical perspectives. Imani et al. (2022) analyse the main indicators that affect hospital efficiency and identify key input, process, and output indicators commonly used to measure technical efficiency. From this perspective, efficiency is often described in relation to resource use and operational performance, and may include financial and technical indices connected to how healthcare activities are organised and carried out. A similar understanding of efficiency can be found in related research. Mateus, Joaquim and Nunes (2015) define efficiency as the maximisation of output for a given level of inputs, ensuring the best possible use of available technology and assets. From this perspective, initiatives that improve operational flows are commonly associated with increased efficiency. While such definitions provide a useful basis for assessing performance, they say less about how efficiency is experienced by healthcare staff in everyday work. Evaluation approaches in the healthcare context have historically struggled to account for qualitative aspects of such work, partly because hospital databases tend to provide more extensive quantitative data than insights into staff practices, work experiences, and quality of care.

Healthcare security is commonly defined as a system of safeguards designed to protect physical property and achieve relative safety for everyone interacting within the organisation, with the primary goal of reducing the probability of harmful incidents and limiting potential damage (Colling and York, 2010). Research in this area tends to focus on identifying and managing key risks within hospital environments, such as drug diversion, workplace violence, infant abduction, and patient elopement. While these approaches address physical security risks, hospitals are becoming increasingly digitalised, and security concerns now extend beyond the physical domain. New technological devices and systems are more tightly interconnected with other parts of the healthcare system, creating a need for evaluation approaches that also consider digital security aspects. In this context, Ahmed, Sindi and Nour (2022) propose a quantitative evaluation model for cybersecurity. However, while these methods provide ways of evaluating organisational and technical security aspects, they provide less insight into how security systems are experienced and managed in everyday healthcare work.

User experience is, according to Imani et al. (2022), harder to measure than efficiency and security, and within health care and other safety-critical domains it has received comparatively limited attention in both practice and research (Grundgeiger, Hurtienne and Happel, 2021). Nevertheless, user experience is crucial, as it influences how systems are perceived, adopted, and used in everyday work. Grundgeiger, Hurtienne, and Happel (2021) suggest that user experience in healthcare should be evaluated using a combination of quantitative and qualitative methods, where the qualitative methods in particular include identification of workflow interruptions, and interviews that capture experiential and emotional aspects of system use. In the context of hospital information systems, usability and user experience are often evaluated using established methods such as user testing, heuristic evaluation, think-aloud protocols, and cognitive walkthroughs, with common evaluation criteria including user satisfaction, efficiency, learnability, flexibility, and error reduction (Dehghani Mahmoodabadi et al., 2025). While these approaches provide structured ways of assessing system usability, they have primarily been applied to digital information systems, with less attention given to how healthcare staff interact with physical systems embedded in everyday workflows. Ultimately, prioritising user-centered evaluation methods that align with healthcare workflows is essential for ensuring that hospital systems are intuitive, safe, and effectively adopted by healthcare professionals.

Together, these perspectives illustrate that efficiency, security, and user experience are closely interconnected aspects of healthcare systems. Existing research has often focused on operational performance, risk management, or digital system usability separately, while less attention has been given to how healthcare workers experience and interact with PACS in everyday hospital workflows. This highlights the need for more user-centered and context-sensitive research approaches that capture both operational and lived aspects of PACS in healthcare environments.

2.6. Identified Research Gap

Taken together, the literature indicates a gap at the intersection of hospital workflows, PACS, and user-centered perspectives. While prior research has addressed access control from technical and security-related perspectives, there is limited understanding of how such systems are experienced by healthcare workers in their daily work and how they influence workflow efficiency, security, and user experience in healthcare environments. Furthermore, existing studies rarely examine PACS through a combined perspective of workflow efficiency, security, and user experience grounded in empirical observations and healthcare workers' experiences. This highlights the need for research that investigates how PACS are perceived and used in practice within healthcare environments.

3. Method

This chapter describes the methodological approach used in the study, including research design, data collection methods, and data analysis procedures. The chapter is structured as follows; the first section presents the research design, followed by the systematic literature review methodology, the interview methodology, and finally the field observations. Finally, ethical considerations are discussed.

3.1. Research Design

This study uses a mixed-methods research design, combining qualitative and quantitative approaches to investigate the role of access systems in healthcare environments. Such an approach is suitable for studying complex organisations, where both measurable operational effects and user perspectives are considered (Mertens, 2024). The thesis was carried out in three phases and utilises multiple data sources; a systematic literature review, semi-structured interviews, and field observations.

In the first phase, a systematic literature review was conducted to investigate how healthcare workers' perceptions of PACS have been described in previous research. This phase addressed RQ1 and helped establish a conceptual understanding of themes related to efficiency and workflows, security and safety, and user experience and design. The findings from the systematic literature review also provided contextual understanding and supported the interpretation of the empirical findings in the second phase of the study.

In the second phase, empirical data was collected through semi-structured interviews and field observations conducted in healthcare environments. This phase addressed RQ2, by examining how healthcare workers experience current PACSs in practice. The interviews provided insights into staff perceptions, challenges, workarounds, and user needs related to efficiency, security, and user experience. The field observations complemented the interviews with observations on user behaviour and how PACS interact with hospital workflows. In addition, quantitative measurements of door passage times were collected, to provide estimations on operational impacts associated with two different access scenarios.

In the final phase, which addressed RQ3, findings from the systematic literature review, interviews, and observations were synthesized to identify design implications for future access solutions in healthcare environments. By combining insights from previous research with empirical findings from healthcare staff, the study aimed to create implications for future access solutions that better support hospital workflows, security and safety concerns, and user experience.

3.2. Systematic Literature Review

A systematic literature review was conducted to establish a foundation of existing research on PACS in healthcare environments. The systematic literature review addressed RQ1, by identifying how healthcare workers' perceptions of PACS have been described in previous research. The review aimed to identify and synthesize existing research addressing efficiency, security, and user experience from the perspective of healthcare staff. The review followed the guidelines proposed by Okoli (2015), which are suitable for information systems research focusing on sociotechnical systems and user perspectives, and was conducted using a structured and transparent process inspired by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al., 2021) .

3.2.1. Procedure

The selected database for the systematic literature review was Scopus due to its relevant and broad coverage of peer-reviewed literature in both healthcare and information systems. The search used a structured search string applied to titles, abstracts, and keywords. The search string was constructed to capture four key concept areas:

1) physical access control systems,
2) healthcare contexts,
3) user groups (healthcare staff) , and
4) outcomes related to perceptions, user experience, usability, workflows, security, or efficiency.

The final search string is presented in Appendix A. The search resulted in 101 records. In addition, three non-English publications and one duplicate record were identified and excluded prior to screening, resulting in a total of 97 records included in the initial screening phase.

Explicit inclusion and exclusion criteria were applied to ensure relevance and transparency in the selection process. Studies were included if they:

- examined physical access systems (e.g., doors, entry systems, or access control mechanisms),
- were conducted in healthcare environments,
- included healthcare staff as participants or explicitly addressed staff perspectives,
- reported findings related to user perceptions, user experience, usability, workflows, security, or efficiency,
- were published in English, and
- were published within the time frame of 2015-2026

The time frame of 2015 to 2026 was chosen in order to capture recent developments in physical access control system technologies and contemporary healthcare workflows, as the study focuses on current perceptions of PACS. This period was considered appropriate since both healthcare environments and access control technologies are developing rapidly, with increasing digitalisation, automation, and adoption of smart technologies in recent years.

Studies were excluded if they:
- focused solely on digital access systems related to information or data,
- addressed patient perspectives without a staff-related component,
- did not examine physical access in relation to user perceptions, user experience, usability, workflows, security, or efficiency,
- were not published in English, or
- were published outside the time frame of 2015-2026.

Additional exclusion criteria applied during the full-text review included studies without staff involvement, conceptual or theoretical discussions without empirical data, anecdotal reports, studies focusing on unrelated aspects, and studies that were not accessible in full text.

The study selection was conducted in two stages. First, titles and abstracts were screened against the inclusion and exclusion criteria, which resulted in the exclusion of 79 records based on lack of relevance. Second, 18 articles were assessed in full text for eligibility. During this stage, 8 articles were excluded for the following reasons: lack of staff involvement (n=3), conceptual or contextual focus (n=2), patient-only focus (n=1), anecdotal evidence (n=1), focus on unrelated aspects such as noise (n=1), and lack of full-text availability (n=1). The process resulted in a final sample of 9 studies included in the review. The study selection process is illustrated in Figure 1.

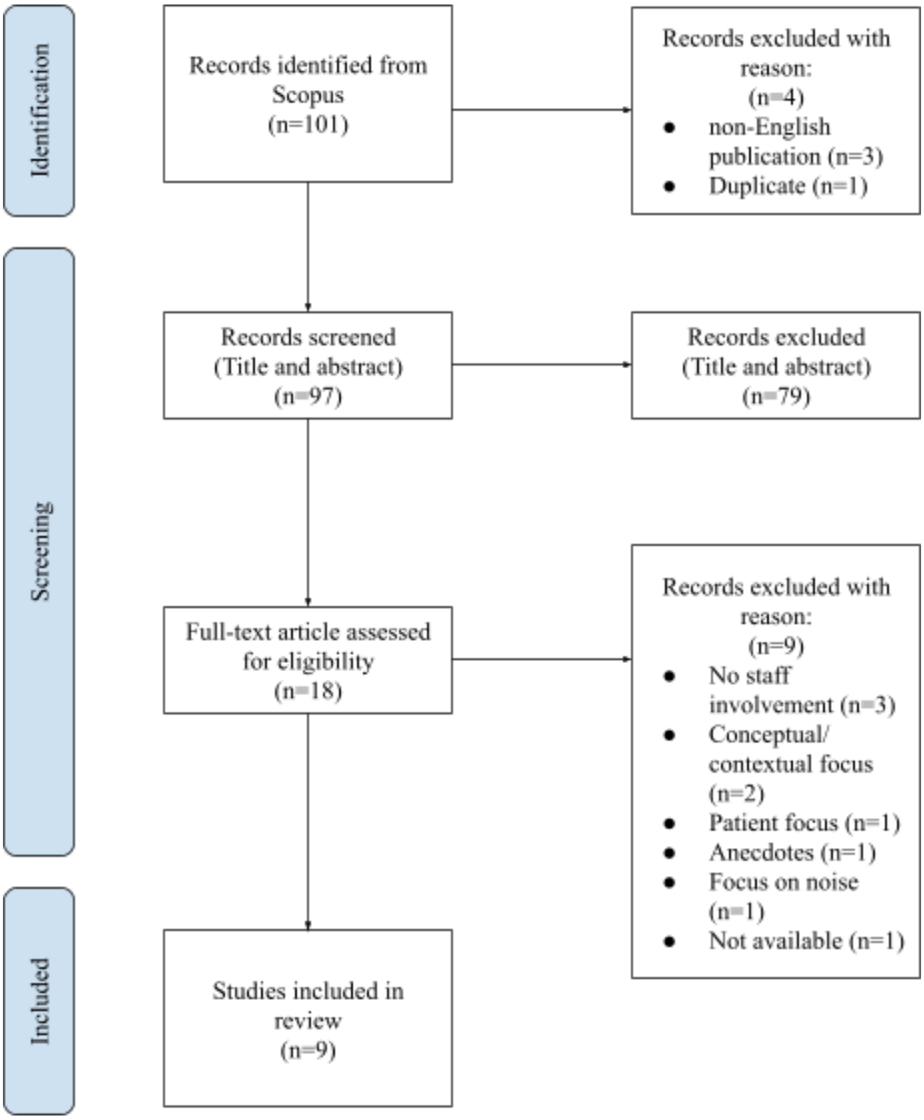

Figure 1. PRISMA flow diagram depicting the process of study selection.

3.2.2. Analysis

The included studies were analysed using a thematic synthesis approach. A table presenting the included studies and extracted data can be found in Appendix B. Relevant findings were extracted from each study with a particular focus on how PACS influence healthcare staff in relation to efficiency, security and safety, and user experience. The analysis was guided by these predefined themes, which were derived from the study's research questions and theoretical background. During the analysis, similarities and recurring patterns across the studies were identified and grouped within these themes, forming the basis for the synthesis presented in the results section.

3.3. Interviews

The interviews addressed RQ2, by exploring how healthcare workers perceive and experience current PACS in their everyday workflows. The semi-structured format enabled participants to describe and expand on challenges, workarounds, and contextual factors related to efficiency, security, and user experience. The interviews were conducted in three different hospitals from the same region in the southern part of Sweden, during a period of two months. To preserve anonymity, the hospitals are referred to as Hospital 1, Hospital 2, and Hospital 3 throughout the study. Hospital 1 is the largest hospital included in the study and consists of both a newly built section and older parts of the facility which enabled a comparison between older systems and brand new ones. Hospital 2 is medium-sized, and Hospital 3 is the smallest. The hospitals also differed in terms of departments, pace of work, and security requirements, which enabled perspectives from different healthcare contexts to be captured. The participants were recruited through snowball sampling where initial participants refer additional participants from their networks (Bryman, 2016), starting with an initial contact person that was involved in the operations of all three hospitals. The initial contact person could then recruit participants through their network using e-mail after which the interviews were scheduled in coordination with the participants' availability. The criteria for selecting interview participants were that they frequently use the hospital's PACS and doors, and that they represented a variety of roles to capture diverse perspectives.

The number of participants and interviews needed for the study was determined through the principles of qualitative data saturation, rather than a predefined sample size, where the concept saturation refers to the point where additional observations no longer provide substantially new insights (Guest, Bunce and Johnson, 2006). Previous methodological research has shown that thematic saturation is often reached within 6-12 interviews in relatively homogeneous samples (Guest, Bunce and Johnson, 2006).

3.3.1. Participants

The study included eleven participants from three hospitals. The participants represented a range of roles, including healthcare staff such as nurses, assistant nurses, and physicians, as well as personnel working in internal supporting functions such as property management and logistics. The participants had varying levels of work experience, ranging from less than one year to over ten years, which was considered important to capture diverse perspectives on hospital PACS.

The study primarily focused on departments with frequent interaction with PACS and varying workflow and security conditions, particularly ERs, surgical departments, and healthcare centres. These environments were selected because they represent different types of healthcare workflows, pace of work, and security requirements. At the same time, participant recruitment was also influenced by practical access and participant availability during the recruitment process.

Some of the interviews were held with two participants at the same time. This was due to the time constraints of hospital staff, and was taken into consideration during the analysis phase, as the participants may affect each other's perspectives. This is further discussed in Section 5.4. A detailed overview of participant characteristics is provided in Table 1.

Table 1. Participant Information

Participant ID	Interview Mode	Hospital	Department	Work Title	Years of Work Experience
PD1	Video Call	Hospital 1-3	Property Management	Property Developer	10+ years
N1	In Person	Hospital 1	ER	Nurse	4 years
AN1	In Person	Hospital 1	ER	Assistant Nurse	4 years
N2	In Person	Hospital 1	Surgery Department	Nurse	9 years
AN2	In Person	Hospital 1	Surgery Department	Assistant Nurse	5 years
AN3	Video Call	Hospital 2	Intensive Care Unit (ICU)	Assistant Nurse/ Medical Technical Responsible	10+ years
N3	Video Call	Hospital 2	Operation Department	Nurse Anesthetist	10+ years
D1	Video Call	Hospital 2	Rotational (Multiple Departments)	Junior Doctor (AT)	7 months

AN4	Video Call	Hospital 2	ER	Assistant Nurse/Project Manager	6 years
D2	Video Call	Hospital 3	Health Care Center	Specialist in General Practice	10+ years
MS1	Video Call	Hospital 3	Health Care Center	Medical Secretary	10 + years

3.3.2. Procedure

The structure of the interviews were designed as semi-structured with an open-ended format, consisting of a small number of introductory questions followed by broader themes for discussion. The interviews therefore become a conversation where both the interviewer and the interviewee actively shape the interaction, as this approach allows the participants to elaborate freely on their experiences and perspectives while the interviewer can ask tailored follow-up questions (Rapley, 2001). The interviews started with initial questions to learn about the interviewee, asking about the participants role and daily tasks, years of experience at the hospital, and which hospital departments they mostly work in. The interviews then proceeded with general questions about their experiences with the current PACS and doors at their hospital, followed by follow-up questions. The interviews also covered topics including enrollment processes, how personnel use current access and identification systems, their perceptions of the doors' impact on workflow, discussions on adaptive doors, and overall user experience priorities. The full interview guide can be found in Appendix C.

The interviews were held in Swedish, with an average length of 30 minutes. The interviews in person were held in the hospitals, and were recorded and then transcribed. The interviews over video call were transcribed during the actual interview with the help of live transcription. The recordings and transcripts were deleted immediately after the end of the study and analysis in accordance with GDPR. All interviews were conducted jointly by the two authors.

3.3.3. Analysis

For qualitative data, thematic analysis is one of the most common and flexible methods in healthcare research (Saunders et al., 2023). It is a family of methods that focus on coding and reporting themes from qualitative data, and allow for both inductive and deductive analyses (Braun and Clarke, 2024).The analysis followed a deductive approach, where the coding was guided by themes derived from the study's research questions and theoretical background. This approach was considered appropriate since the study aimed to explore participants' perceptions of efficiency, security, and user experience in relation to PACS. The analysis process was inspired by Braun and Clarke's (2006) six phases of thematic analysis, but was adapted to fit the collaborative and deductive approach of this study.

First, the interviews were reviewed by both authors in order to familiarise themselves with the material and identify recurring patterns and initial ideas. Relevant extracts and features of the data were then coded in relation to the predefined themes of efficiency, security and safety, and user experience. Based on these codes, preliminary subthemes were collaboratively developed and discussed by the authors. After the preliminary subthemes had been established, the themes were divided between the authors for the initial writing and analytical process. Each author revisited the interview material individually, selecting and analysing quotes and extracts considered relevant to the assigned themes and subthemes. Both authors reviewed and refined each other's themes and interpretations through repeated discussions and comparisons with the interview material, adding additional relevant data, quotes, and refinements where necessary. Finally, representative quotes and extracts were selected to illustrate the findings presented in the results section.

3.4. Field observations

Field observations were conducted to observe door interactions and user behaviour by healthcare workers, and to measure the time taken to pass through doors. The field observations complemented the interviews by examining how PACS were interacted with in practice within real workflows. The observations supported RQ2 by enabling direct observation of user behaviour, workflow disruptions, and door interactions, and the quantitative measurements complemented the qualitative findings by illustrating the additional time associated with door passages. In total, three observational studies were conducted, where each study lasted between 1-1.5 hours. The chosen doors were employee entries and were selected based on the following criteria; the door must require an access card to enter, and it must receive sufficient traffic by workers with and without equipment, meaning that the door is used frequently in daily workflows.

In observational studies, there is rarely a predefined amount of observations needed to ensure reliability, instead, the sample size depends on the specific topic studied. Calculating the sample size is an important step in planning an observation study to produce reliable results and not waste resources (Haynes et al., 2021). For the field study, two criteria had to be fulfilled. Firstly, enough observations were needed to reach saturation, meaning that any additional data did not provide any more insights into user behaviour. Secondly, enough observations were needed to estimate the distribution for the time spent passing through the door. The first criterion was considered to be fulfilled when no new user behaviours were identified in the observations, indicating that data saturation had been reached. In practice, this corresponded to a period of approximately 30 minutes without the identification of additional user behaviours. To satisfy the second criterion, a method to calculate the necessary sample size was needed, and according to Bland (2009), sample size calculations should be based on the width of the confidence interval. The number of observations needed were determined through a precision-based sample size approach where a confidence interval of 95% was chosen. A pilot study was used to obtain an estimated standard deviation that was then used to obtain a minimum number of observations. The pilot study was conducted during 1.5 hours in Hospital 1 and observed a door requiring an access card that led to the surgical department. The time it took for workers to pass through the door was measured, along with other data such as if they had any equipment, which direction, and if they used the automatic door opener or not. The pilot study provided 25 observations for the estimation of the standard deviation. The sample size was then determined such that the estimated mean door opening time would fall within $\pm\ 0.5$ seconds of the true mean with 95% confidence. The following formula was used to calculate the minimum number of observations required (Guthrie, 2012):

$$N \geq \left(\frac{z_{1-0.025}}{\delta}\right)^2 \sigma^2 \tag{1}$$

Where $z_{1-0.025} = 1.96$ is the critical value from the normal distribution, $\delta = 0.5$ is the maximum error of estimation with a probability of 95%, and $\sigma \approx 1.74$ is the estimated standard deviation from the pilot study. Equation (1) gave a minimum of 47 observations to fulfill the requirement. The time it takes for a worker to pass through a specific door was assumed to be following a normal distribution.

3.4.1. Procedure

The observations were conducted by observing the selected doors on-site during regular working hours to capture typical operational conditions. The set-up of the observation was created to minimise interference with hospital activities and ensure a clear view of the door interactions. No interaction with staff or patients occurred during the observation periods. For each observed door passage, the time required to pass through the door was recorded. The time was measured using a stop watch, starting when the user was approximately one metre from the door and ending once the user had completed the passage and was approximately one metre beyond the door on the opposite side. Other metrics that were recorded include; if they were carrying any equipment, if they used the automatic door opener, and from which side they approached the door. If the automatic door opener was used, the total time the door was opened was also noted. In addition, qualitative notes were taken regarding user behaviour, such as hesitation, if they understood what was required to open the door, and what happened when multiple persons passed through at the same time. Observations were conducted across multiple time periods and locations to capture variations in usage patterns. A table of the recorded data can be found in Appendix D.

3.4.2. Analysis

The data collected from the field observations was analysed using both qualitative and quantitative methods. The qualitative analysis focused on the observational notes recorded during the field study. These notes were reviewed and analysed to identify recurring patterns in user behaviour, such as interaction with the card reader with and without equipment, and understanding of the PACS. The identified behaviours were grouped into categories and used to support the findings from the interviews. The combination of observational data and interview insights enabled triangulation, allowing the findings to be validated across different data sources and strengthen the credibility of the analysis.

The quantitative analysis focused on the recorded door passage times. For each observed interaction, the time required to pass through the door was measured and recorded. These measurements were used to calculate the mean passage time and standard deviation for each door type and access method. The mean passing times were used to illustrate the differences in passage times with and without equipment.

3.5. Ethical Considerations

Throughout the data collection process ethical considerations were taken into account. Before the interviews, the participants were informed of the scope of the project and the fact that their answers would be anonymised. The participants were also asked to give consent to being interviewed and for the interview to be recorded. All recordings were deleted after the analysis stage, where the identification of the interview participants was pseudonymised. No confidential patient information was shared in the interviews. To ensure that the observational field studies were carried out in an ethical way, each location of the studies were discussed with hospital staff before starting. All observations were therefore carried out in public accessible areas of the hospital where privacy was not expected. All entries in the observational field studies were done without any identifying features or personal information being noted. The studies were carried out from a distance, in a way that did not affect the people being observed.

4. Results

This chapter presents the results of the systematic literature review, semi-structured interviews, and observational field study. The findings are organised around the three main themes; efficiency, security and safety, and user experience. Section 4.1 presents the findings from the systematic literature review and addresses RQ1. Sections 4.2 and 4.3 present the findings from the interviews and observational field study respectively, addressing RQ2. Finally, Section 4.4 presents the design implications for future physical access control solutions based on the findings in earlier sections, addressing RQ3.

4.1. Existing Research on Healthcare Workers' Perceptions of PACS

Existing studies on healthcare workers' perceptions of PACS are shaped by a balance between security needs, workflow efficiency, and their impact on the work environment. The results of the systematic literature review are presented in a set of identified themes based on patterns observed in the data. The full table presenting the studies and the extracted data can be found in Appendix B.

4.1.1. Impact on Efficiency and Workflows

Previous literature on PACS in healthcare environments suggest they affect workflow efficiency. Studies on healthcare environments highlight that the design and placement of physical infrastructure, including doors, can either support or hinder efficient workflows. For instance, in trauma room settings, certain design choices such as automatic doors have been associated with delays and interruptions in time-critical processes (Aghaei and Bayramzadeh, 2024). Additionally, design decisions related to access points often involve trade-offs between competing priorities, such as visibility, privacy, and safety, which can have unintended consequences for staff workflows (van Heel, Herweijer and van Oel, 2024). Nurses emphasise the importance of "peripheral visibility", and in modern department designs with solid doors, staff report a "feeling of unsafety" due to the inability to easily observe patients or locate colleagues (van Heel, Herweijer and van Oel, 2024). Another highlighted aspect in regards to efficiency and workflows is the placement of doors, specifically in operating rooms, where surgical staff reported that swing doors interfere with equipment transitioning and sliding doors were often preferred (Bayramzadeh et al., 2018). These findings indicate that access systems play a role in shaping operational efficiency, although this aspect is often considered indirectly rather than as a primary focus in existing research.

4.1.2. Security and Safety

According to the literature, healthcare workers often view access systems as essential for safety, even though they also recognise their limitations. In mental health settings for example, nurses frequently hold the belief that locked external doors are necessary to prevent absconding, which can be defined as patients leaving without authorization (Searby et al., 2023). Nurses also report that they often feel a sense of personal failure or responsibility despite the doors being locked when absconding actually occurs, which often happens through tailgating or climbing walls (Searby et al., 2023). In other high-risk areas like the ER, staff tend to favour access control measures including metal detectors, card-based entry systems, and security glass to enhance physical protection against potentially aggressive patients or visitors (MohammadiGorji et al., 2021). Among the identified measures, the visible presence of security personnel appears to play a particularly important role in enhancing staff's perceived sense of safety (MohammadiGorji et al., 2021).

Beyond protection from external threats, access systems are also associated with operational and physical safety in everyday work. For instance, manual handling of heavy doors while transporting equipment is identified as a potential safety hazard, and staff perceive sensor-based, hands-free access as a way to reduce physical risks, such as slip-and-fall incidents, when their hands are occupied (Khan et al., 2015). Similarly, in operating theatre environments, automated doors were viewed positively as they minimise physical contact, thereby supporting both hygiene protocols and safe working conditions (Menon et al., 2025). Overall, these findings suggest that healthcare workers' perceptions of PACS are strongly influenced by safety considerations, even though the effectiveness of such measures remains uncertain.

4.1.3. User Experience and Design

In addition to efficiency and safety, several studies highlight the impact of access systems on healthcare workers' user experience. While PACS are often implemented to enhance security, they are frequently perceived as restrictive and misaligned with the needs of staff in practice. In psychiatric care settings for example, locked doors are described as necessary for preventing patients leaving, but also as contributing to negative effects on the relationship between patients and healthcare professionals (Searby et al., 2023). Another example from psychiatric care is restrictive doors being viewed as symbols for loss of control, social distance, and stigma, and revolving doors were a source of frustration and indignation for nurses (Missouridou et al., 2022). This shows how different access systems can impact user experience and the perceived role of the doors by users.

Another topic covered by the literature is the experienced usability in contrast to intended design. Van Heel, Herweijer and Van Oel (2024) discuss the trade-offs between visibility, privacy, and safety. The authors describe how design intentions in healthcare environments can differ from how the design is experienced and used in practice. The patient room was designed to balance these three aspects with staff workflows, but the evaluation revealed several unintended consequences. For example, the solid door improved visual privacy, but also made it harder for staff to monitor patients and locate colleagues. In this way, a design solution intended to support patient wellbeing also created new challenges for staff usability. The study highlights a mismatch between intended design and experienced usability, where a solution that fulfills one purpose may create new problems elsewhere. The study therefore emphasises the importance of evaluating access systems not only from a technical or design perspective, but also from the perspective of healthcare workers' everyday use.

4.2. Healthcare Workers' Perceptions of PACS

The findings from the interviews are presented through a thematic structure, capturing healthcare staff's perceptions of access systems in practice. The analysis was guided by a deductive approach, based on three predefined themes: efficiency, security, and user experience. Within these overarching themes, subthemes were developed by identifying recurring patterns and key codes across the interview data. The results are presented as a mapping of these themes, each described and illustrated with quotes from the interviews. Although the analysis is structured around three main themes, the findings indicate that these aspects are closely related and often overlap in everyday practice, as visualised in Figure 2 below.

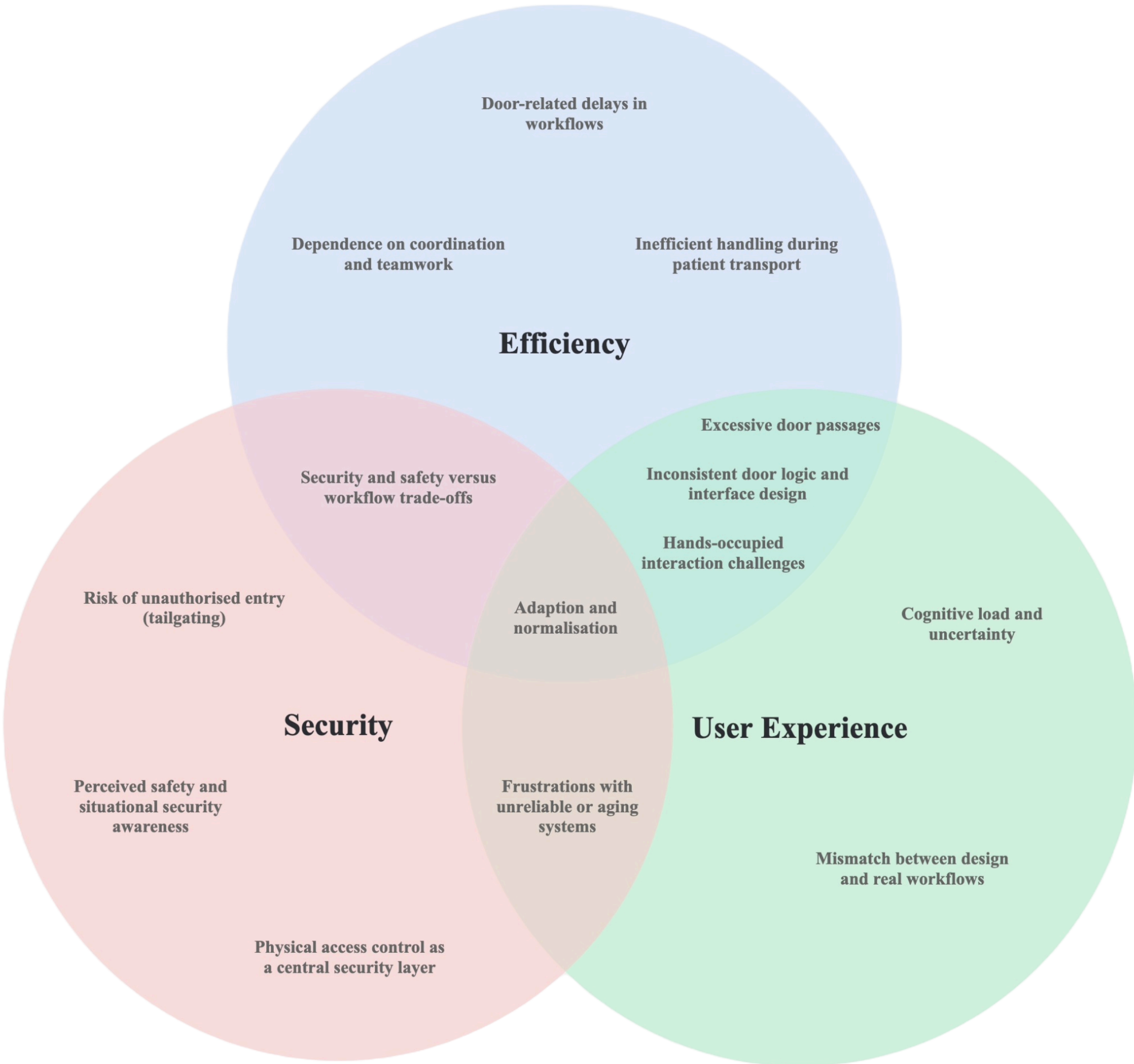

Figure 2. Main themes and subthemes of hospital workers' perceptions.

4.2.1. Efficiency

This section presents findings related to how healthcare workers perceive the effect of PACS on workflow efficiency. It focuses on subthemes that discuss delays caused by door functionality, the impact of repeated door passages, challenges during patient transport, and the need for coordination between staff. The findings also highlight how inconsistencies in door logic and system design affect movement and workflows.

Door-related delays in workflows

A recurring theme identified in the interviews concerns door-related delays in workflows, where participants described their work being delayed or paused because of door characteristics. The most prevalent causes were that doors were perceived as opening too slowly, that these delays interrupted workflows and created frustration, and that safety-oriented door features were sometimes viewed as obstacles during urgent situations. Participants frequently described how slow door openings forced them to stop and wait during movement through the hospital:

> "*I think the new [doors] open too slowly, I think I walk too fast or something*" (Participant D2).

Another described how the delay could become emotionally frustrating, and noted:

> "*They are so slow that it can be really frustrating sometimes, like having to stop and wait*" (Participant MS1).

These statements indicate that even quite short delays were experienced as frustrating when repeated across a work shift. These delays did not only affect time, but also disrupted workflow continuity, repeatedly interrupting movement and breaking its flow. In addition to the general slowness of the doors, some participants explicitly linked the slow and interrupted door movements to door safety features, such as motion sensors and proximity detection, and explained the delays as a consequence of safety-oriented design choices. The door speed was described as intentionally limited in order to reduce the risk of injury, particularly in environments where patients in beds or wheelchairs frequently pass through. As one participant reflected:

> "*Maybe it was some kind of safety thinking that made them go more slowly*" (Participant D2).

While several participants explained slow door movements as a result of safety features, the same features were in some cases described as creating safety risks, particularly in emergency situations. During time-critical events, delays in door opening were perceived as problematic, as staff may attempt to force doors open when they do not respond quickly enough. One participant described this as a significant issue:

> "*In emergency situations, [the doors] would open extremely slowly. That's a major problem, because those doors will end up being forced open.*" (Participant AN1)

This shows how features designed to improve safety may, in urgent situations, instead create new risks by slowing down movement and interrupting workflow. Participant AN3 named the motion sensors as especially time consuming, explaining that they had to be removed because they were overly sensitive and frequently prevented doors from opening when someone was nearby. This resulted in staff having to stop, back up, and manually open the door, which was described as particularly disruptive during urgent situations involving patient emergencies.

Excessive door passages

The second subtheme of efficiency captures how staff described the cumulative effects of having to pass through many doors in sequence during shifts. Participants described how repeated and often unavoidable door passages disrupted workflow continuity, both in emergency situations and in routine staff movement throughout the hospital. Participants explained that even relatively short movements often required passing through several doors in sequence. One participant explained that unless staff were already located inside the trauma room with a patient, they still had to pass through several doors to reach them:

> "*...one door, no two doors, because there is also a door into the emergency room itself*" (Participant N1).

This illustrates how the process of reaching an emergency patient may involve multiple door passages that collectively slow down urgent workflows. In addition to patient-related movements, routine activities such as getting to and from staff changing rooms and other kinds of staff facilities were also described as involving repeated passages. One participant noted:

> "*There are about four doors before you get [to the changing room], and that happens everyday, twice a day, when you arrive and when you leave*" (Participant N3).

These repeated passages were, as participant N3's account shows, not limited to clinical transports, but also appeared in ordinary staff routines such as moving between changing rooms, work areas, storage rooms, and administrative spaces. This shows how door-related inefficiencies become embedded in both clinical and non-clinical work. Similarly to the previous subtheme, excessive door passages were linked to safety-driven design decisions. In particular, many participants described the large number of doors as a consequence of fire safety requirements, which were perceived to conflict with the need for smooth and efficient movement. As a result, staff encountered "door after door after door" even in situations where continuous movement would have maintained the workflow better. The trade-off between safety requirements and workflow continuity is discussed further in the subtheme *Security and safety versus workflow trade-offs*.

Inefficient handling during patient transport

Building on the issue of door-related delays and excessive door passages, the subtheme of inefficient handling during patient transport focuses on how door design and placement affected the handling of patients in beds during transport. Participants described how physical access control systems often failed to support smooth and continuous patient transport, particularly in situations involving beds and medical equipment. Participants particularly described challenges related to button and card reader placement, and door opening direction and logic during transport situations. One recurring issue concerned the placement of door opener buttons and card readers, which in some cases forced staff to leave the patient bed in order to open the door. However, some departments had better placements for buttons:

> "*In the emergency room, the button is located quite far from the door, which can actually be beneficial when transporting a patient on a bed, as you can press it while moving*" (Participant N1)

This illustrates that the impact of PACS on patient transport varies depending on their design and placement, since some button placements actually support smoother patient transport by allowing continuous movement. However, participants also described how these designs could create inefficiencies in other situations, particularly when staff moved without equipment:

> "*We often move through these areas without patients, and then you are used to walking up to the door and pressing the button next to it. However, in this case the button is located several metres away, so you have to walk back. 'Right, this is where the button is,' and then walk back to the door. Until you realize that the button is not located close to the door, this can be difficult, or rather, it results in a lot of extra steps. Constantly having to walk back and forth*." (Participant N1)

Beyond the placement of the buttons and readers, the door movement also proved to have an effect on the transport. Depending on whether the door opens inwards or outwards, the staff reported having to sometimes stop and back the bed up in order for the door to open:

> "*Sometimes the doors open inward, causing them to collide with the intensive care bed. In other cases, staff have to stop and move the bed closer in order for the door to open*" (Participant AN3)

The quote highlights how current door design does not support continuous bed transport, instead requiring repeated stops and repositioning that disrupt the transport process. Taken together, these accounts illustrate how patient transport was repeatedly disrupted by access systems not adapted to the reality of moving beds and equipment. Rather than enabling smooth, continuous movement, card reader and button placement, opening direction, and door logic introduced frequent bottlenecks. As a result, patient transport became disrupted and physically demanding, illustrating how the PACS constrained operational efficiency.

Dependence on coordination and teamwork

This subtheme describes how inefficiencies in door design and access systems increased staff reliance on coordination and teamwork to maintain efficient workflows. Participants particularly described the need for staff to coordinate movement during urgent situations, compensate for unclear door interactions, and develop collaborative workarounds to avoid delays during patient transports. Several participants explained that doors often could not be handled efficiently by a single person during urgent movement or patient transport, making collaboration necessary to avoid delays. One participant explained that during acute situations:

> "*...there is usually someone standing by the door, holding it open and calling the elevator so that the transport can move smoothly*" (Participant N2).

Rather than the system supporting continuous movement, efficiency is achieved by positioning staff at key points along the route to prevent stops. This kind of teamwork was also described as especially necessary when working with new or unfamiliar staff. One participant noted that interaction could be "illogical", requiring experienced staff to run ahead and open doors in advance:

> "*We sometimes have new staff with us who don't know what to press, so you have to send someone experienced ahead of time when it's urgent*" (Participant AN3)

In these situations, staff relied on each other's local knowledge to compensate for unclear door logic. Participants further described how such coordination had become a routine workaround rather than an exception, where staff asked colleagues to stand by doors or hold them open when rapid movement was required. While these practices enabled work to continue, they placed the burden of efficiency on staff cooperation rather than on the design of the PACS. Taken together, these accounts illustrate how those access systems that do not support independent use increase dependence on teamwork. However, there were also instances where PACS were described as supporting coordinated teamwork and efficiency, particularly in emergency workflows. For example, in acute caesarean section scenarios, doors and elevators were integrated into the emergency response chain to enable uninterrupted movement:

> "*Acute and extremely urgent caesarean sections are transported in beds. […] They are part of an emergency response chain. We have a block paging function, which means that the elevator is automatically called. […] Our doors open and remain open in a special mode to facilitate the flow in.*" (Participant N3)

This illustrates how PACS can support coordinated workflows, although such solutions were primarily described in specialised emergency contexts rather than being widely implemented in everyday settings.

Inconsistent door logic and interface design

This subtheme captures how staff described doors and their interfaces as lacking consistent logic, contributing to workflows becoming more inefficient. Participants particularly described inconsistencies related to button placement, door opening behaviour, and the lack of visual guidance for door interaction. Rather than being able to rely on learned patterns, the participants emphasized door interaction often varied between locations, requiring staff to think about how to operate each door. One issue that was frequently mentioned concerned the illogical and inconsistent placement of door opening buttons. Participants described how differences in between doors made interactions less predictable and interrupted otherwise routine movement. As one participant explained concerning a door button in the emergency ward:

> *"It's illogical. Totally illogical"* (Participant AN1)

Another participant spoke on how the buttons could differ even within the same department:

> "*The doors are not consistently planned [...], sometimes the buttons are on the right side, and then suddenly on the left.*" (Participant PD1)

Participants portrayed these inconsistencies as making door interaction less intuitive. From a planning perspective the inconsistencies were described as the result of non-coordinated design rather than isolated errors. This will be discussed in more detail in the section of the subtheme *Mismatch between design and workflow*. In addition to button placement, participants described a lack of visual guidance that would make the door interaction easier to understand. Several participants pointed out that markings indicating how doors open, or where to position oneself when activating them, were often missing, particularly in newer hospital environments. This lack of guidance was described as leading to confusion and repeated failed attempts at door activation:

> "*People don't see any markings showing how the doors open. So they tap their access card, stand right in front of the door, and then it stops. [...] They don't understand that they need to step back. There are no markings showing how the doors are supposed to open*" (Participant AN1)

This became particularly evident when staff had previously worked in areas with markings. Further examples highlighted how doors could behave in unpredictable ways, such as opening in the unexpected direction or when buttons triggered the wrong door instead of the intended one. These issues were described as confusing when moving between floors, where staff expected the system to respond to their intended direction of movement. Such inconsistencies were also described as challenging for staff unfamiliar with a specific area, as interaction relied on knowledge rather than logic and visual guidance.

4.2.2. Security and Safety

This section presents findings connected to how healthcare workers perceive and interact with PACS in relation to security and safety. The subthemes discuss access control as a central security layer, risks of unauthorised entry, variation in perceived safety, and trade-offs between security and workflow. Together, these themes illustrate different aspects of security and safety that healthcare workers experience and manage in their daily work.

Physical access control as a central security layer

An important finding in the interviews concerns how PACS are viewed as a central part of hospital security as society is moving in a more violent direction. Participants described locked doors, card readers, personal codes, and restricted zones as necessary for controlling who can enter different parts of the hospital. This was especially clear in relation to department boundaries, where access control was used to separate public accessible areas from clinical spaces with a so-called "shell". Normally, higher security in the form of access cards and personal codes were implemented on doors leading into departments, whereas lighter security such as only access cards or tags was used within the department. This was used to protect staff, patients, equipment, and sensitive information, which shows that access control is not only used to restrict individual rooms, but also to create security boundaries around entire departments or operational areas. In some cases, participants explicitly linked locked doors leading into departments to increased safety. One participant described the increase of threats and violence in their department where unauthorised access could create risks as:

> *"The doors are locked. That is good. We do have threats and violence up here"* (Participant AN2)

The worry about the state of the society today was repeated by several participants during the interviews. Some mentioned a general trend in society where organised crime and gun violence are increasing, while others described how violent incidents in the hospital had become more common in recent years. These perceptions were specifically illustrated by the fact that several departments have shifted towards more locked doors, and affect how staff within healthcare environments view security.

Overall, this suggests that healthcare workers generally accept access control as necessary for security. However, this acceptance appeared to be related to the perceived risk level of the environment, the amount of people in circulation, and the pace of the department. Access control is therefore not only understood as a technical system, but as an important part in shaping the perceptions of security, safety, and control in hospital processes.

Risk of unauthorised entry

Participants highlighted that, despite the presence of PACS, unauthorised entry remains a concern in practice. The most important findings were that tailgating was perceived as difficult to prevent, that staff often felt responsible for monitoring doors and preventing unauthorised entry themselves, and that concerns about threats and violence increased the perceived importance of controlled access. Tailgating was often not perceived as malicious, but rather as a result of everyday routines and the functionality of the PACS. Several participants described situations where they felt uncertain about whether individuals entering behind them were authorised or not. In some cases, staff expressed hesitation to challenge others, particularly in busy work environments where questioning access could feel confrontational. In relation to a secure door leading into the department that stayed open for a significant duration, one participant said:

> *"I think it is a bit uncomfortable there, because then I don't know who is following behind me"* (Participant N1)

This reflects a lack of visibility and control over who actually passes through secured doors, even when access systems are in place. Additionally, participants raised the issue of unauthorised individuals intentionally tailgating into secured areas of the hospital. This was raised as a particular threat in the ERs, where the staff are sometimes dealing with violent and potentially dangerous cases. Additionally, staff working in various departments raised this issue as especially concerning when working evening and night shifts. During these shifts, fewer personnel are working and the risk of unauthorised people entering with malicious intent is higher, leading to staff feeling more vulnerable during these times. Some participants described how they would watch high security doors after they had passed through them to ensure that no one followed behind them into the department. One participant described how she would turn around and wait for the door to close:

> *"I almost stay and wait, because no one is allowed into the department"* (Participant N1)

Another common point that was brought up in the interviews connected to this was the increase of violence and the state of society today. Several participants raised the concern of being under increased threat of violence and how their departments were moving towards implementing more doors and increasing security on existing doors. One participant described how they had made changes to their department as a response to this change in society:

> *"... there is so much threat and violence in society now, so we have reduced the number of entrances for the patients"* (Participant MS1)

This indicates that concerns about tailgating are not only related to the functionality of the PACS themselves, but are also influenced by broader societal developments and changing perceptions of security. As a result, departments have increasingly adapted their security in an attempt to strengthen control over who is able to enter clinical spaces.The findings suggest that current PACS alone are not sufficient to fully prevent unauthorised entry. Instead, their effectiveness heavily depends on how they are used in practice, as well as on staff awareness and behaviour. Tailgating therefore represents a gap between intended security functionality and real-world use, highlighting the importance of designing systems that account for human behaviour in addition to technical control.

Perceived safety and situational security awareness

In addition to the structural and functional aspects of PACS, participants frequently described how their perception of safety varies depending on the situation. The most important findings were that security awareness increased in contexts where staff experienced higher risks, that PACS contributed to a sense of safety and control, and that hygiene concerns related to physical interaction with door components were viewed differently among healthcare workers. Security was not experienced as constant, but as something that changes based on factors such as time of day, staff numbers, and the type of department they were currently working in. As described before, several participants expressed how they felt more vulnerable during evening and night shifts, when fewer staff are present and the risk of threatening situations is perceived to be higher. In these situations, access control measures were described as more important, and staff reported being more attentive to doors and their surroundings. This indicates that security awareness increases in contexts where perceived risk is higher.

At the same time, participants described how the presence of PACS contributes to a sense of safety, even if these systems are not always fully effective in preventing security breaches such as tailgating. For example, locked doors and restricted access points were associated with increased feelings of control and protection, particularly in departments that have experiences of threats or violence. As described above, when staff moved to a newly built department with more locked doors, they felt a sense of increased safety. In another department, when describing how their department had gained more security in the form of more locked doors, one participant said:

> *"During on-call hours, when you feel that no one should be able to enter now, it definitely feels worth it"* (Participant D2)

However, this sense of safety was also described as conditional. In situations where staff felt that PACS could be bypassed, for example through tailgating, or when doors remained open for practical reasons, the perceived level of security decreased. This suggests that perceived safety is not only influenced by the presence of security measures, but also by how reliably they function in practice and how they are used.

PACS play an important role in shaping this perception, but their effectiveness is closely tied to context, usage, and staff awareness.

Another safety-related issue that was brought up by several participants was the hygiene and infection risks in relation to hands-operated access systems. Participants highlighted that minimising physical contact with surfaces is important in healthcare environments, particularly when handling patients or equipment. They brought up the issue of having to touch the access cards every time they had to pass through a door, with the additional complication of having to touch the keypad when the personal code was required as well. This in turn led to workers having to sanitise their hands more often, which took more time away from other duties. One participant described the possibility of spreading infection in relation to the access cards and keypads as:

> *"There is no one cleaning them for us. So if you have an infection like the winter vomiting disease somewhere, then it is basically over"* (Participant AN1)

This quote highlights the issues with a PACS that relies on physical involvement and physical items in relation to controlling the spread of infections. However, some participants stated that sanitising their hands is a routine part of their workflow. As one participant said:

> *"... it is kind of ingrained in you [...] that you sanitise your hands everywhere. And I think people clean their access cards quite often too. We wipe down what we call contact surfaces every day, and that includes card readers and door handles"* (Participant AN3)

This indicates that there is variation among healthcare workers in how hygiene related to door interaction is perceived. While some participants expressed concern about having to touch access components, others did not view this as an issue, as hand sanitisation is an established part of their workflow routines.

Security and safety versus workflow trade-offs

In the interviews, healthcare workers consistently described how PACS introduced a trade-off between maintaining security and enabling efficient workflows. The most prominent findings were that security measures frequently disrupted workflow continuity in time-critical situations, that healthcare workers adapted through informal workarounds, and that staff continuously balanced security requirements against the need for efficient movement. While PACS are designed to restrict unauthorised access and protect patients, staff, and sensitive information, they also create friction in everyday work, especially in time-critical situations. A recurring issue was the reliance on access cards and repeated authentication across multiple doors. Participants described how access control is prevalent throughout the hospital environment, requiring staff to carry and use their access cards continuously. As one participant explained:

> *"It is locked everywhere. So you have to have your access card with you, otherwise you get locked in or locked out"* (Participant N1)

This creates a strong dependency on a physical item for access, which can disrupt workflows if the item is forgotten, lost, or stolen. This is particularly problematic in urgent or unpredictable situations. Staff described scenarios where they had to leave their current task immediately, for example in response to an emergency alarm elsewhere in the department, while forgetting, or not having time to retrieve their access card. In such cases, PACS can become an obstacle to action, as one participant described it:

> *"[...] it might be an emergency alarm somewhere and [you] drop everything and run. Then you can't get in anywhere, you're locked out. Because you need the access card if you don't have a tag"* (Participant N1)

This particular case was caused by the access cards in the hospital being used for access to electronic health records as well. This issue was something that several participants brought up; the fact that the access cards were being used for multiple purposes was the cause of many disruptions in their workflow. Several participants described situations in which they inserted their access cards into workstations to access electronic health records and other information and then forgot to retrieve them. As a result, they were unable to move freely within the facility, since the same access card was required for door access, leading to disruptions in their workflows. This illustrates how systems designed for controlled access may conflict with the need for rapid, flexible movements in emergency care. In even more critical situations, this conflict becomes even more explicit. One participant described how technical safety mechanisms in access systems could delay access to patients in urgent need of care:

> *"So then we have to consider the trade-off there. If we should go in and save lives or leave them lying there"* (Participant AN3)

The safety mechanism in question was a door sensor that prevented the door from opening if there was anything obstructing its way. This quote highlights a dilemma identified across interviews; security mechanisms are not always aligned with the realities of healthcare workflows, where immediate access can be essential to save lives. At the same time, staff described how they actively adapt their behaviour to manage this trade-off in practice. Informal workarounds, such as holding doors open for colleagues or allowing multiple people to pass through an access point on a single authentication, were commonly mentioned. For example, one participant described how it is common to hold doors open for other staff:

> *"One example could be that if you're two people, one goes ahead and holds the door open since it usually closes, so you can get through in one go"* (Participant N3)

While such practices improve efficiency, they may also weaken the intended level of security, which further illustrates how the effectiveness of PACS depends on how they are used in practice. Taken together, this suggests that current PACS are often designed with a primary focus on security, while workflow considerations are secondary, placing a lot of strain on healthcare workers to adapt, instead of the other way around. Regarding the closing speed of doors in different situations, one participant noted:

> *"Then you would like for the door to close quickly behind you. But not too quick, because I also want to be able to pass through with a bed if I have that"* (Participant PD1)

This illustrates the trade-off between security and workflow efficiency while highlighting the need for more flexible access systems that can balance security requirements with the demands of a fast-paced and unpredictable healthcare environment.

4.2.3. User Experience

This section presents the findings related to how healthcare workers experience and interact with PACS connected to usability and user experience. It focuses on subthemes discussing cognitive effort, system reliability, physical interaction, alignment with workflows, and user adaptation over time. Together, these themes highlight how access systems influence usability, workload, and overall user experience in complex healthcare environments.

Cognitive load and uncertainty

A recurring theme in the interviews relates to the cognitive effort required to interact with doors, particularly in situations where their functionality was not intuitive or consistent. The most important findings were that inconsistent door logic and design increased the cognitive effort required, that staff frequently had to consciously interpret how doors functioned rather than relying on routine behaviour, and that a trade-off existed between standardisation across departments and adaptation to local workflow needs.

Several participants described uncertainty regarding how to interact with doors, especially when encountering unfamiliar parts of the buildings. This was particularly evident among new staff, but was also mentioned by more experienced personnel when working across different departments or new buildings. The lack of standardisation in door design contributed to this uncertainty. Although there existed standards for an individual door, there was a lack of standardisation on a higher level across different departments. Participants highlighted that doors varied in terms of opening mechanisms, button placement, and direction of movement. This required users to actively interpret how to operate each door rather than relying on habit, which resulted in routine actions such as passing through a door involving hesitation or trial-and-error, increasing the cognitive load in already demanding work environments. However, the lack of standardisation across departments can partly be attributed to planners accommodating the specific needs and preferences of individual departments. As one participant who was involved in project management, noted:

> *"It varies depending on what the departments have requested. [...] if there is a door that needs to open faster or stay open longer"* (Participant AN4)

The possibility of adapting access systems to preferences within a department was highlighted as a positive thing by several participants. This introduces a trade-off between standardisation across departments to lower cognitive load for workers and accommodating the individual needs and preferences of different departments to increase efficiency. The issue of inconsistent door components was especially prevalent in newer buildings which contained an increased number of doors compared to older parts of the hospital. One participant working in the new part of the hospital described finding the corresponding card reader and door opener for the intended door as:

> *"People approach the door and then they start looking [for the card reader or the door opener]"* (Participant N2)

This illustrates how door interactions are not always intuitive, but instead require conscious attention, which may increase cognitive load and reduce overall efficiency. While experienced staff often develop routines over time, the initial cognitive burden remains significant and may contribute to stress, particularly in high-pressure environments like the ERs.

Frustrations with unreliable or aging systems

Another prominent theme concerns the frustration related to unreliable or aging access systems. Participants frequently described situations where access mechanisms, particularly keypads and door sensors, did not function as expected. These issues included delayed responses, missed inputs, or the need to repeat actions multiple times before the door would open. Such inconsistencies were perceived as disruptive, especially in situations where staff were under time pressure. The unreliability of these systems introduced uncertainty into otherwise routine tasks and often required users to adjust their behaviour. For example, participants described needing to slow down when entering codes to ensure that inputs were registered correctly. This did not only increase the time required to pass through doors, but also contributed to irritation and reduced trust in the system. One participant expressed this in relation to entering the personal code to the keypad:

"You enter your code and then [it] misses two digits, so you have to start over. [...] you can't be that quick" (Participant N3)

These types of issues were often attributed to older systems or lack of maintenance, suggesting that technological degradation over time plays a role in shaping user experience. While staff generally adapted to these limitations, the need to compensate for unreliable and aging systems was consistently described as a source of frustration and reduced usability.

Hands-occupied interaction challenges

A recurring issue highlighted by participants was the difficulty of interacting with access systems while carrying equipment or assisting patients. In many situations, healthcare staff approach doors with their hands occupied, for example when handling medical equipment or transporting patients. Under these conditions, the need to manually operate doors through keypads, buttons, or handles was described as problematic and inefficient. Participants noted that current access systems are often not designed with these situations in mind. Interacting with doors may require staff to temporarily release equipment, reposition themselves, or rely on assistance from colleagues. This introduces additional steps into the workflow and can disrupt tasks, particularly in time-sensitive situations. Participants described how such situations are common in routine work, where they frequently carry various items between rooms or departments. One participant described how a foot operated opener could help in their daily workflow:

"You approach with lots of things. Sometimes it would be easier to just have a button down there so you could press it with your foot and then enter" (Participant N2)

Participants highlighted some cases where door openers could be operated by foot, not requiring hand involvement. However, these were not the standard but rather deployed at access points where the need for hands-free interaction was crucial. This challenge was described in general terms by many participants, and it reflects a broader mismatch between system design and real working conditions. The need to manually operate doors while handling equipment introduces additional effort and may interrupt task flow. As a result, participants expressed a preference for systems that reduce the need for manual interaction, such as automatic doors or alternative activation mechanisms.

Mismatch between design and real workflows

This subtheme concerns the misalignment between the design of the access systems and the actual workflows of healthcare workers. The most significant findings were that PACS were often perceived as insufficiently aligned with real healthcare workflows, that design decisions were described as being made from separate non-clinical perspectives rather than across departments, and that this mismatch contributed to reduced usability in everyday work. Participants described how access systems are often implemented based on the needs of several units such as logistics, fire safety, and property developers rather than reflecting how staff move and work across departments in practice. Although some preferences from the departments are taken into account when planning PACS, as mentioned before, most of the specific needs are accommodated after implementation. This lack of coordination with user needs beforehand results in systems that do not adequately support real working conditions. In particular, participants highlighted that door functionality and placements are not consistently designed with cross-departmental workflows in mind, leading to inefficiencies and unnecessary friction when moving between departments in the hospital. One participant highlighted how design decisions are often made from a limited perspective of one unit in planning:

> *"They have built this based on their own organisation"* (Participant N3)

This illustrates the trade-off between customisation within a department for specific needs and cross-departamental design and implementation. As a result, staff must adapt to systems that do not align with their actual needs, rather than the systems supporting their work. Together, these findings suggest that PACS are frequently developed in isolation, without sufficient consideration of how different roles, departments, and workflows interact in practice. This mismatch contributes to both inefficiencies and reduced usability, as staff are required to navigate systems that differ between departments and do not reflect the realities of their workflows.

Adaption and normalisation

A notable theme in the interviews relates to how healthcare workers adapt to existing access systems and gradually normalise inefficiencies in their daily work. The most important findings were that healthcare workers gradually adapted to and normalised disruptive system behaviour in PACS over time, that informal workarounds became integrated into workflows, and that these adaptations could hide underlying usability, security, and safety issues rather than resolving them. In contrast to viewing access-related challenges as exceptions, participants described how they become integrated into routine behaviour over time. Staff often develop personal strategies and habits to navigate access systems efficiently, even when these systems are perceived as suboptimal. This includes learning specific issues with certain door components, adjusting movement patterns based on how doors typically behave, and most notably, propping up doors that are supposed to be closed. As a result, interactions that may initially require conscious effort become automated through repetition. One participant described it as:

> *"It's kind of in your muscle memory, you just do"* (Participant AN2)

This indicates that users adapt to system limitations rather than expecting the system to adapt to their needs. While such adaptation can reduce the immediate cognitive burden, it also risks hiding underlying usability and efficiency issues. Over time, inefficiencies may become accepted as part of normal workflow, reducing the likelihood that they are identified and thereby addressed. This normalisation process suggests that the perceived functionality of PACS does not necessarily reflect their actual performance. Instead it reflects the extent to which users have adjusted their behaviour to compensate for system shortcomings. As a result, the impact of inefficient or poorly designed systems may be underestimated, especially when relying solely on user familiarity or reported ease of use. Normalisations and workarounds can also affect security and safety aspects when doors that should be closed for fire safety or security reasons are being propped up. One participant described propping up doors in relation to fire safety as:

> *"So it has almost become a work environment issue, because they prop doors open in the wrong way. In the end, it becomes dangerous, both in terms of fire safety and security"* (Participant AN4)

Another common talking point in the interviews was how many doors are individually adapted to different situations. This is especially prevalent in newer buildings, where doors are not working optimally when implemented, but are later adjusted to fit the needs of that specific door. The most common aspects that were changed were the door speed and the duration for which the door stayed open. However, this could only be changed to a fixed speed and duration, and could not change depending on the situation. Taken together, these findings suggest that healthcare workers continuously adapt to the limitations of existing PACS, but that this adaptation may mask underlying usability and workflow issues while also potentially introducing new security and safety risks.

4.3. Field Observations

The field observations focused on employee entries requiring access card authentication and included two primary use cases; personnel passing through the door without equipment and passage while transporting a hospital bed. The observations intended to examine how access points are used in practice and to obtain data on the time required to pass through them. The findings are divided into qualitative results of user behaviours and door functionalities, and quantitative results of the time measurements.

4.3.1. Qualitative Results

Several door and user behavioural patterns were identified during the field observations. The second criterion regarding saturation, described in Section 3.3, was reached in all three observation studies. A selected sample from the results from the field observations can be seen in Table 2 below. The column *Staff/staff and patient* describes whether the observed passages involved only staff or staff transporting a patient. *Time [s]* refers to the measured passage time, while *Understanding* indicates whether the user appeared to understand how to interact with the door system. *Equipment*, *In/out*, and *Automatic door opener* describe whether equipment was involved, the direction of movement, and whether the automatic door opener button was pressed or not. Finally, *Notes* and *General notes* contain observations related to the specific passage or general context. A complete table of the recorded data can be found in Appendix D.

Table 2. A selected sample of the results from the field observations

Staff/staff + patient	Time [s]	Understanding	Equipment	In/out	Automatic door opener	Notes	General notes
Staff	9	Yes	None	In	No	Ensured no one tailgated	
Staff	4	Yes	Scooter	Out	Yes	Used a scooter	
Staff	6	Sort of	None	In	No	They seemed to forget where the automatic door opener was located, stopped and looked around.	
Staff + patient	20	Yes	Hospital bed	In	Yes	Used code, needed to walk to the door and then backtrack, while also waiting for the door to open.	Door stays open for 30 seconds when using the automatic door opener
Staff + patient	30	Yes	Hospital bed	In	Yes	Rang the door bell, did not seem to have their card. Waited for others to pass by before going in. A non-staff person tailgated into the department after this group passed through.	

Staff	15	Sort of	None	In	Yes	Got stuck between the doors because they wanted to hurry.
Staff	5	Sort of	None	In	No	Tailgated behind relatives entering
Staff + patient	13	Sort of	Hospital bed	In	Yes	Sensor interference when staff reached out their hand, did not seem like they understood how the sensor worked. The soor stalled a bit but not too much
Staff	13	Yes	Hospital bed	Out	Yes	Ensured no one tailgated
Staff x2	9	Yes	None	In	Yes	Had to walk around the door

Observed workflow disruptions

Several patterns that introduced disruptions in door passage workflows were identified during the field observations. One recurring pattern was sensor interference when the doors were opening. All automatic doors had a sensor on the top that stopped the door if something obstructed its way. This often caused confusion, as users did not understand why the door stopped. This was especially noticeable for users in a rush, since walking faster or jogging caused them to approach the door more quickly and trigger the sensor. As a result, they often had to stop or adjust their position, which interrupted the flow of movement. This aligns with the interview findings, where participants described having to stop, step back, or wait due to overly sensitive sensors, particularly in time-critical situations.

In the interviews, the door interactions were described as illogical and inconsistent, where staff had to adapt to different placements of buttons and readers. This was reflected in the field observations as well, where the placement of the card reader extended the passage time. The reader was most commonly placed on one side of the door, meaning that if a worker approached from the other side, they had to walk past the door to reach the reader and then backtrack. This added extra steps and increased the time required to pass. When the door opened towards the user, the situation became even more complicated, as they also had to move around the door while trying to avoid triggering the sensor.

This became an even bigger issue when patient beds were involved. In some cases, it was difficult for staff to reach the reader in an efficient way. If only one worker was transporting a bed, they usually stopped it in front of the door, walked to the reader to authenticate, and then returned to the bed. This interrupted the movement and is one of the reasons why the passage time with a bed was significantly longer than without equipment, at 15.31 seconds on average compared to 5.92 seconds without equipment, as shown in Table 3. These observations correspond with the interview findings, where hospital staff described patient transport as particularly inefficient due to door design. For example, stopping in front of the door, walking to the reader and going back was explicitly mentioned. The direction in which the door opened further contributed to these delays. The field observations showed that when doors opened towards the approaching bed, the bed itself sometimes obstructed the sensor area, causing the door to stop or remain partially closed. This aligns with interview findings, where staff described the lack of floor markings or other visual cues indicating how doors open. The participants also described how door interactions relied on previous experience rather than design, especially during patient transport. The workers also explained how they sometimes had to learn through trial-and-error how close they could position a bed before the sensors reacted. As a result, staff were often unsure where to position the bed during authentication and opening. To prevent the door from stopping, they sometimes had to stop the bed even further away from the door, which increased the walking distance and added additional time to the passage.

It was also observed that staff sometimes waited to make sure no one entered behind them before the door had closed. Since the doors remained open for a relatively long time, which led to additional waiting time and further reduced workflow efficiency. This behaviour was reflected in the interviews as well, where staff often described staying by the door to ensure that no unauthorised person can enter restricted areas.

Observed security vulnerabilities

The observations also revealed several security vulnerabilities related to how the doors function in practice. When staff used the automatic door opener, the doors stayed open for a fixed amount of time regardless of whether someone had passed through them or not. The opening time varied between 25 and 35 seconds for the observed doors. As shown in Table 3, the average passage time was significantly shorter, at around 6 seconds for passages without equipment, meaning that the doors were left open for an additional 18 to 28 seconds. This created a time window where unauthorised access could occur. This supports interview findings where healthcare staff expressed concerns about doors remaining open too long, and tailgating was described as a recurring issue. Several instances of tailgating were actually observed during the field observations. Most involved personnel passing through doors that were already open, but one case included a non-staff person entering behind an authorised user. This happened when a worker did not stop and wait to ensure that the door closed behind them, allowing the other person to enter unnoticed. However, these observations also nuance the interview findings, as tailgating was often framed as a significant concern, but many of the observed cases involved authorised staff. This suggests that tailgating may not only be understood as a security issue, but also as a behaviour emerging from efficiency-driven practices, such as allowing multiple staff members to pass through a door at the same time.

Since the PACS rely on physical access cards or tags, there is also a risk of users forgetting or misplacing them. One such instance was observed, where a worker appeared to not have their access card and instead rang a doorbell, requiring another staff member to open the door. Although this was only observed once, it shows how access control can be bypassed in practice. It also highlights how reliance on physical credentials can lead to additional use of staff time and resources, as staff are required to interrupt their own tasks to assist colleagues who are unable to access secured areas. This identification functionality creates both security and safety concerns, but also leads to inefficient use of staff time. If a person tailgates with malicious intent, it can pose risks to both patient and staff safety, as well as to sensitive patient information. Even when there is no malicious intent, the situation may still require staff to respond, which takes time and resources. This reflects the trade-off between maintaining security and ensuring efficient workflows that was described in the interview findings.

Observed user adaptations

In response to the system limitations identified in the previous section, several types of user adaptations were observed. In some cases, sensor interference caused users to force their way through half-opened doors, which could potentially damage the components. This suggests that users prioritise maintaining their workflow rather than waiting for the system to function as intended. Forcing the doors was mentioned in the interviews, but it was only described as a potential action in urgent situations when the system was perceived as a hindrance because they were too slow. However, in the field study, several instances of this user behaviour were observed.

Users also adapted their movement in response to the placement of the card reader and door automation, relying on experience rather than intuitive interaction. These adaptations included changing how they approached doors to avoid sensor interference. This aligns with interview findings describing how staff learn to navigate doors through experience, rather than relying on consistent design. In the interviews, participants described that patient transport often involves additional effort and interruptions, a pattern that was also observed in practice during patient transport. This further indicates that the system does not fully support situations where users have their hands occupied.

Another observed behaviour was that staff waited to ensure that no one entered behind them before the door had closed. This shows that users take an active role in maintaining security, rather than relying entirely on the system. This supports the interview findings where staff described monitoring doors and taking responsibility. However, as described in the observed security vulnerabilities, the majority of staff passing through the door did not wait for it to close, showing that users do not always adapt to the system design. Finally, the confusion caused by sensor interference suggests that the interaction is not intuitive, as users often had to stop or adjust their behaviour when approaching the door.

4.3.2. Quantitative Results

The time required to pass through an access-controlled door was measured for two different cases; passage without equipment and passage while transporting a hospital bed. All observation studies were conducted on doors that required authentication through an access card, and in some cases both an access card and a personal code. The results are presented in Table 3 below. For passages without equipment, the average time required to pass through a door was 5.92 seconds. The observed variation was moderately high with a standard deviation of 2.49 seconds compared to the mean. This indicates that passing times varied considerably between observations, suggesting that some interactions with the doors were relatively smooth while others involved significant delays or interruptions. The number of observations for this case was 59, fulfilling the criterion of a minimum sample size of 47 observations, as described in Section 3.3.

For passages involving the transportation of a hospital bed, the average time required to pass through a door was 15.31 seconds, with a standard deviation of 5.30 seconds. Compared to passages without equipment, this represents an increase of 9.39 seconds on average. The larger standard deviation also indicates greater variability in these situations, suggesting that transporting a patient bed introduced additional complexity and inconsistency to the interaction. However, only 13 observations involving patient beds were recorded, which means that these results should be interpreted with caution. Due to the lower number of observations, the findings are less statistically reliable and should primarily be viewed as indicative rather than fully representative. Still, the observed trend clearly suggests that patient transport has a substantial impact on door passage times.

Table 3. Passage times through an access-controlled door

Case	Mean time [s]	Standard deviation [s]	Number of observations (n)
Without equipment	5.92	2.49	59
Transporting a hospital bed	15.31	5.30	13

The quantitative findings support the qualitative results by showing that PACS can have a measurable impact on workflow efficiency, particularly in situations involving transportation of patient beds. Although an individual delay of several seconds may appear minor in isolation, the repeated occurrence of these interactions throughout a work shift means that the cumulative effect may become significant. This was also reflected in the interviews, where healthcare workers described having to repeatedly stop, wait, reposition themselves or equipment, or adjust movement around doors during passages through access points.

4.4. Design Implications for Future Access Solutions

The following design implications are derived from the systematic literature review and the empirical findings and aim to inform the design of future smart access solutions in healthcare environments. The suggestions are formulated as empirically grounded design principles that highlight key functional needs rather than proposing specific technical implementations, but illustrative examples are included to clarify how these principles could be applied in practice.

DI1. Support continuous and uninterrupted hospital workflows

Several subthemes in the empirical interview findings, such as *Door-related delays in workflows* and *Excessive door passages* (Section 4.2.1), together with observed workflow disruptions, illustrate how current PACS contribute to workflow delays and interruptions. These disruptions were described as negatively affecting workflow continuity and increasing stress and frustrations during routine tasks. This indicates that future access solutions should enable continuous and uninterrupted hospital workflows. For example, smart access solutions that leverage contextual or intent-aware technologies, as described in Section 2.3, could allow doors to respond proactively to approaching staff and ongoing movement, reducing the need for explicit interaction and unnecessary stops. Such systems could potentially identify approaching staff, interpret movement patterns, and adapt door behaviour accordingly, in order to support more efficient movement through the hospital environment. In addition, future systems could potentially coordinate door behaviour along transport routes or temporarily prioritise workflow continuity during emergency situations, enabling more continuous movement in time-critical workflows. For example, future access solutions could support continuous movement by coordinating multiple doors along transport routes based on a single authentication or ongoing workflow activity. Similar to the emergency caesarean section workflows described in the interviews (Section 4.2.1), systems could temporarily create prioritised movement pathways where doors and elevators automatically coordinate to support uninterrupted patient transport and emergency response workflows.

DI2. Enable hands-free and low-friction interaction

In the subthemes *Hands-occupied interaction challenges* (Section 4.2.3) and *Inefficient handling during patient transport* (Section 4.2.2), healthcare staff described difficulties interacting with PACS while carrying equipment or transporting patients in beds. This is further supported by the time differences found in the observational field study, where door passage time took approximately 10 seconds longer on average when staff were transporting patients. Transporting patients or equipment is an integral part of healthcare workflows, and should therefore be supported by access solutions that minimise the need for manual interaction and unnecessary interruptions, enabling smoother and more continuous movement through the hospital environment. Future access solutions should support hands-free and low-friction interaction in situations where healthcare workers have their hands occupied or limited ability to interact with physical interfaces. Such systems could include proximity-based authentication, long-range RFID technologies, or context-aware door behaviour, as outlined in Section 2.3. This could potentially reduce the need for manual actions during movement and better support transport workflows. For example, long-range authentication could allow authorised staff to be identified while approaching a door, enabling authentication and door preparation to occur before reaching the access point. However, RFID technology might not be the best option for this use, as it has some limitations at range. Instead, technologies like bluetooth might prove to be more appropriate. Also, wearable authentication devices, foot-operated controls, or automatic detection of beds and equipment could potentially reduce the need for repeated manual interaction with access cards, keypads, buttons, and door handles. Such solutions could allow staff to move more naturally through the environment without interrupting ongoing tasks or disrupt workflows while transporting equipment through doors. Reducing physical interaction may have additional benefits beyond efficiency. Several participants described concerns related to hygiene and the risk of spreading infections associated with repeated touching of access cards and keypads throughout the workday. Enabling more touchless interaction could therefore not only support workflow continuity, but also reduce unnecessary physical contact with shared surfaces.

DI3. Reduce cognitive load through consistent door logic and interfaces

Healthcare staff described how inconsistent door logic, interface design, and placement of access features increased cognitive effort during workflows. Across the subthemes *Cognitive load and uncertainty* (Section 4.2.3) and *Inconsistent door logic and interface design* (Section 4.2.1), participants described having to actively search for card readers or door openers, as well as interpreting how individual doors would behave, and adapt to variations between departments and locations. These interactions were described as disruptive, particularly in high-pressure situations or when moving between different areas. This indicates that future access solutions should prioritise consistent and predictable door logic and interfaces across hospital environments in order to reduce cognitive load. The findings suggest that consistency should not only concern the technical behaviour of the doors, but also the placement and visual design of access components. For example, future systems could standardise the placement of card readers and door openers across departments. However, the findings indicate that achieving standardisation across departments is challenging due to the differences in how departments operate and use physical spaces. Departments vary in terms of workflow pace, patient types, security requirements, transportation needs, which creates different demands on access systems. As a result, the design of PACS involves balancing the benefits of standardised and predictable interactions with the need to accommodate specific workflows within different departments. Future solutions could potentially support both standardisation and local adaptation by adjusting authentication and door behaviour based on user roles, movement patterns, and contextual information, rather than relying solely on department-specific configurations. For example, doors could respond consistently to nurses across departments while still adapting opening speed, opening duration, or authentication requirements for department-specific movement patterns. Such context-aware behaviour could reduce the cognitive load for healthcare workers while also reducing the need for departments to manually adapt individual doors, as the system itself could dynamically adjust to different situations and operational contexts.

DI4. Balance security measures with real hospital workflows

The empirical findings illustrate a recurring tension between security requirements and maintaining efficient hospital workflows. The subthemes *Security and safety versus workflow trade-offs* (4.2.2) and *Risks of unauthorised entry* (Section 4.2.2), together with the observed security vulnerabilities, highlights how the safety and security features of the PACS, such as repeated authentication, slow door behaviour, and safety mechanisms, often disrupted time-critical work and continuous movement. In practice, staff frequently adapted their behaviour through workarounds, such as holding doors open or allowing multiple people to pass through a door on a single authentication, in order to maintain workflow efficiency. These adaptations illustrate the mismatch between intended security design and real-world use. This indicates that future access solutions should balance security measures with the realities of hospital workflows, supporting both safety and efficiency. Although regulatory and safety requirements constrain access design, the empirical findings indicate a need for solutions that accommodate different workflow conditions and urgency levels without relying on staff workarounds or compromising security. For example, access systems could better distinguish between routine movement and high-risk situations by using contextual data such as user role and movement patterns, or the presence of patient beds and medical equipment, allowing security measures to be adjusted dynamically without relying on staff to compensate for the system in practice.

DI5. Increase transparency and feedback in door interactions

The findings across the subthemes *Cognitive load and uncertainty* (Section 4.2.3), *Frustrations with unreliable or aging systems* (Section 4.2.3), and *Observed workflow disruptions* (Section 4.3.1), indicate that healthcare staff sometimes struggled to understand how doors would respond during interaction, particularly when systems behaved unpredictable or provided no clear feedback. In these subthemes, participants described situations where doors stopped unexpectedly, failed to respond, or required users to step back and reattempt authentication. This lack of transparency increased hesitation and repeated interaction which in some cases led to doors being forced open or informal workarounds. These findings suggest that future access solutions should make system behaviour more transparent during interaction, providing clear feedback that can help users understand what the system is doing and how to proceed. This could include clearer visual guidance regarding door opening direction and positioning, more informative interface layouts, and feedback mechanisms that communicate door status or authentication progress. Future context-aware access solutions, as discussed in Section 2.3, could further support this by making system behaviour more transparent, communicating why a door opens, waits, or stops in a given situation.

DI6. Design for adaption without relying on workarounds

The findings show that healthcare staff frequently adapted their behaviour to compensate for limitations in the existing PACS. Across the subthemes *Dependence on coordination and teamwork* (Section 4.2.1), *Security and safety versus workflow trade-offs* (Section (4.2.2), and *Adaptation and normalisation* (Section (4.2.3), participants described how informal workarounds, such as holding doors open, coordinating colleagues to manage access points, and propping doors open, became normalised parts of everyday work. Several of these user adaptations, such as holding doors open, were also directly observed during the field observations. While these adaptations allowed workflows to continue, they often shifted the responsibility for efficiency and safety from the system to the users, and in some cases introduced new security and safety risks. This suggests that future access solutions should be designed to accommodate necessary flexibility and variation in real hospital workflows, enabling adaptation within the system itself rather than relying on staff workarounds. For example, adaptive access solutions could accommodate variations in transport or coordination by adjusting door behaviour dynamically. Systems could also better support patient transport, teamwork, and hands-occupied movement through more intuitive door behaviour, improved placement of interaction points, and reduced need for manual coordination. Furthermore, future systems could enable this context-aware adaption through the detection of workflow-related indicators. For example, the presence and detection of face masks, as mentioned in Section 2.3.1, or other protective equipment could potentially signal that a specific clinical workflow or situation is taking place, allowing the system to adapt door behaviour accordingly.

DI7. Ensure secure closure and access control after passage

The subthemes *Risk of unauthorised entry* (Section 4.2.2), *Security and safety versus workflow trade-offs* (Section 4.2.2), and *Observed security vulnerabilities* (Section 4.3.1) show that door behaviour after passage is a critical aspect of how security is maintained in everyday work. Healthcare staff described how they often feel the need to stay by doors to ensure that they close properly or to prevent unauthorised individuals from following them into restricted areas. This was further supported by the field observations, where doors frequently remained open for a fixed duration (additional 18 to 28 seconds) that exceeded the actual passage time, creating opportunities for tailgating. Here, staff were observed taking responsibility for maintaining access control by pausing their movement to ensure secure door closure after passage. These findings indicate that future access solutions should ensure secure door closure after passage maintaining security through system behaviour. For example, adaptive access solutions could adapt door closing behaviour based on actual passage completion rather than fixed timeouts, reducing the risk of unauthorised entry without disrupting hospital workflows. Such systems could potentially use context-aware sensor technologies to detect movement patterns, completed passages, or the transport of equipment, allowing door closing functionality to adapt depending on the situation. As described in Section 2.3.1, smart doors could provide an active approach to take immediate action during a security or safety threat. This may reduce the need for healthcare workers to monitor doors after passage, shifting back the responsibility for maintaining security from the user to the PACS itself.

5. Discussion

This chapter discusses the findings of the study in relation to previous research and the purpose of the study. The discussion focuses on broader topics emerging from the results, particularly regarding the relationship between workflow efficiency, security and safety, and user experience. The chapter further discusses how healthcare workers' perceptions of PACS vary depending on the healthcare context and reflects on the methodological limitations of the study. Finally, the chapter concludes by summarising the main findings and contributions of the thesis.

5.1. Existing Research on Healthcare Workers' Perceptions of PACS

The findings from the first phase indicate that research on PACS in healthcare environments remains limited and fragmented. Existing studies largely discuss access systems indirectly, often in relation to broader topics such as patient safety, violence prevention, or infection control, rather than examining physical access systems as a primary subject of investigation. As a result, healthcare workers' own experiences and perceptions of these systems remain overlooked in current literature. A prevalent focus within previous research concerns security and safety where several studies describe physical access control measures such as locked doors, restricted areas, and monitored entrances as necessary for protecting patients, staff, and sensitive environments. This was particularly evident in psychiatric and emergency care settings, where access control was associated with preventing absconding, reducing violence, and improving staff safety (MohammadiGorji et al., 2021; Searby et al., 2023). Similar perceptions were expressed by participants in the interviews, where locked doors and restricted access were described as important for maintaining safety and preventing unauthorised entry. These studies suggest that healthcare workers often accept restrictive access measures when they are perceived as necessary for safety. At the same time, the literature also highlights limitations in the effectiveness of such systems. Searby et al. (2023), for example, showed that unauthorised exits still occur despite locked doors, illustrating how security systems may fail when actual human behaviour differs from intended use. This aligns with the findings from the interviews and field observations, where healthcare workers both described and demonstrated workarounds such as tailgating and propping doors open in order to maintain workflow efficiency. While these adaptations supported efficiency, the findings showed that they could also weaken intended security measures and introduce additional safety and security vulnerabilities.

Compared to security and safety, workflow efficiency and usability related to PACS receive significantly less attention in existing literature. While previous studies acknowledge that the physical environment can influence healthcare workflows, PACS are often treated as secondary components within broader discussions regarding logistics. Existing studies mainly focus on specific design features, such as automatic doors, sliding doors, or room layouts, rather than examining the overall experience of interacting with PACS. For example, Aghaei and Bayramzadeh (2024) identified delays caused by automatic doors in trauma environments, while Bayramzadeh et al. (2018) discussed how door types affected equipment transport in operating rooms. Similarly, Van Heel, Herweijer and Van Oel (2024) highlighted how design decisions intended to improve privacy and safety could create new workflow challenges for staff. These findings are reflected in the interviews, where healthcare workers repeatedly described how slow door openings, sensor interference, and poorly positioned card readers disrupted workflow continuity. The field observations further supported these findings by showing how staff frequently had to stop, reposition themselves, or backtrack when passing through a door, especially when transporting patients in beds.

Another important finding from the literature review concerns the mismatch between intended design and actual use. Several studies describe how healthcare environments are designed according to safety principles and regulatory requirements, while the resulting systems are experienced differently in practice by healthcare workers. Van Heel, Herweijer and van Oel (2024) particularly illustrate this through the trade-offs between privacy, visibility, and staff workflows in patient room design. Their findings show how systems intended to support one objective may unintentionally create new usability challenges for workers. Similar patterns were identified in the interviews and field observations. For example, doors designed with safety mechanisms such as motion sensors and delayed closing functions were intended to prevent injuries, but were often experienced as disruptive during urgent movement and patient transport. Additionally, access systems designed to strengthen security were observed to create workflow interruptions, workarounds, and situations where staff adapted their behaviour by holding doors open, forcing half-open doors, or allowing multiple to pass through the door on a single authentication. The field observations expanded on this and showed how users frequently adjusted their movement patterns to compensate for unclear door logic, poorly positioned readers, and sensor interference.

Overall, the systematic literature review suggests that previous research has primarily focused on intended functions of PACS, particularly regarding security and safety. Less attention has been given to how these systems are experienced, interpreted, and adapted to in practice by healthcare workers.

5.2. Healthcare Workers' Perceptions of PACS

The findings of the second phase, consisting of the interviews supported by the observational field studies, suggest that PACS are an important part of healthcare workers' daily workflows, and that they affect the way hospital work is organised and carried out in practice. The empirical findings indicate that efficiency, security and safety, and user experience should not be understood as separate or independent aspects of PACS in healthcare environments. This extends previous research, which has largely examined security, safety, and workflow efficiency separately. While studies such as van Heel, Herweijer and van Oel, (2024) and Aghaei and Bayramzadeh (2024) identify specific workflow consequences of design decisions, the findings of this study suggest that these aspects are closely interconnected in practice. Design features intended to optimise one aspect often have direct consequences for the other, which is evident in how security- and safety-related features in doors introduce workflow disruptions and increase cognitive and physical effort for healthcare workers. This is, for example, illustrated by how access system features such as authentication steps, sensors, and door opening behaviour, can delay workflow continuity in time-critical situations. This highlights a conflict between maintaining security requirements and acute demands.

Overall, the findings suggest a mismatch between how healthcare workers actually carry out their work in practice, and how the PACS are designed. This is evident both in subthemes where healthcare workers explicitly described that the systems are not designed with their work practices in mind, and in the identified challenges that reveal gaps between system functionality and clinical workflows. Examples of this mismatch are illustrated in how the PACS features interfere with patient transport, frequent movement, and hands-occupied work, where door behaviour slows down those processes instead of improving them. Over time, this mismatch prompted some staff to adapt their behaviour in order to maintain efficient workflows. Similar patterns have been identified in previous research, where healthcare workers adapted environments designed according to safety principles to better support work practices (van Heel, Herweijer and van Oel, 2024). However, while previous studies primarily discuss such adaptations in relation to environmental design, the findings of this study show that similar behaviours occur specifically around PACS, suggesting that access systems themselves become objects of adaptation. One possible explanation for the mismatch is that the PACS appear to be designed primarily from a technical, regulatory, and security perspective, rather than from the perspective of healthcare workflows. Healthcare work is characterised by continuous movement, multitasking, interruptings and, in some settings, time-critical coordination, where staff frequently move while transporting patients and carrying equipment. In such environments, even minor interruptions may have significant consequences. This tension may also be understood in relation to healthcare environments functioning as complex sociotechnical systems, where workflows, technologies, regulations, and human behaviour are closely interconnected. In such environments, optimising one aspect of a system often creates unintended consequences elsewhere. As mentioned previously, security mechanisms intended to prevent unauthorised access may simultaneously reduce workflow efficiency, increase cognitive effort, or encourage workarounds in practice. Similarly, safety-oriented door behaviour designed to prevent physical injury may introduce delays during urgent movement. The findings therefore suggest that PACS cannot be optimised only from one perspective, since changes intended to improve efficiency, security, or user experience continuously influence other aspects of healthcare processes.

Furthermore, the findings indicate that perceptions and consequences of PACS vary depending on the departmental context and the professional role of the user. In more fast-paced settings, access-related delays were experienced as particularly disruptive, where staff in less time-critical contexts described fewer immediate consequences. These differences can be linked to varying security requirements between departments. In environments with higher security demands and a larger number of locked doors, healthcare workers interacted more frequently with access systems, which increased the cumulative impact of them. While individual door interactions and passages may appear minor, the findings suggest that their cumulative effect becomes significant in healthcare environments. Staff interact with doors continuously throughout their shifts, meaning that small delays and interruptions are repeatedly experienced during their work. The experience of PACS was therefore shaped by how many doors were controlled, how many were kept locked or unlocked, and what type of access system was in use, in addition to the type of work performed. This also indicates that the consequences of PACS are dependent on the context in which they are used. The differences between departments will be further discussed in Section 5.3.

The findings also point to the fact that healthcare workers' perceptions of safety and security is closely tied to everyday work practices, rather than relying solely on PACS. While security measures were generally viewed as important, they were often evaluated in relation to their impact on workflow. In practice, efficiency and the ability to act quickly were at times prioritised over strict compliance to secure access procedures. This is illustrated by the occurrence of tailgating, which was observed as a recurring behaviour among authorised staff. The observations showed that staff often needed to remain by doors to ensure that they closed properly, indicating that responsibility for maintaining security was at times transferred from the system to the user. This also created periods where doors remained open unnecessarily, increasing the risk of unauthorised entry and placing sensitive patient information at risk. At the same time, healthcare workers have to spend additional time and energy monitoring doors and addressing and preventing tailgating, transferring both security responsibility and resource costs to staff. This behaviour further illustrates how efficiency, security, and user experience interact in practice, as healthcare workers actively compensate for system limitations in order to balance security requirements with their workflows.

Overall, the findings suggest that PACS in healthcare environments are often shaped by technical, regulatory, and security-related priorities, while the practical realities of healthcare staffs' work receive less attention in the design process. PACS can be said to shape movement patterns, coordination practices, and staff behaviour within healthcare environments. The study therefore highlights the importance of viewing PACS not only as a purely technical solution, but as a complex system embedded within healthcare workflows.

5.3. Contextual Differences between Healthcare Departments

The findings indicate that the role of PACS differ substantially depending on the healthcare context in which they are implemented. While several challenges and perceptions were recurring across departments, the significance and impact of these issues varied depending on the workflow pace, movement patterns, and security requirements. This suggests that PACS in healthcare environments has to be considered in the context of which they are intended to operate. While previous research has largely focused on specific healthcare settings, such as psychiatric care, emergency departments, or operating theatres, the findings of this study suggest that the consequences of PACS are highly dependent on workflow context, movement intensity, and security requirements. This indicates that findings from one healthcare environment may not be directly transferable to another, highlighting the need for more context-sensitive approaches to the design and implementation of PACS.

One of the clearest contextual differences concerns the pace and predictability of the work to be performed. In ERs, where patient flows were described as unpredictable and time-critical, workflow interruptions caused by PACS were experienced as particularly problematic. Delays related to authentication, slow door openings, or sensor interference were mentioned not only as inefficiencies, but also as potential risks in urgent situations where rapid movement was essential. For example, ERs sometimes handle situations where patients require immediate surgery or other time-critical care. In these situations, healthcare workers may need to move rapidly through multiple access points while transporting patients and equipment. ERs were also described as environments with elevated security concerns due to the possibility of violent incidents, threats, or patients connected to shootings and other criminal activity. In such contexts, stricter access control measures were perceived as more necessary in order to protect staff, patients, and sensitive areas. In comparison, staff in surgical departments and healthcare centers generally described more structured workflows with fewer immediate consequences of interruptions, even though similar usability and workflow issues were still present. These environments were generally described as slower-paced and more open. As a result, workflow disruptions and usability issues associated with door interactions were perceived as less significant in slower-paced and more structured environments.

The findings further suggest that departmental differences in perceived security risks influence how PACS are experienced and accepted by healthcare workers. Concerns related to threats and violence were primarily expressed by participants working in ERs and healthcare centers, where staff described greater exposure to unpredictable situations and aggressive behaviour. In comparison, participants working in surgical departments generally described fewer immediate security concerns and mentioned threats and violence to a lesser extent. This may be related to the fact that ERs and healthcare centers are often the first point of contact for patients entering the healthcare system, resulting in a larger flow of unknown individuals and more unpredictable situations. Surgical departments, in contrast, are typically located further within the healthcare environment and require an appointment with another department before arriving there. Participants working in environments associated with threats or violence described restrictive access measures as more necessary and justified. In these departments, locked doors and stricter authentication procedures were more strongly associated with feelings of security and safety. At the same time, these environments also involved more frequent interaction with PACS, increasing the cumulative burden of repeated authentication, interruptions, and cognitive effort. This highlights how security requirements and workflow demands become especially integrated in departments with both high movement intensity and elevated security concerns.

Another contextual difference relates to how departments adapt and configure PACS locally. The findings showed that doors were often individually adjusted depending on departmental needs, for example through changes in opening speed or opening duration. While such adaptations may improve local workflows, they also contributed to inconsistencies between departments, increasing cognitive load when staff moved between different areas of the hospital, especially for new staff. This illustrates the difficulty of balancing standardisation with local adaptation in healthcare environments, which highlights the need for context-aware door behaviour. PACS capable of adjusting its behaviour and functionality based on user roles and context could better accommodate the varying workflow and security requirements between departments. The findings further indicate that the technological advancement of PACS varied considerably both between hospitals and within different parts of the same hospitals. These differences contributed to variations in how healthcare workers experienced PACS in practice. While newer systems often supported more efficient movement and advanced functionality, they also introduced challenges related to inconsistent door logic, increased system complexity and uncertainty. This suggests that contextual differences and user experiences were significantly affected by the technological maturity and implementation of these systems.

5.4. Methodological Reflection

This study aimed to explore healthcare workers' perceptions of PACS in healthcare environments through a combination of a systematic literature review, semi-structured interviews, and field observations. The use of multiple methods enabled triangulation, where findings from one method could be compared and reinforced through another. For example, themes identified in the interviews, such as workflow interruptions, tailgating concerns, and user adaptations, were also observed during the field studies. Combining qualitative interview data with direct observations therefore strengthened the findings by allowing both perceived and observed behaviours to be analysed together.

Rather than focusing solely on technical performance or security requirements, the chosen methodology enabled an investigation of how healthcare workers experience and interact with PACS in their daily work. The observational field study both supports and nuances the interview findings. While several issues described in the interviews, such as sensor interference and inefficiencies during patient transport, were clearly observed in practice, other aspects were less visible. For example, experiences of stress and frustration were primarily captured in interviews, as these cannot be directly observed. Also, certain issues discussed by participants, such as problems related to unreliable or aging systems, were not directly observed during the observation sessions. This may be related to the specific locations selected for the observations or the difficulty of observing infrequent events during limited observation periods.

Finally, as with all qualitative thematic analyses, the findings are influenced to some extent by the researchers' interpretations of the data. The identification of themes, categorisation of findings, and interpretation of meaning are influenced by the researchers' perspectives. To reduce this risk, findings were compared across interviews, observations, and literature, and themes were developed iteratively throughout the analysis process.

5.5. Limitations

Several limitations of this study should be acknowledged. First, the study was conducted within three hospitals belonging to the same regional healthcare organisation. Although the hospitals differed in many aspects, they still operated within similar organisational structures and regulations. The findings should therefore not be understood as statistically generalisable to all healthcare environments. Instead, the study contributes to a contextualised understanding of healthcare workers' perceptions of PACS and identifies recurring patterns and challenges that may be relevant in similar healthcare settings.

Another limitation concerns participant recruitment and representation. Access to interview participants depended largely on contacts within the hospitals, which may have influenced which professions and individuals participated in the study. As a result, the empirical results primarily reflect the perspectives of healthcare workers involved in clinical workflows, especially within emergency and surgical departments. The interview findings are based on a relatively limited number of participants across three hospitals. Although recurring themes and patterns emerged across interviews, the findings cannot be assumed to represent the perspectives of all healthcare workers or all healthcare environments. Perceptions may differ depending on role, department type, organisation, and access systems. The study should therefore be understood as providing an in-depth exploration of recurring experiences and challenges rather than a comprehensive representation of all user perspectives.

Additionally, some interviews were conducted with two participants simultaneously. While these interviews often enabled participants to build on each other’s experiences, the presence of colleagues may also have influenced how openly certain experiences or opinions were expressed. This was taken into consideration during the analysis by focusing on recurring themes and patterns across both individual and paired interviews rather than isolated statements. The observational studies also contain limitations. Observations were conducted during selected periods and therefore only captured a limited portion of everyday hospital activity. Additionally, the presence of the researchers may have influenced participant behaviour during observations. However, since the researchers positioned themselves so as not to disrupt workflows and most likely appeared as visitors to staff, the impact of this effect is likely limited. This is further reinforced by the fact that many observed behaviours aligned closely with interview findings.

Additionally, the quantitative measurements conducted during the field observations were limited to specific situations and should therefore be interpreted with caution. Since the measurements were conducted manually during ongoing workflows, small variations in the exact timing of passages may have occurred. The measurements were intended to provide illustrative examples rather than statistically generalisable results.

6. Conclusion

The purpose of this study was to explore healthcare workers’ perceptions of PACS, in relation to efficiency, security and safety, and user experience. Furthermore, it aimed to identify design implications, based on the insights from the research. To achieve this, the study combined a systematic literature review with interviews and field observations to examine both existing research and healthcare work in practice. Existing studies, though limited, show that PACS influence healthcare workers workflows, safety, and user experience, especially highlighting recurring tensions between security and efficiency. However, the existing literature often focuses on operational or security separately, while healthcare workers' experiences with PACS remain relatively underexplored. The empirical findings from the interviews and field observations show that healthcare workers perceive PACS as important for maintaining security and safety, especially in higher risk-departments such as the ER. At the same time, current systems were frequently described as disrupting workflows through repeated authentication steps, slow door behaviour, and unclear door logic. The findings suggest that healthcare workers often adapt their behaviour in order to maintain workflow continuity through informal workarounds. The field observations supported several of the interview findings by illustrating workflow interruptions, tailgating, and user adaptation in practices. An important conclusion is that the consequences of PACS differ depending on the workflow context, department type, and security level.

The design implications for future access solutions were developed from these findings, and overall suggest that future systems should better support real healthcare workflows and user practices. The findings highlight the importance of reducing workflow interruptions, improving transparency and consistency, and better supporting hands-occupied and time-critical processes. Furthermore, the study indicates that future solutions should better balance security requirements with workflow efficiency in order to reduce the need for workarounds. Finally, the findings emphasise the importance of more user-centered and context-aware approaches when designing and implementing future access solutions in healthcare environments.

Overall, the findings suggest that efficiency, security and safety, and user experience are closely related aspects of PACS in healthcare environments, and that they introduce several trade-offs. PACS actively influence movement, coordination, and workflows, while also shaping how healthcare workers perceive safety and usability. Many of the identified challenges appear to stem from a mismatch between security- and safety-related priorities and the realities of healthcare workflows, where systems designed to strengthen access control and protection may introduce disruptions and increased cognitive effort. However, the findings also indicate that healthcare workers generally view security measures as important, particularly in departments with higher perceived risk. The findings further indicate that PACS do not always function as intended in practice, since healthcare workers continuously adapt system use to meet the demands of real clinical workflows. As a result, intended security procedures and actual use practices do not always align. The study therefore highlights the importance of designing PACS with greater consideration of healthcare workers' everyday practices and needs, while still maintaining necessary levels of security and safety.

The study contributes to existing research by providing an in-depth understanding of healthcare workers' perceptions of PACS in healthcare environments. Furthermore, the study contributes theoretically by expanding the understanding of PACS in healthcare from a user-centered perspective in relation to workflows, efficiency, security and safety, and user experience. Practically, the thesis contributes by identifying design implications that can support future solutions that better align with healthcare workers' needs for PACS in healthcare. The findings of the study should be understood in relation to the context in which it was conducted. For example, the study was conducted within a limited number of hospitals and departments. The findings are context-dependent and should not be understood as statistically generalisable. Future research could therefore investigate PACS in other healthcare contexts, and additional quantitative studies could examine the cumulative operational impact of PACS on workflows. Future studies could also include additional user perspectives, such as patients, cleaners, or security personnel. Moreover, there is potential for future research on adaptive or context-aware access solutions in healthcare environments.

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Appendix

Appendix A: Systematic Literature Review Search String

TITLE-ABS-KEY (("physical access control" OR "electronic locks" OR "smart locks" OR "badge access" OR "keyless entry" OR "smart doors" OR "doors") AND ("healthcare" OR hospital OR "clinical environment") AND ("healthcare workers" OR nurses OR clinicians OR "medical staff") AND ("user experience" OR usability OR perception* OR workflow* OR efficiency OR security)) AND PUBYEAR > 2015 AND PUBYEAR < 2026)

Appendix B: Extracted Data from Systematic Literature Review

Study	Healthcare Context	Method	Main Focus	Relevant Findings
Searby et al. (2025)	Acute mental health inpatient units	Qualitative interviews	Locked doors and absconding prevention	Locked doors were perceived as necessary for safety, but tailgating and unauthorised exits still occurred. Staff also experienced responsibility when security failed.
van Heel et al. (2024)	Hospital patient rooms	Evidence-based design evaluation	Trade-offs between visibility, privacy, and safety	Solid doors improved privacy but reduced staff visibility and workflow awareness, illustrating trade-offs between design intentions and usability.
Aghaei and Bayramzadeh (2024)	Trauma rooms	Focus group study	Technology and workflow efficiency	Automatic doors and room design contributed to interruptions and delays in time-critical workflows.
Searby et al. (2023)	Mental health inpatient care	Scoping review	Effects of locked doors in psychiatric care	Locked doors were associated with safety and prevention

				of absconding, but also affected staff workflows and relationships with patients.
Missouridou et al. (2022)	Acute psychiatric care	Qualitative study	Symbolic meaning of doors	Locked and revolving doors were associated with frustration, stigma, and negative user experiences among staff.
Khan et al. (2015)	Hospital environments	Technical study	Hands-free access technologies	Sensor-based and hands-free access systems were proposed to reduce physical strain and support hands-occupie d work.
Menon et al. (2025)	Operating theatres	Healthcare environment study	Operating theatre quality and workflow	Automated doors were perceived positively for supporting hygiene and reducing physical contact.
MohammadiG orji et al. (2021)	Emergency rooms and healthcare environments	Systematic literature review	Environmenta l design and staff security	Staff perceived access control measures and visible security presence as important for safety.

Bayramzadeh et al. (2018)	Operating rooms	Simulation-based evaluation	Operating room design and usability	Swing doors interfered with equipment transport and workflow continuity, while sliding doors were preferred by staff.

Appendix C: Interview Guide

Introductory questions

- What is your title, and what does it entail?
- How long have you worked at your current position and hospital?
- What tasks are typically part of your daily work?
- Which departments do you spend the most time in?
- Can you describe your typical moving patterns during a shift?

Initial questions

- How do you generally perceive the physical access control systems at your department and the hospital overall?
- What works well? What works poorly?
- How and when do you use your RFID card? Do you ever need to use a code?

Checklist/themes

- Enrollment processes
- Current access control systems and identification methods
- How existing systems influence workflow, pace, and movements
- Frustrations and pain points
- Perceptions of safety and security
- Informal methods or workarounds
- User experience
- Future needs

Appendix D: Recorded Data of the Observational Field Study

Staff/staff and patient	Time [s]	Understanding	Equipment	In/out	Automatic door opener	Notes	General notes
Staff	7	Yes	Telephone	In	No	Spoke on the phone, took some time to open	The automatic door opener is located quite far back.
Staff	3	Yes	None	In	No	Smooth	The door stays open for 33 seconds when using the automatic door opener.
Staff	10	Yes	None	Out	Yes		Staff needs card to enter, card reader is on the left side of the door
Staff	3	Yes	None	Out	Yes	Took a long time for the door to close after they passed through	
Staff	4	Yes	None	In	Yes	Door stayed open for 33 seconds when using the automatic door opener	
Staff	4	Yes	Telephone	Out	Yes		
Staff	4	Yes	None	Out	No		
Staff	3	Yes	Telephone	Out	Yes		
Staff	4	Yes	None	In	No		
Staff * 2	5	Yes	None	In	No	Interference by another person	
Staff	3	Yes	None	In	No		
Staff	3	Yes	None	In	No		
Staff	3	Yes	None	Out	No		
Staff	4	Yes	None	In	No		
Staff	3	Yes	None	Out	Yes		
Staff	3	Yes	None	Out	Yes		
Staff + Patient	11	Yes	Hospital bed	In	Yes		

Staff	9	Yes	None	In	No	Ensured no one tailgated	
Staff	4	Yes	None	Out	No		
Staff	3	Yes	None	In	No		
Staff	3	Yes	Bag	In	No		
Staff	3	Yes	None	Out	No		
Staff * 2	5	Yes	None	In	Yes	Two workers passed through	
Staff	3	Yes	None	In	Yes	Tailgated after the two staff that passed through just before	
Staff	10	Yes	Cleaning cart	Out	Yes	Took their time, stopped in the door opening	
Staff	3	Yes	None	Out	Yes	Fast, but still used the automatic door opener	
Staff	6	Yes	None	In	Yes	Walked into the door because they were too fast for the opener, had to stop and wait. Had scrubs on	
Staff	4	Yes	None	Out	Yes	Tailgaited out after the last, the door remained open	
Staff	7	Yes	Telephone	In	No	Held something in their hand, had to have their phone against their shoulder to be able to use the card. Took a while to pass through	
Staff	4	Yes	Scooter	Out	Yes	Used a scooter	
Staff	5	Yes	None	Out	No		
Staff	6	Sort of	None	In	No	Seemed to forget where the automatic door opener was located, stopped	

						and looked around	
Staff	2	Yes	None	Out	No		
Staff	4	Yes	None	Out	No		
Staff	3	Yes	Trash bag	Out	Yes	Carried a trash bag	They seem to always use the door opener when holding items in their hands.
Staff	5	Yes	None	In	No	Same person, without the trash bag this time. Did not use door opener	
Staff	5	Yes	None	In	Yes	Staff used the computer behind the door on the inside. Was a bit squeezed by the door opener	
Staff	4	Yes	None	Out	Yes	Tailgaited!	
Staff	3	Yes	None	Out	No		
Staff	5	Yes	None	In	Yes		
Staff + Relative	10	Yes	None	In	Yes	Used code but unsure if it required it. Let someone else into the reception.	
Staff	5	Yes	None	Out	No		
Staff	5	Yes	None	Out	No	The door seem to stay open for quite a long time even when not using the automatic door opener	
Staff * 2	5	Yes	None	Out	Yes	Used door opener, the door stays open a long time	
Staff + Patient	20	Yes	Hospital bed	In	Yes	Used code, needed to walk to the door and then backtrack, while also	Door stays open for 30 seconds when using the automatic door opener

						waiting for the door to open.	
A lot of Staff	75	Yes	None	Out	Yes	A lot of staff passed through the door during one opening	
Staff	5	Yes	None	In	Yes		
Staff	10	Yes	None	In	No	Held the door open and asked others if they were going in as well	
Staff	5	Yes	None	Out	No		
Staff	5	Yes	None	In	Yes		
Staff	5	Yes	None	Out	Yes		
Staff * 2	5	Yes	None	In	No	Tailgated since the door remains open for so long	
Staff + Patient	20	Yes	Hospital bed	In	Yes	Had to reach for the door opener. Was a bit tricky with the bed since the door opened towards it. Door stayed open for a total of 36 seconds	
Staff * 2	10	Yes	None	Out	Yes	They used the opener and had to walk around the door since it opened towards them.	
Staff + Patient	30	Yes	Hospital bed	In	Yes	Rang the door bell, did not seem to have their card. Waited for others to pass by before going in. A non-staff person tailgated into the department after this group passed through.	
Staff * 3	20	Sort of	None	In	Yes	They stood to close to the door so it stopped -	

						sensor interferance. Had to back up for it to open fully	
Staff	15	Sort of	None	In	Yes	Got stuck between the doors because they wanted to hurry	
Staff	10	Yes	None	In	No	Entered the code and then had to backtrack to pass through the door	
Staff	10	Yes	None	In	Yes	Entered the code and then had to reach for the opener, looks a bit cumbersome	
Staff	10	Yes	Bag	Out	Yes	Did not check behind for anyone tailgating	
Staff	20	Yes	Cart	In	No	Did not use the door opener, had some real struggles getting the cart inside, had to backtrack etc.	
Staff	10	Yes	Cart	Out	Yes	(Same person as above) now used the door opener	
Staff * 2	5	Yes	None	In	No	One presented the card and entered the code, the other opened the door	
Staff + Patient	15	Yes	Hospital bed	Out	Yes	Went smoothly for a bed	
Staff	10	Yes	Bag	In	Yes	Had to wait before the doors opened.	
Staff * 2	5	Yes	None	In	Yes		
Staff	10	Yes	None	Out	Yes	Another non-staff person walked by at the same time with a walker, which	

						caused sensor interference	
Staff * 3	20	Sort of	None	In	Yes	Waited quite long for the door to open	
Staff	5	Yes	None	Out	Yes		
Staff * 2	5	Yes	None	Out	Yes		
Staff	5	Yes	None	In	No	Tailgated behind relatives entering	
Staff	5	Yes	None	Out	No		
Staff	5	Yes	None	Out	No		
Staff + Patient	10	Yes	Hospital bed	In	Yes		
Staff	5	Yes	None	Out	Yes		
Staff * 3	15	Yes	None	In	No		
Staff	3	Yes	None	In	No		
Staff	3	Yes	None	Out	No		
Staff * 2	5	Yes	Telephone	In	No		
Staff * 2	5	Yes	None	Out	Yes		
Staff	5	Yes	None	In	No	Had to reach for the door after entering the code	
Staff * 2	15	Yes	Cart	Out	Yes		
Staff	7	Yes	None	In	Yes	Opened the door with their back?	
Staff	5	Yes	Telephone	In	No		
Staff	5	Yes	Telephone	Out	No		
Staff	5	Yes	Bag	Out	No		
Staff	7	Yes	None	In	No		
Staff + Patient	14	Yes	Hospital bed	Out	Yes	The door stayed open for 24 seconds in total.	
Staff	6	Yes	None	In	No	Card and code entered	
Staff	3	Yes	None	Out	No	From the inside, it looks like they can just open the door	
Staff + Patient	13	Sort of	Hospital bed	In	Yes	Sensor interference when staff reached out their	

						hand, did not seem like they understood how the sensor worked. The door stalled a bit but not too much	
Staff	13	Yes	Hospital bed	Out	Yes	Ensured no one tailgated	
Staff	3	Yes	None	Out	No	Passed through using the handle	
Staff * 2	9	Yes	None	In	Yes	Door opened towards the card reader, the worker had to walk around the door	
Staff + Patient	12	Yes	Hospital bed	Out	Yes	2 workers assisted the transportation together, one pushed the bed and the other identified themselves	
Staff * 2	9	Yes	None	In	Yes	Had to walk around the door	
Staff + Patient	14	Yes	Hospital bed	Out	Yes	3 staff and 1 patient	
Staff * 2	7	Yes	None	In	Yes		
Staff * 2	43	Yes	Telephone	In	Yes	One member of the staff stood and talked on the phone and held the door open	
Staff + Patient	12	Yes	Hospital bed	Out	Yes	2 staff and 1 patient	
Staff + Patient	9	Yes	Wheelchair	Out	Yes		
Staff * 2	10	Yes	None	In	Yes		
Staff + Patient	12	Yes	Hospital bed	Out	Yes		
Staff + Patient	14	Yes	Hospital bed	In	Yes		